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Air Safety Through Investigation

Proceedings of the 35th Annual International Seminar

'Investigate—Communicate—Educate'

August 30–September 2, 2004
Gold Coast, Queensland, Australia

ISASI
GOLD COAST 2004
AUSTRALIA

ISASI 1964 2004 40TH ANNIVERSARY

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PREFACE
Investigate, Communicate, and Educate

By Frank Del Gandio, President

As always, I am pleased to welcome everyone to ISASI's annual seminar. I am especially pleased to welcome everyone to Australia's Gold Coast. Whether we are from Australia or elsewhere, most of us probably agree that "Gold Coast" is an appropriate name for this area. Those of us from the northern hemisphere can easily forget that this is winter here.

Winter should be so pleasant for those of us living well above the equator.

As anyone in our business knows, we are also in a country where the aviation regulator, CASA, and the safety investigative authority, the ATSB, are world-class organizations. Each of these agencies is a regional leader in its field, and each has an influential voice worldwide among the aviation safety federation. Australia's enviable safety record is the best testimony to the professionalism of CASA, the ATSB and the industry.

Thanks to Lindsay Naylor's sound guidance and the diligent industry of his team, I know that the quality of this year's seminar will reflect the professional quality of Australia's aviation community.

This year's seminar will carry the theme of "Investigate, Communicate, and Educate." The issues that compose the theme are appropriate for ISASI. Aviation in much of the world faces the difficult challenge of continuing to improve on an already very low fatal accident rate.

Since we last met in Washington, D.C., we have had the usual mixture of evidence that things are continuing to get better but, on the other hand, that we still have work to do. The good news is that the world airline industry has had a relatively small number of major accidents since our meeting in Washington. Though the precise definition of "major accident" might vary a bit, I believe we had a maximum of five such events in the past year. The most significant accidents were

- In December 2003, an apparently overloaded B-727 crashed on takeoff in Benin, killing at least 140 of 160 or more occupants.
- In January 2004, a B-737-300 crashed on departure from Sharm-el-Sheikh, killing all 148 occupants.
- In January 2004, a Yak-40 crashed on landing at Tashkent, killing all 37 occupants.
- In February 2004, a Fokker F-50 crashed on approach in the Arab Emirates, killing all 46 occupants.
- On May 14, 2004, an Embraer 120 crashed on descent into Manuas, Brazil, killing all 33 occupants.

To some degree, we are the victims of our own success, for as good as the safety record has become, the public has long judged our performance against a de facto standard of zero accidents. Every incremental improvement in the rate may well require an exponential increase in effort.

Five major accidents worldwide is a relatively low number, but it is not zero. At least three of the five, and perhaps all five, at least partly indicate basic issues about physical or regulatory infrastructures. Clearly, the only way we can hope to address these types of issues is through international cooperation. That cooperation needs to include active international assistance with infrastructure, training, etc., plus international efforts to increase the knowledge base of responsible officials. Cooperation is "not a sentiment—it is a economic and safety necessity."

The cooperation function is the type of function in which ISASI can help, and can help a lot. In fact, the theme that our hosts selected for this year's seminar actively reflects ISASI's capacity to help strengthen the required knowledge base: Investigate, Communicate, Educate.

Investigation certainly will remain part of these efforts. However, in order to constantly improve upon an already strong record, we and other segments of the aviation safety community must communicate our knowledge effectively. We must use our communal knowledge base to inform and indeed to educate not just those of us who already are a seasoned part of aviation, but also those who are at the threshold of aviation.

Education will continue to include traditional issues, such as basic flight skills, aircraft systems, etc. However, we will find aviation education focusing more and more on issues like standard operating procedures, safety culture, governance, and all those other issues that wear the cloak of ambiguity. Indeed our profession will be a major contributor to the overall effort of making the exponential increases to achieve incremental improvement.

I sincerely hope each of us in this room, over the next several days, takes advantage of this seminar to improve his or her own knowledge base. I think many of you will agree with me when I say that our seminars get more and more substantive each year. I am sure this year's seminar will be no exception.

I also hope those of you who have traveled from other countries will take some time to see this great land. I know that the very size of this country can seem down right intimidating to some folks. However, I think the Americans here today will tell you, as will our colleagues from countries like Canada, Russia, Brazil, and other outsized countries, that the scale and variety of a country with extended borders are among the characteristics that make traveling in it so exciting and Australia is no different—as our hosts would agree.

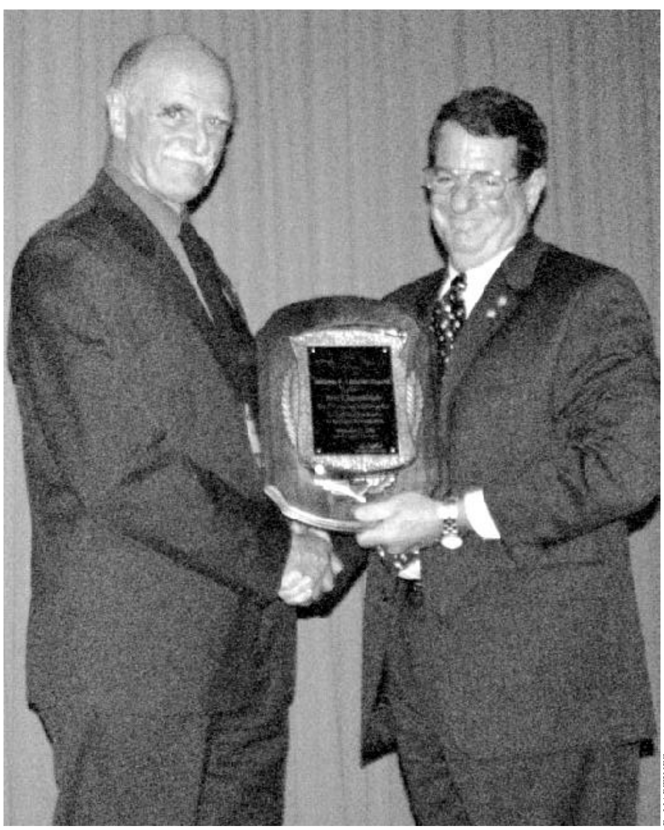
Finally, do make an effort to educate and be come more educated while we are here, but make sure you enjoy yourselves while you are at it. ◆

Ron Chippindale: 2004 Lederer Award Winner

By Esperison Martinez, Editor

The International Society of Air Safety Investigators (ISASI) bestowed upon Ron Chippindale, a Society Fellow, the coveted 2004 Jerome F. Lederer Award. ISASI President Frank Del Gandio made the presentation at the Awards dinner on the last evening of ISASI 2004, the annual air safety seminar, held on Australia's Gold Coast. The Award is conferred for outstanding lifetime contributions in the field of aircraft accident investigation and prevention and was created by the Society to honor its namesake for his leadership role in the world of aviation safety since its infancy. Jerry Lederer "flew west" on Feb. 6, 2004, at age 101. Awarded annually by ISASI, the Lederer Award also recognizes achievement of the Society's objectives and technical excellence of the recipient.

Chippendale's short acceptance speech exemplifies the characteristics of his demeanor and accident investigative manner known to so many of his peers: short on banter and long on meaningful action. Upon addressing the near 400 persons attending the Awards dinner he said: "We have made many good friends in the 30 some years we have been attending ISASI seminars. Since I joined ISASI in 1971, I have been in awe of those who have been nominated for the coveted Jerry Lederer Award. To have myself been selected for this honor is rather overwhelming. From very early on, Jerry and his wife, Sarah, exchanged views with my wife, June, and me whenever we met at a seminar. We will miss this contact.



E. MARTINEZ

Ron Chippindale, left, receives the 2004 Jerome F. Lederer Award from ISASI President Frank Del Gandio at the Awards dinner during ISASI 2004.

"I discovered the advantages of the ISASI fellowship early in my career. No overseas or domestic mishap in which I was involved was without generous support from one or more state agencies or manufacturers, often obtained in a large measure from contacts made through our Society.

"Stress has been referred to several times in the course of this seminar, and from my experiences in the controversy surrounding the outcome of the investigations into the major air carrier accident known to many as 'Mt. Erebus,' I can attest to emotions one experiences from stress. In this respect, I should like to express my appreciation for the support June and I received from so many ISASI members and their partners.

"Ladies and gentlemen, this award culminates a career involving June and me in nearly 40 years of accident investigation. The Lederer Award will most certainly take a place of honor in our home, and the memory that it is given in respect of aviation's 'Father of Aviation Safety' fills us with humble pride. Thank you."

In presenting the awardee to the audience, President Del Gandio said, "Ron Chippindale exemplifies the highest level of professionalism in the field of accident investigation and is truly worthy of receiving this year's Jerome F. Lederer Award." The Award citation read, "Presented to Ron Chippindale for outstanding contributions to technical excellence in accident investigation."

President Del Gandio noted that one of Ron's most illustrious investigations was the 1979 crash of a Air New Zealand DC-10 that descended into an ice field near Mt. Erebus killing 257 Antarctica sightseers. "As investigator-in-charge (IIC) of the accident, his work on that case has been described as nothing short of brilliant, gaining for him international attention and respect. With a very small team, he managed an investigation that is said to be New Zealand's equivalent of TWA 800. The investigation was conducted in a very difficult environment, both politically and culturally. Political pressures challenged his findings, but he survived, steadfastly expressing himself and standing by his principles on behalf of safety," said Del Gandio.

Chippindale serves as New Zealand Councillor to ISASI. As such, he is a sitting member of ISASI's International Council, which sets direction and policy for the Society. "His contributions have added extra dimension to ISASI's deliberations and issues resolution, providing valuable international perspective. A quiet demeanor often disguises his technical and leadership skills, and his associates always appreciate his ability to think ‘outside the box,’” Del Gandio told the audience. A member of ISASI since 1971, Chippindale has been an active participant in its operations. In 1986 and in 1996, he led groups that hosted the ISASI international seminars in Rotorua

“We have made many good friends in the 30 some years we have been attending ISASI seminars. Since I joined ISASI in 1971, I have been in awe of those who have been nominated for the coveted Jerry Lederer Award. To have myself been selected for this honor is rather overwhelming.”
—Ron Chippindale

and Auckland. Since 1971, he has attended every ISASI seminars, except for three, and was instrumental in developing regional seminars in connection with the Australian Society of ISASI. He is a Fellow in both ISASI and the prestigious Royal Aeronautical Society (RAeS).

His aviation career began in the Royal New Zealand Air Force where he served for 23 years as a transport and instructor pilot. He was the flight safety officer during his last 9 years with the military. This introduced him to the world of accident investigation.

In 1974 he started his career with the government’s civil aviation Office of Air Accidents Investigation. He subsequently was promoted to chief inspector and manager of the office. When the office was disbanded in 1990, he became the chief inspector of the new multimodal Transport Accident Investigation Commission and acted as the chief executive of the Commission for its first 2 years of operation. Before retiring in 1998, Ron was the investigator-in-charge of 48 aircraft, marine, and rail accidents and incidents and overall responsible for more than 400 investigations.

Recognizing the long-term investigator’s expertise, ICAO has developed a long-standing relationship with him. In 1986 he worked with the ICAO Technical Cooperation Bureau, assisting in the South African investigation where a TU314 aircraft, operated for Mozambique by the Russians, was lost, resulting in the death of the president of Mozambique. In 1993, when the Russian Federation finally made the flight recorders available to ICAO in the shoot down of the Korean Airlines B-747 Flight KLA 007, over Sakhalin Island, ICAO assigned him to the team in the reopened investigation. He has been an enthusiastic supporter of the ICAO AIG meetings, and has served several times as a consultant assisting in various projects including the development of the ICAO circular on family assistance and enhancement to the ICAO ADREP data system.

The presentation of the 2004 Lederer Award to Chippindale marks the first selection of someone outside North America since 1998. Equally as meaningful was that the seminar was being conducted in Australasia close to the selectee’s own “territory,” where his prominence as an air safety advocate is so well appreciated. Indeed, it was the years of experience that created such prominence and demonstration of that experience to which President Del Gandio’s alluded in his presentation comment: “I am truly honored to bestow the prestigious Jerry Lederer Award to Ron Chippindale, who exemplifies the highest qualities of an air safety investigator.” ◆

Past Lederer Award winners

1977—Samuel M. Phillips
1978—Allen R. McMahan
1979—Gerard M. Bruggink
1980—John Gilbert Boulding
1981—Dr. S. Harry Robertson
1982—C.H. Prater Houge
1983—C.O. Miller
1984—George B. Parker
1985—Dr. John Kenyon Mason
1986—Geoffrey C. Wilkinson
1987—Dr. Carol A. Roberts
1988—H. Vincent LaChapelle
1989—Aage A. Roed
1990—Olof Fritsch
1991—Eddie J. Trimble
1992—Paul R. Powers
1993—Capt. Victor Hewes
1994—U.K. Aircraft Accidents Investigation Branch
1995—Dr. John K. Lauber
1996—Burt Chesterfield
1997—Gus Economy
1998—A. Frank Taylor
1999—Capt. James McIntyre
2000—Nora Marshal
2001—John Purvis and the Transportation Safety Board of Canada
2002—Ronald L. Schleede
2003—Caj Frostell

Welcome to Australia

By Bruce Byron, Chief Executive Officer, Civil Aviation Safety Authority (CASA), Australia

(In his opening and welcoming address to the accident investigators attending ISASI 2004 at Australia's Gold Coast region on August 31, the author explains the role and functions of CASA and issues challenges to air safety investigators to expand the horizon of their roles and functions to meet the needs of today's changed industry.—Editor).

Thank you for inviting me to be with you for what I know is one of the more significant aviation gatherings in the international calendar for 2004. May I welcome you, and for those of you from beyond these shores, welcome to Australia.

I believe the last such seminar in this country was more than a decade ago. As elsewhere, the Australian aviation industry has seen profound changes in that time, and I am sure this gathering will be an opportunity for you to gain some insight into those changes and the implications they may have for aviation safety investigation.

As the chief executive of Australia's aviation safety regulator, it is probably sensible that I say a few words about where CASA fits into the aviation safety framework in this country. And to do that I need to say something about the functions we are required to perform by the legislation under which we operate. I would also like to give you some food for thought.

If you ask the public or indeed members of the aviation industry what the role of an aviation safety regulator is, you will never get the same answer. I know—I've tried it. Some would have us exercise dominant control of industry organizations while others would prefer we leave industry players to get on with it without "interference." Like most issues where there is a range of opinions, or options, the right answer is somewhere in the middle. A careful look at the legislation that empowers CASA provides that clarity, and in my view, strikes the right balance.

Now, reviewing legislative matters is a dry subject at the best of times, so I promise to be brief, but these are the things we are required to do by law, so they are a proper starting point for an understanding of our place in the aviation safety system. We are required to perform, or take account of, a whole range of statutory functions in pursuing our legal obligations. Most of them are fairly standard and have parallels in most international jurisdictions, so I won't subject you to them.

But there are a few that I would like to highlight because it should explain the basis for directions we are planning to take CASA in the near future. Section 9 (1)(f) of the Civil Aviation Act says we have the function of "conducting comprehensive aviation industry surveillance, including assessment of safety-related decisions taken by industry management at all levels for their impact on aviation safety." This part of the legislation is where we get our "head of power" to conduct surveillance of

Bruce Byron

the industry. What is particularly noteworthy here is that the only specific item of surveillance activity highlighted here does not target technical areas, but asks us to put the spotlight on safety-related decisions by management. I'll come back to this later.

In 9(1)(g) we have the responsibility of "conducting regular reviews of the system of civil aviation safety in order to monitor the safety performance of the aviation industry, to identify safety-related trends and risk factors, and to promote the development and improvement of the system." Some interesting points of focus here are the need to look at the "system," and specifically the safety performance of the industry. Again, I'll talk more on this in a moment, particularly in the context of management's contribution.

And under 9(3)(a) we have the formal function of "cooperating with the Bureau of Air Safety Investigation in relation to the investigation of aircraft accidents and incidents." BASI is, of course, now the Australian Transport Safety Bureau, and the ATSB's Kim Bills will be talking to you shortly. To take this last one first, in one sense it should hardly be necessary for there to be a formal provision in our functions requiring the regulator to cooperate with the independent aviation accident investigator. It just makes good sense, and we would be crazy to even think of having some other model. In our case, the cooperative process is facilitated because both organizations operate within the same ministerial portfolio, and at a practical level the relationships between our people are good. But it is important not to get complacent, and we need to regularly review the relationship between the accident investigator and the regulator to make sure it is optimal, while being sensitive to the necessary points of independence within the respective roles.

And in this context, I should recognize that it is not just the relationship between the statutory regulator and the statutory investigator that is important. The industry has significant aviation safety investigation skills and experience, and we need to be sure that arrangements are in place for that knowledge to be part of the overall aviation safety management framework, in other words, part of the system. We have to avoid the idea that only the government-based organizations are the sole repositories of skills and knowledge. We are all in this together.

The other statutory functions I highlighted are interesting in the context of this gathering in that one of them gives us a statutory function of reviewing the overall aviation safety system, and this must include the contributions made to that system by the various players, including, of course, air safety investigators.

What I am clearly saying here is that the task of investigation is unquestionably part of the system—you don't sit passively outside looking in all the time. In the same way that decisions and actions taken by pilots, mechanics, chief pilots, maintenance controllers, operational managers, and CEOs can affect safety outcomes, so, too, can the content of an investigation process and the recommendations that flow from that activity.

In reviewing the system, we should constantly test each component for the quality of the outcomes and the contribution made to the full system. In your case, I would encourage you to ask those questions of yourselves during the next few days.

Now this requirement for CASA to review the system has not been an area of our responsibilities that has been front and center for us in the past, but we are changing that. It is easy for all of us to be focused on the things that are immediately in our face, that come out of left field and have to be responded to. But ensuring that the overall aviation safety system is in the best possible shape is very important, and it is something to which I intend to give some focus.

There have been many accidents and incidents investigated and a lot of very good data have been generated. But we need to be sure the process is not seen as an end in itself, that an accident is investigated, that a complex range of contributing factors is identified, probable cause findings are reached, and we declare victory and ride off to tackle the next investigation. We need to be sure that the results of your work do translate into improved safety, otherwise they become simply interesting technical exercises.

It follows that we need to have an overall safety system in place that ensures that the outcomes of accident investigations do feed into the system, and in particular that conclusions and recommendations that impact on systemic issues are tested, recognized by all those who need to take action, and are in a form that is amenable to action being taken.

Most importantly, it is vital that all the good material that you produce does not fall into some electronic black hole or database—without being used by the decision-makers in the system. Your information needs to be constantly trended, assessed, and compared with data from other sources—not every decade, not every year, but all the time.

At the risk of being controversial, I think we have a bit of work to get this one perfect. A good start would be to ensure that the terms, definitions, parameters, safety measures, and health indicators used by operators, manufacturers, regulators, and investigators are the same. This is one item of our system, here in Australia, that CASA has identified as needing attention.

I am encouraged to see that your code of ethics includes a provision requiring the application of facts and analysis to develop findings and recommendations that will improve aviation safety—a sensible outcome-based approach perhaps, but one that is important not to lose sight of.

And I am further encouraged to see that your seminar papers include titles such as "Investigate, Communicate, Educate: Are We Doing All Three with the Same Energy?" and another title, "Lessons Learned in the Investigate, Communicate, Educate Cycle." These titles suggest to me that the issue of how we go beyond the investigation stage is one that is alive and well in this gathering, and that is a very good thing.

For our part, that is CASA, we have already commenced a review of the system, with modest beginnings, but this will increase as we expand our research capabilities. I look forward to some of this work being conducted industrywide, and I hope some will be able to be undertaken in association with the industry and academic bodies, not just within government.

And I should touch on the remaining statutory function I highlighted, the one that mentions looking at safety-related decisions taken by aviation industry management. This one highlights an issue for us at CASA, and I suspect it may also be one for you. Our people have a lot of good technical skills and experience, and so do you. In your case it particularly relates to the skills and experience needed to analyze accidents and incidents and to come up with sensible conclusions and recommendations. In the last 25 years we have added people with behavioral or human factor expertise to the well-tested group of people with technical background in aviation operations.

But where do we all stand when we push the envelope beyond the immediate technical issues associated with an accident and start to get involved with an organization's management processes? In my experience with large organizations, particularly where they have a duty of care for the safety of people, I have seen evidence of potential deficiencies in management decision-making. This is nothing new, but we need to be confident we have the skills to objectively review management processes and procedures that may be somewhat removed from the technical fields with which we are most comfortable.

This may mean we need to involve people with no aviation experience, but who have well-developed management systems knowledge. In our case, as the regulator, my hope is that we can identify such system deficiencies before they cause problems, not recognize them only once we have started to pick up the pieces; and I hope your outputs will play a part in that process.

We need to be proactive in targeting, for example, management systems. This becomes a real issue for an organization like ours since we are drafting regulations requiring implementation of safety management systems.

In your case, you tend to be involved after the event. You have a tradition or providing excellent technical skills, but I suggest you also need to ensure you have the skills required to assess safety systems, management approaches, and so on.

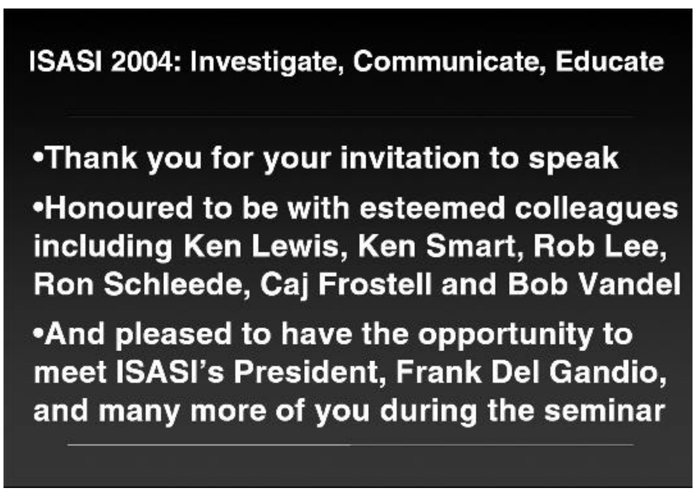
Again, I see you have a paper "Uncovering Organizational Deficiencies in Maintenance Operations," so it would seem systemic and management-related issues are on your radar, and that is a good thing. So, maybe I am preaching to the already converted.

It gives me great pleasure to formally declare the 2004 seminar of the International Society of Air Safety Investigators officially open. I wish your seminar the success it deserves and that you will all have an enjoyable and informative time. ◆

Aviation Investigation in Australia: Sex, Drugs, Rock 'n Roll, and the Law

By Kym Bills, Executive Director, Australian Transport Safety Bureau

__Kym Bills__ was appointed executive director of the newly formed Australian Transport Safety Bureau on July1, 1999. Prior to his current position with the ATSB, he was the first assistant secretary of the Bureau's Maritime Division from 1994. He was also a director of ANL Limited during its restructuring from September 1995 to the signing of sale contracts at the end of 1998 and was a member of the Board of the Australian Maritime Safety Authority from 1995 to 1997. In 1998, Bills led negotiations at the International Maritime Organization, which established a new legal regime for archipelagic sea lanes, including a precedent-setting case for protecting Australia's shipping and other interests through the Indonesian archipelago. In addition to transport, Bills has held a number of Australian government public-service positions since 1978.



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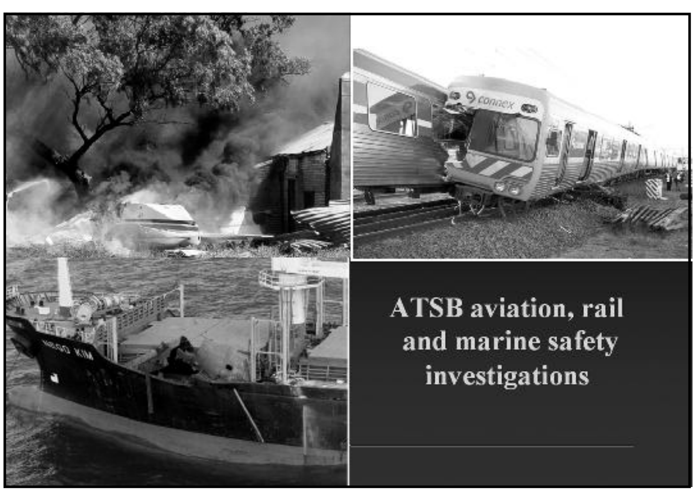

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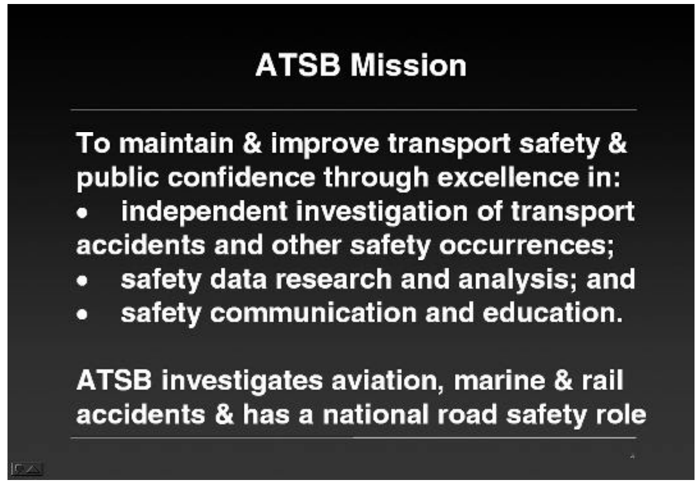

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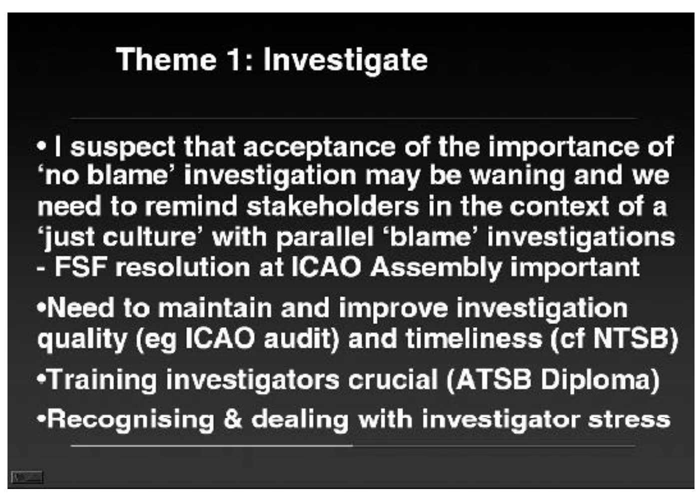

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Theme 1: Investigation & stress

- Mary Cotter of Ireland has produced some helpful initial research on investigator stress: sample of 50 air investigators from 22 countries
- Above average stress particularly: investigating when children killed/injured; when know killed or injured crew; fatal/traumatic accidents incl. body parts/smell; legal etc challenges to reports by bereaved families; investigating with media on the scene; and interviewing surviving crew.

6

Theme 2: Communicate

- While we may wish it were otherwise, we must respond to media's information requirements - otherwise they'll make it up/bag investigators
- ATSB investigator media training central; more prelim. & interim factual reports – but these can be misreported as inconclusive final reports!
- Media releases in reports so legal immunity and explain what we think is key to inexpert media

7

Theme 3: Educate

- 2nd (non-occurrence investigation) branch in ATSB renamed Safety Research and Education a couple of years ago to emphasise education
- Tight resources have limited what could be done (& CASA most aviation education budget)
- It is not sufficient to investigate, communicate and educate – we really want to change safety behaviour and culture - perhaps a step further

8

Sub-theme 1: the law

- Increasing litigiousness, so need to ensure all investigations, including as accredited rep, recorders etc covered by legislative protection
- Awareness of all laws – OH&S, finance, contracts, staffing, archives, privacy, negligence
- Security interfaces more important
- Coroners issues and MoU
- Personal relationships and understanding key

9

The law: Investigation Legislation

- Primacy to the 'no blame' independent investigator after the emergency response
- Australia's Transport Safety Investigation Act & Regulations passed last year are state-of-the-art
- Powers to compel evidence and protect it but work cooperatively with other investigations such as by Coroners, regulators, police, etc
- Independence of the ATSB mandated

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Investigation Legislation

- CVRs – protected under TSI Act or CA Act
- Restricted information – ED test before courts
- May wish to agree to let others hold evidence & get copies to ensure evidential continuity chain
- Reports can't be used in civil or criminal proceedings, except coronial inquests
- Strong immunity clause protects ATSB and investigators against damages litigation etc

11

Sub-theme 2: rock 'n roll

- Unfortunately, there has also been a bit of rock 'n roll in and around Australian skies that we have investigated recently
- Eg, VH-TJX, a B737-400 was on approach into Brisbane on 18 January 2001 when caught in a serious microburst windshear incident
- At 500 feet, climb performance in the go around initiated dropped from 3600ft/min to 300ft/min

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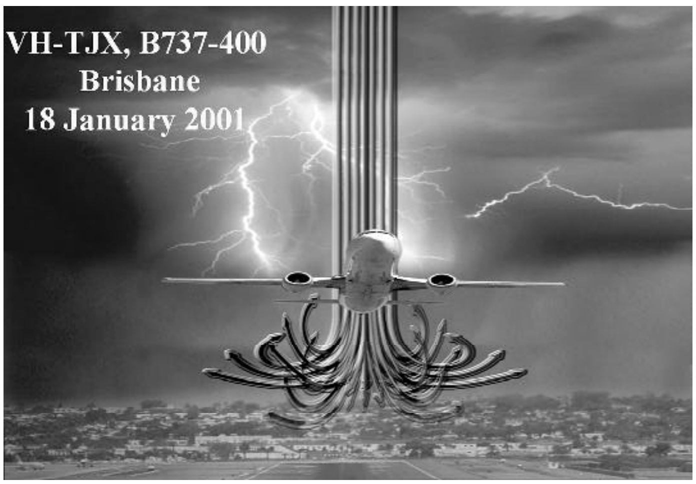

13

Sub-theme 2: rock 'n roll

- The public weather forecast of severe thunderstorms wasn't provided to the flight crew or Airservices and ATC tower concerns about intensity of approaching thunderstorm not conveyed to TJX crew until final approach
- To avoid such rock 'n roll, without better Doppler/windshear equipment, need better information sharing and collaborative decision-making among BoM, Airservices & crew

14

Sub-theme 2: rock 'n roll

- There are plenty of examples of serious rock 'n roll investigated in the GA sector, some fatal as VFR pilots fly in weather suitable only for IFR
- Helicopter fatal, 29 August 2001, involved lead singer of former Australian rock band Skyhooks
- The ATSB investigation found it likely control was lost in the helicopter because of a serious mountain wave or rotor effect – education opp.

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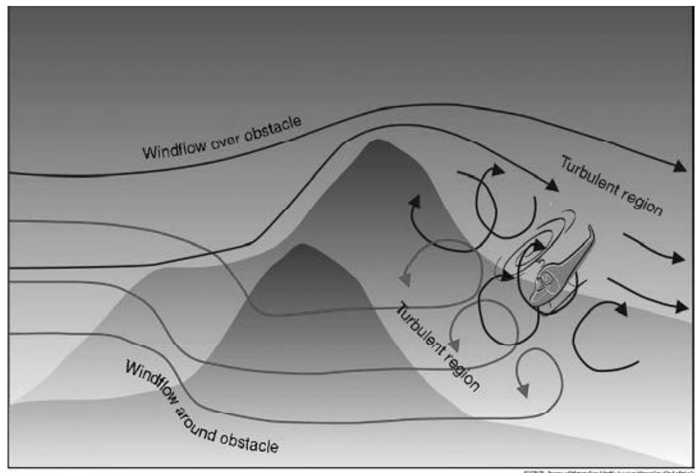

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Sub-theme 2: rock 'n roll

- Two SAAB 340 serious incidents involve icing
- The 1st, VH-LPI, was on 11 November 1998
- ATSB recommendations to SAAB: short shrift
- The 2nd was on 28 June 2002: icing raised the stall speed but also VH-OLM power only 17%
- Two losses of control & last recovery < 120ft
- With ice on wings, stall prior to stall warning

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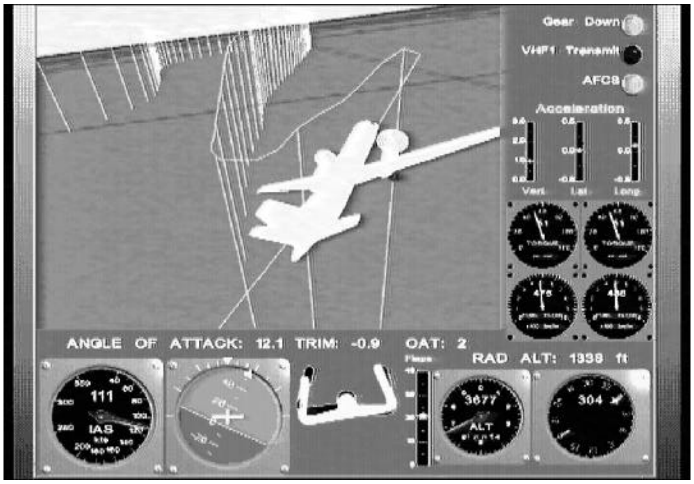

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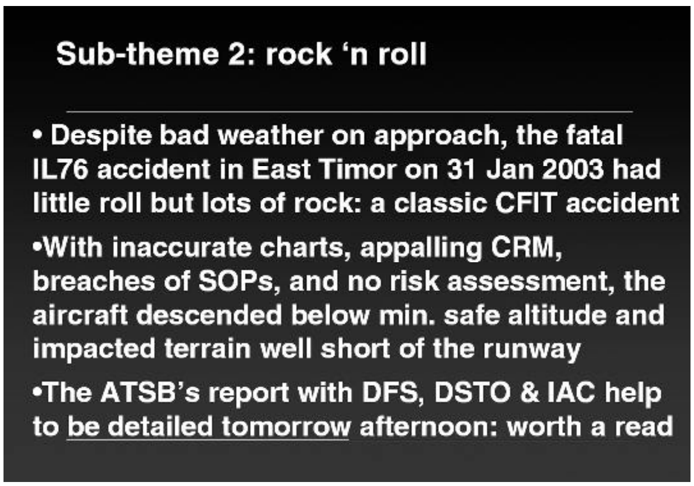

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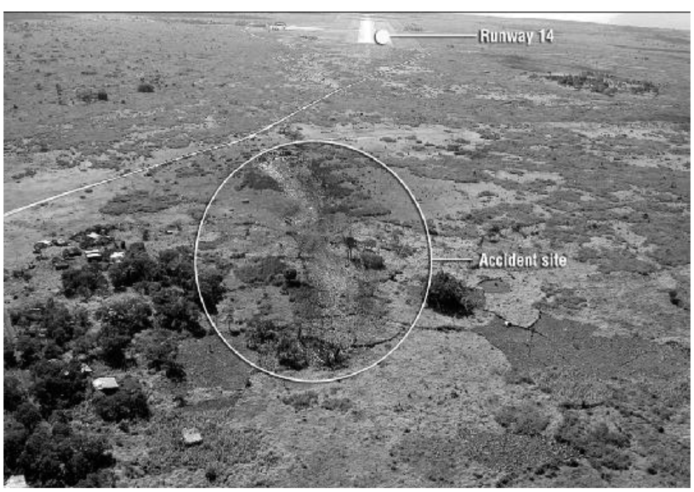

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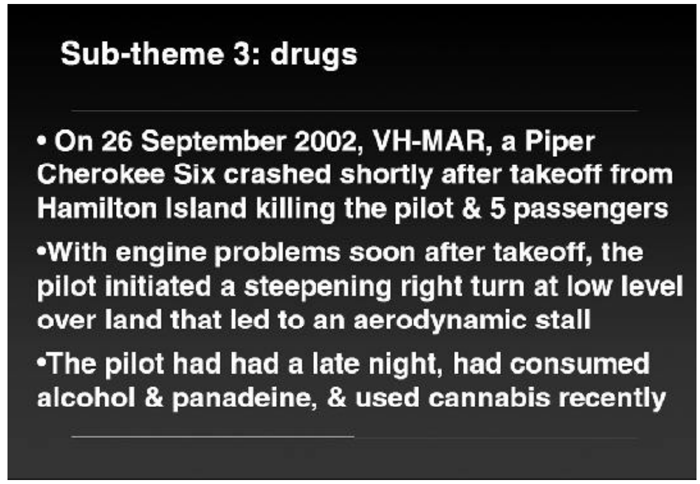

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Sub-theme 3: drugs

- The investigation couldn't prove that drugs were causal factors in the accident, eg 'Coriolis' & 'G-excess' phenomena or judgment via THC
- However, ATSB research papers were released on both alcohol and cannabis to educate pilots
- Issue re how much of 0.08 BAC post-mortem
- Modern cannabis typical 150mg THC cf 10mg more typical of 1960s reefers & much research
- Drug & alcohol testing recommendations

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Sub-theme 4: sex

- Occasionally hormones swamp common sense and fatal accidents occur as NTSB reported on Piper PA-34-200T fatal accident of 23 Dec 1991
- Unfortunately, other examples can be given
- I wanted to note a few issues with sex/gender differences, including the dearth of aviation data
- Cost of small GA aircraft may limit number of youth risk-taking accidents but they do happen

26

Sub-theme 4: sex

- We would like to see more data on young male GA pilots & accidents compared with exposure
- In road safety, males to their mid-20s tend to engage in higher risk behaviour (esp. with peer passengers) & have much higher fatality rates - young males may also take more aviation risks
- In driving, women improve to age 30, men to age 40 via increasing skill and experience, ie competency, & reducing higher risk behaviour

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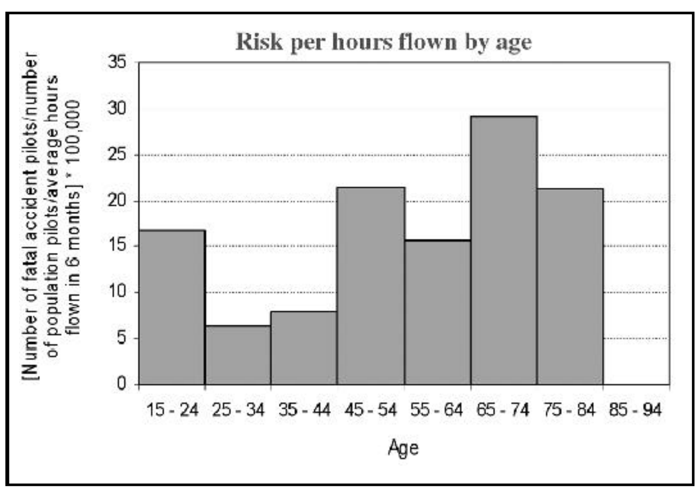
Sub-theme 4: sex

- A recent ATSB research investigation 'General Aviation Fatal Accidents: How do they happen?' reviews 10 years of Australian data (215 fatals)
- Risks based on exposure are relatively high for younger, less experienced pilots, as expected
- Unfortunately, we don't have gender data
- Apart from a jump in risk from age 65, the following figure also shows a jump for 45-54s

28



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Sub-theme 4: sex

- The following fatal accident involved a mid-20s male pilot at Groote Eylandt on 24/3/02
- Just after takeoff the Cessna 210 diverged right toward a ticketing office maintaining about 20ft then banked left & adopted a nose-high attitude
- The left wing struck a 5.2m high floodlight on a pole, a 5.6m VHF aerial and palm tree fronds before crashing, sliding and burning

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Sub-theme 4: sex

- A second fatal accident example also with an mid-20s male pilot was at Lake Evella on 4/2/01
- The pilot had indicated an intention to conduct a low pass over the runway and shortly after takeoff the C210 was observed at about 400ft undertaking what appeared to be an aerobatic manouevre before diving steeply to the ground

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Sub-theme 4: sex

- A third fatal accident example involved an 18 year old male pilot with 68 flying hours & friends aged 21, 19 and 17 at Gisborne on 1/12/99
- The Cessna 172 flew over the house where one of the friend's sisters had been told to watch
- Some steep 360 degree left turns at 500-1000 ft over the house while taking photos in gusty conditions before stalling & loss of control

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Sub-theme 4: sex

- Average adult woman's neck about twice as prone to neck injury (eg whiplash) as males
- Contrary to popular myth, drunk passengers face higher risk of fatality in a crash than sober
- Leonard Evans's analysis of US road fatality data shows that on average, women are more vulnerable than men to a crash death
- But age is much more important than gender in physiological terms as well as in skill and risk

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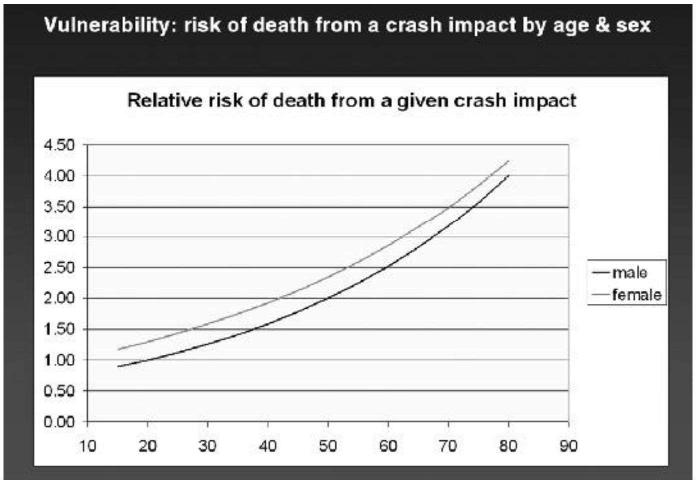
Vulnerability: risk of death from a crash impact by age & sex
Relative risk of death from a given crash impact
4.50
4.00
3.50
3.00
2.50
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40
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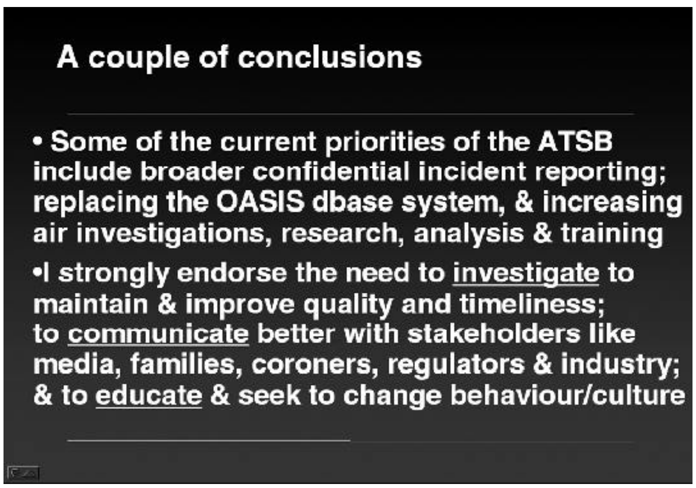
80
90
male
female

36


A couple of conclusions
• Some of the current priorities of the ATSB include broader confidential incident reporting; replacing the OASIS dbase system, & increasing air investigations, research, analysis & training
•I strongly endorse the need to investigate to maintain & improve quality and timeliness; to communicate better with stakeholders like media, families, coroners, regulators & industry; & to educate & seek to change behaviour/culture

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ATSB: learning from systemic 'no blame' accident investigation. Thank you for your invitation to speak.

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Investigate, Communicate, and Educate: Are We Doing All Three With the Same Energy?

By Réal Levasseur (CP0060), Transportation Safety Board of Canada

Réal Levasseur is the chief of Air Investigation Operations for the TSB. A former fighter pilot with the RCAF and later the CAF, he retired from the military after having served for 30 years in various functions and positions of command, as a pilot and in senior administrative positions. In his last military job, he held the position of chief accidents investigator for the Directorate of Flight Safety within Canada's Department of National Defense. Réal joined the TSB in 1993, and has since been involved in various capacities, in a number of Canadian and foreign civilian aircraft accidents.

An "association" is generally defined in dictionaries as the organizational outcome of the banding together of individual entities having common traits, interests, and purposes, and sharing a common objective to support their mutual interests. Thus the traditional roles for an association are advocacy—the act of speaking or writing in support of something—and using its group influence in order to attain this common interest, goal, or objective. This definition certainly seems to fit ISASI. Now that we have sorted out who we are, what are the goals of ISASI members? I will define for you the mandate of the TSB, and I am confident that this mandate will be fairly close to the goals of ISASI members. It is to advance transportation safety in the marine, pipeline, rail, and air modes of transportation by

- conducting independent investigations, including public inquiries when necessary, into selected transportation occurrences in order to make findings as to their causes and contributing factors;
- identifying safety deficiencies, as evidenced by transportation occurrences;
- making recommendations designed to eliminate or reduce any such safety deficiencies; and
- reporting publicly on its investigations and related findings.

We are aviation professionals involved in aircraft accident investigation. Whether we may be also employed as pilots, engineers, technicians or other, we like to think of ourselves as experts in our field. And why should we not feel this way? After all, we have received extensive training in basic and advanced investigation procedures, biohazards, interview and photography techniques, jet engine and propeller mechanics, crash site survey, team leadership and management, safety deficiency analysis, human factors, and a multitude of other assorted specialty courses. We feel good about our capabilities. We can all recite the SHELL and Reason theories backwards. Anyone who has ever been involved in an accident investigation as investigator-in-charge, team member, accredited representative, observer, or in any other capacity, believes that his/her efforts have helped advance safety. We identify safety deficiencies evidenced during the course of our work, and make recommendations to mitigate or eliminate those risks to the travelling air passenger. The question is, or rather, the questions are How well are we advocating our safety communications? Is the message consistently passed to all of those who need to receive it? Do we consistently target those entities who can learn from our investigations and who are in a position to fix the deficiency that caused the safety communication? Are we fooling ourselves in believing this is so? We can investigate every transportation accident and derive exact conclusions and findings all we want, but if we do not properly pass the safety communication aimed at fixing the problem, we have wasted our money, time, and effort, and we also have missed the boat, to use a common expression.

The most important aspect of an investigation is the identification of unsafe acts, unsafe conditions, and underlying factors that led to the incident or accident. This methodology will allow an investigator to validate safety deficiencies that will also have been identified through this process. A validated safety deficiency preamble and its concluding section must

- demonstrate that defenses were inadequate, missing, or failed.
- address the possibility of a recurrence.
- consider and analyze the severity of consequences.
- provide risk-control options (is improvement feasible?).
- result in safety communications aimed at mitigating or eliminating the identified risk by those responsible.

Naturally, each State investigation agency has to consider a number of factors in determining whether an incident or accident will be investigated. Although ICAO Annex 13, Chapter 5, INVESTIGATION, States that accidents **shall** be investigated and that serious incidents **should** be investigated, it is evident that we cannot do everything, as our resources are limited. Having said that, we should naturally concentrate on those occurrences where the safety payoff appears to be the best. This requires that we have a close initial look at each occurrence to determine the possible level of that safety communication payoff.

The challenge is that if we cannot "communicate" adequately, we will de facto fail to do the "educate" part of the this year's trilogy theme, as both go hand in hand. The result is that the safety message will not be passed, and recurrence under similar circumstances becomes simply a matter of time.

Although we may be excellent at investigating for causes and contributing factors, we have yet to consistently advocate our bread and butter: communication and education. As stated, we are very good at determining the who, what, and why of crumpled aluminum and rotating parts. Most major accidents include unsafe acts, conditions, or underlying factors where the risk was real and the defenses to prevent the mishap were less than adequate or non-existing. Sometimes, however, we simply fail to properly

Bombardier RJ100 crash.

communicate a validated safety deficiency to the right party—the one who can fix the problem. At other times, our reports do not explain clearly what the exact nature of the deficiency was, leading the recipient of the safety communication to disagree with our recommendations aimed at reducing this risk; as a result, nothing gets fixed. (How often have you heard the statement "We disagree with your risk analysis"?) On occasion, it becomes too difficult to fully develop a safety deficiency for a number of reasons (lack of factual evidence, difficult analysis, industry pressure, or other), and we just give up.

Finally, we do not advocate or push our product sufficiently. We write our recommendations and then let others take action as they see fit, hoping they will do the right thing. We consider our work done once the investigation report has gone out the door. If those others do not take appropriate action, we see this as **their** problem, because we told them about it... right? On many occasions, we have not been very good at following up and evaluating government and industry responses to recommendations. Specifically, we have failed to consistently track their proposed actions in response to our recommendations, and we have not verified the timely implementation of those proposed actions. Our reports and proposed safety action often do not reach each of those who need to be appraised of this information. Sometimes they don't get the safety message in time; at other times, they simply do not get it and as a result we later observe a repeat of an earlier accident.

Our overall past performance in passing the communicate and educate safety message has certainly had its ups and downs. The jury is still out, I believe, whether the ups are winning the battle. Hopefully, I might be able to conclude my presentation today with measures, ideas, and solutions that may help us improve the results of our investigating efforts, that of saving lives, property, and environmental damage. In order to set the scene for the remainder of this paper, I will now to use a few examples highlighting difficulties to get safety deficiencies corrected.

On Dec. 16, 1997, an Bombardier RJ100 crashed while conducting an approach to a Canadian airport. The reported aerodrome weather at the time of the accident was vertical visibility 100 feet obscured, horizontal visibility one-eighth of a mile in fog, and runway visual range 1,200 feet. After the autopilot was disengaged at 165 feet above ground, the aircraft deviated from the desired flightpath. The aircraft crashed shortly after the captain ordered a go-around because he was not sure that a safe landing could be made on the runway remaining.

Canadian regulations permit Category I approaches to be flown in visibilities lower than would be permitted in most other countries (including the United States), and the regulations are not consistent with what is recommended in ICAO international standards and recommended practices. To compensate for the risk associated with landing an aircraft in conditions of low ceiling and visibility, extra aids and defenses should be in place. Therefore, to reduce the risk of accidents in poor weather during the approach and landing phases of flight, the Board recommended that

The Department of Transport reassess Category I approach and landing criteria (realigning weather minima with operating requirements) to ensure a level of safety consistent with Category II criteria.—TSB Recommendation A99-05

On Aug. 12, 1999, a Raytheon Beech 1900 crashed while on approach to a Canadian airport at night. At the time of the approach, the reported ceiling and visibility were well below the minima published on the approach chart. The crew descended the aircraft well below safe minimum altitude while in instrument meteorological conditions. Throughout the approach, even at 100 feet above ground level (agl), the captain asked the pilot flying to continue the descent without having established any visual contact with the runway environment.

The accident report concluded that the issue of additional regulatory restrictions for instrument approaches in poor weather has been discussed in Canada for several years because of the number of accidents that occur during the approach and landing phase. Indeed, from January 1994 to December 2001, the Board investigated 24 such accidents where low visibilities and/or ceilings likely contributed to the accident. Consequently, controlled-flight-into-terrain accidents on approach that result in loss of life and damage to property have continued to occur and will likely continue to occur. The Board therefore recommended that

The Department of Transport expedite the approach ban regulations prohibiting pilots from conducting approaches in visibility conditions that are not adequate for the approach to be conducted safely.—TSB Recommendation A02-01

And that

The Department of Transport take immediate action to implement regulations restricting pilots from conducting approaches where the ceiling does not provide an adequate safety margin for the approach or landing.—TSB Recommendation A02-02

The Cessna 335 was on an instrument flight with two pilots and two passengers on board. After checking the prevailing weather conditions at destination, the pilot decided to make a back course approach on Runway 29. The pilot reported by radio at 2 miles on final approach. This was the last radio contact with the aircraft. The aircraft was found by a search team travelling along a dirt road bordering the runway. The aircraft was consumed by a very intense fire. All four occupants received fatal injuries. The reported weather at the time of the accident was as follows: visibility one-quarter mile in heavy snow and vertical visibility 300 feet. No aviation regulation in Canada prevents pilots from making instrument flight rules (IFR) approaches where weather conditions are below the approach minima (ceiling and visibility) and no RVR is available at the airport

Wait, there is more. On Feb. 25, 2004, a Boeing 737 aircraft landed beside the runway in the wee hours of the morning. You guessed it. The weather was not very cooperating once again. The reported runway visual range was 1,200. The crew lost visual references with the ground after committing to the landing. Fortunately, no one was hurt. Close, but no cigar as they say.

On April 25, 2004, another Beechcraft C-100 overran the end of a runway and crashed when it landed near the departure end in poor visibility. I could mention many more commercial operations approach and landing accidents related to low ceilings and visibility investigated by the TSB in the last 10 years.

What happened to the above recommendations? In September 1999, TC had initiated action to implement new approach ban regulations aimed at reducing the likelihood of accidents during instrument approaches in low-visibility conditions. **Good idea!** This process is still ongoing. Until these regulations are promulgated, there will continue to be inadequate defenses against the risks associated with pilots descending below the decision height or minimum-descent altitude in an attempt to land in visibility conditions that are unsafe. We will continue to investigate this type of accident until some day, large amounts of blood are spilled under these conditions. The deficiency will then be vigorously addressed, but it will of course have been too late. Why is the message not getting through?

Let's look at two cases involving maintenance issues. The Beech A-100 aircraft crashed near the airport shortly after takeoff. After getting airborne, the aircraft was observed to immediately pitch up to approximately a 70-degree angle. It then appeared to stall at an altitude estimated to be between 500-700 feet agl. The nose then fell through the horizon to a pronounced nose-down attitude. As the airspeed built up, the aircraft began to recover from the excessive nose-down attitude. The aircraft contacted the ground and crashed as it was beginning to enter into a second roller-coaster sequence. The wreckage trail, consisting of the underbelly baggage pod and its contents, all landing gear, and the left propeller assembly, covered a distance of 491 feet. The remainder of the aircraft came to rest essentially in one piece after it had crossed over a railroad bed and track. A small fuel-fed fire from the punctured left wing ensued a few minutes after the occupants exited the aircraft but was rapidly extinguished by the airport firefighting services. Miraculously, no one aboard was seriously injured.

Raytheon Beech 1900D accident.

The investigation quickly determined that the primary and alternate trim "H" bracket attaching the aircraft's stabilizer to the airframe had been improperly reconnected during weekend maintenance performed prior to the flight. After the occurrence, investigators found that the top of the actuators was not attached to the airframe. The two bolts did not pass through the actuator holes when reinstalled, but only through the attachment holes in the airframe. When the bolts were tightened during installation, they squeezed the ends of the actuators to the attachment points on the airframe. The inspection was carried out superficially without close inspection from inside the tail cone or using the tools, such as a mirror, that would be standard for this type of inspection. The accident report mentioned the difficulty in visually verifying that the bolts were inserted properly in the airframe channel, and suggested that the aircraft maintenance manual directives concerning this task could be enhanced.

Then, it happened again! On April 23, 2003, a Beech 99A was on a scheduled flight from Saskatoon to Prince Albert, Saskatchewan, with a crew of two and four passengers on board. This was the 12th flight following major inspection and repair activity and the aircraft had flown approximately 7 hours since completion of the work. Shortly after the flaps were selected for approach, a loud bang emanated from somewhere in the tail and the aircraft immediately started to pitch up. The crew applied full forward elevator and reduced power. The airspeed slowed and from a near-vertical attitude, the aircraft rolled left then pitched steeply nose down. The crew applied full-up elevator and full engine power to recover from the dive. The nose of the aircraft came up and the crew extended the landing gear just prior to a high-speed touchdown on rolling agricultural fields. On contact with the ground, all three landing gear and the belly baggage pod were torn from the aircraft. The aircraft slid to rest approximately one-half mile from the initial ground contact point. The crew and passengers exited the aircraft through the main cabin door. Injuries incurred were not life threatening.

Post-accident inspection revealed that the stabilizer trim actuator had detached from the fuselage structure allowing the stabilizer to move freely under the influence of air loads. During installation, the two bolts had been installed behind the actuator mounting lugs, trapping the lugs between the shanks of the bolts and rivets in the airframe structure. Sounds very much like the other one? You bet! The findings of this report as to cause and contributing factors were generally the same as those of the first one. An interesting finding as to risk read as follows: "The nature of the installation presents a risk that qualified persons may inadvertently install Beech 99 and Beech 100 horizontal stabilizer trim actuators incorrectly. There are no published warnings to advise installers that there is a potential to install the actuator incorrectly."

On May 2, 2003, 10 days after the accident, the TSB issued an occurrence bulletin detailing the factual information relative to this occurrence and the Beech King Air 100 occurrence of June 1999. On June 20, 2003, the TSB forwarded a safety advisory regarding the facts of this occurrence to Transport Canada for potential safety action. Transport Canada produced a Service Difficulty Alert (AL-2003-07, dated July 17, 2003) based on the TSB occurrence bulletin, advising of the occurrence and indicating that the installation procedures in the maintenance manual are being reassessed. Transport Canada contacted the U.S. Federal Aviation Administration, requesting its assistance and that of the aircraft manufacturer, suggesting issuance of a service letter and incorporation of warnings in the appropriate aircraft maintenance manuals. Raytheon Aircraft issued King Air communiqué No. 2003-03 to alert appropriate operators and maintenance personnel of the possibility of incorrect installation of the actuators.

Has the message now been passed to all those who need to receive it? I sincerely hope so. Will all maintenance personnel working on those types of aircraft heed the message? I simply don't know. One thing is evident: if AMEs do not look at their maintenance manual when performing this function, my guess is that it will happen again.

How come the first lesson was not learned? Was it because our safety message was not strong enough in the first report? Was it ignored? Was it not received by all operators who have this type of trim bracket arrangement? Was it simply forgotten after a year? What could we/should we have done to ensure this did not happen again? We sometimes say that there are seldom new accidents, just old accidents revisited. For your sake and my sake, I hope we don't really mean this.

Lets now look at the communications aspect. There are various methods by which each State investigation agencies communicate safety deficiencies. These can range from the very informal verbal communications between the investigator-in-charge (IIC) of an incident or accident and the parties involved, all the way to the formal recommendations issued with a final report. Between these two extremes, we find initial reports, interim reports, factual reports, 60-day reports, occurrence bulletins, information and advisory letters, Board concerns, et j'en passe. All of those can and often convey a safety message that the intended recipient(s) should catch, understand, and act upon.

In Canada, the only safety action that requires a formal response is that expressed in the form of a Board recommendation to the Minister or Transport. All other interested parties, such as operators, NAV CANADA, and other organizations need not respond or comment on any TSB Safety communications. Finally, each State investigation agency has its own standards and processes as to how a safety action message should be drafted. Sometimes, States put the emphasis on defining the safety deficiency in the text of their recommendations and leave the nuts-and-bolts aspect of fixing the problem to those in the best position to do so. At other times, they are much more specific in the wording of their recommendations concerning the actions that need to be undertaken. It would be nice to have a recognized method or standard of accomplishing this, but are we dreaming in color?

Practices differ between State investigation agencies concerning safety actions that require to be directed at another State. The TSB has no set policy in this regard, and I suspect that other States may be in a similar situation. In some cases, safety action communications are sent directly to the foreign State' s regulatory authorities. In other cases, recommendations are sent through the State's accident investigation authority, such as the NTSB, the ATSB, and the AAIB. Because the TSB has no set policy, our Board uses a mix of the two methods. I should point out that foreign regulatory authorities are not required to respond to safety communications issued by another State, but that they usually do. A State accident investigation authority can also put pressure on its own regulatory agency, manufactures, and operators to respond, but the State issuing the safety communication may not get adequate feedback, due to this lack of an internationally recognized policy in this respect.

When it comes to operators, a formal response on their part to a State recommendation or other safety action proposal is, of course, not mandatory. Operators can take action to reduce the risk based on the safety communication, or they can simply ignore it. An operator can also agree to take action to mitigate a validated risk or deficiency and subsequently do nothing about it. Some of the factors are company set up, finances, attitude, and the importance attached to maintaining a healthy safety culture at all levels of the company. Furthermore, communications passed to an operator do not always simultaneously get transmitted to all other operators who need to receive the communication, especially when the deficiency has ramifications over more than one continent. Finally, States are not well equipped to monitor or track safety action taken by their own operators in response to a recommendation issued by another State. For these reasons, monitoring safety action taken by operators can be, and regularly is, a hit-and-miss affair.

Manufacturers of aeronautic products are also not required to respond formally to safety action emitted directly to them by a foreign State either, but they generally do. It is important for manufacturers to substantiate on paper the reason or reasons they may disagree with a given safety communication. If they agree with it, they must indicate the actions they will take or intend to take to mitigate or eliminate the safety risk. When the risk and its consequences are judged unacceptable, State regulatory authorities will normally issue an airworthiness directive directly to manufacturers and operators.

On issues where it can be argued (truthfully or not) that the risk is lesser than presented, manufacturers may choose to issue a service bulletin to operators and owners of the concerned aircraft, equipment, or part. To do nothing might be foolish, but at the same time, the manufacturer has to be concerned about the legal implications of admitting a deficiency in his product, especially if said product was found to have been at cause in previous occurrence(s). For that reason, manufacturers sometimes object to the issuing a particular service bulletin as this action may imply some degree of responsibility for previously recorded or investigated events. Finally, the difficulty that investigation authorities have with service bulletins is, of course, the fact that they have no mandatory compliance, even when the manufacturer-recommended action has a "mandatory" status or a required completion deadline based on a given date or time in service of the part. Operators may choose to disregard a service bulletin, and some do.

Let's now look at how we actually monitor those responses we do receive, and what we do with these. Most investigation authorities such as the TSB have no power to mandate or require action to mitigate or eliminate the risk specified in its safety communications issued following investigation. The implementation of air regulations is the responsibility of the State regulatory authority, and there is an excellent reason for that. This method allows investigation authorities to maintain a complete independence from the regulatory arm of a government. On the other hand, that same reason distresses us as investigators when we see recurring accidents like those described earlier year after year because the risk-control options evidenced in our safety action recommendations are not being implemented.

At the TSB, one of my responsibilities is to track all formal responses to safety action, including those responses emitted by foreign States, operators, and manufacturers. Each response to a recommendation is initially sent to the IIC, who then provides my office with his assessment in one of the following categories: fully satisfactory, satisfactory intent, satisfactory in part, or unsatisfactory. The assessment is then reviewed at head office against the standard and then forwarded to the Board. The assessments are reviewed on an annual basis to ascertain progress on mitigating risk evidenced in safety communication. Currently, in Canada, the assessment category given is not passed back to those who provided the response and, therefore, the feedback stops at that point. As a result, there is no impetus for the action addressee to show due haste in addressing the problem. The risk may, therefore, remain unchanged.

The last issue I would like to address at this time with the tracking and assessment of responses to safety communications is the type of response we all too often receive. Life would be great if each response began with a statement of agreement with the recommendation, the actions that will be taken to reduce or eliminate the risk, and the milestones to accomplish the task clearly shown. Unfortunately, that is not what we get. How can we properly address and assess a response that contains mostly explanations rather than actions, and where no implementation timeframe is given? I wish I knew how to answer this question, because if there ever was a million-dollar question, that is it. This should not, however, stop us from searching for the answer.

I would now like to offer some concluding thoughts on the communication theme. Sadly, our safety communications do not always convincingly demonstrate the residual risk, the probability of recurrence, and the severity of consequence (weak evidence or wording) to the interested party. This results in a weak impact of the safety message we are trying to convey, and, accordingly, it receives an inappropriate level of attention and response. As an example, parties to an investigation are not always involved in the full analysis process that allows for better understanding of the safety issues involved. Some States may feel that they are losing a degree of independence in doing so. However, I believe we can retain our independence while ensuring involved parties understand the thought process behind each safety issue being analyzed. This method makes it easier to reach a consensus on a deficiency that needs to be addressed.

Furthermore, our recommendations are sometimes directed at the wrong addressee, that is, they are not communicated to those requiring the information. Because we do not have international standards related to safety communications to a foreign State, we sometimes miss the mark. As stated earlier, action taken is often not adequately tracked and the response assessments are not made public by all investigating authorities. Those entities responsible for effecting change are often not challenged when their response is judged inadequate. Finally, the response often does not provide mitigating action milestones. These are important issues that organizations such as this esteemed body or ICAO may wish to pursue further in order to advance safety.

Having said that, have our investigative efforts produced results? Let's take a look at our past performance and take a shot at the future. It is a fact that deadly mistakes by commercial and airline pilots have decreased dramatically over the last decade. In other words, the old "pilot error" findings have been on a steady downward slide. That is a good thing, as Martha Stewart would say. Year 2003 was in fact one of the best in commercial air transport history. Was that a fluke? I don't think so. We will never know how many accidents we have prevented due to our concerted efforts, but the numbers do not lie. We are indeed making progress with the "beast," but we must not rest. CFIT continues to be one of the main causes of accidents. The enhanced ground proximity warning system (EGPWS) is reported to be a major player in helping to reduce CFIT accidents. Indeed, no aircraft equipped with this updated system has been involved in a CFIT accident to date. These are good news. I wish everything else was this rosy, but it is not. Fatal accidents caused by maintenance errors are seen to be on the increase. There are claims that there will be one major accident per week in 10 years due to air traffic increase unless the accident rate is reduced. The risk of mid-air accidents is also real, as evidenced by the recent mid-air collision in Germany. RVSM rules will make navigation and altitude-bust errors yet more critical. ETOPs and over-the-pole flights will increase, with the associated risk of someday having to investigate an accident around the polar cap. We can also expect there will continue to be major accidents over water or at sea, like TWA 800, SWR 111, and the more recent Alaska Airline and Flash Air flights.

So, what are we doing to make things better? Flight Operational Quality Assurance (FOQA) is coming on line in some States. FOQA is seen as a great tool for tracking and investigating incidents before they become accidents. Quick access recorders (QARs) offer the possibility of increased FDR data gathering capabilities. The technology is already there. Manufacturers and their engineers need only invest a little more time, money, and effort into developing a hardened QAR, and the capability to extricate the facts of an accident will increase exponentially. Any accident investigator can see the advantages of having additional data. An accident sequence sometimes begins well over the half-hour that older CVRs capture. Two-hour CVRs are being installed in new aircraft, and some older ones are being retrofitted with the improved boxes. There are still some hurdles to clear, but the possibility of having video recorders in aircraft cockpits in the future is beginning to take hold, as the advantages of this technology are real and are being recognized. A large number of aircraft systems now capture information into non-volatile memory chips that can reveal important information to help determine the cause of an accident. Finally, many investigation authorities have, or are developing, a list of safety issues that they are interested in. It would be a good idea for us to exchange notes on those safety issues we each are interested in pursuing.

The challenge to educate is real. Aviation safety does not improve by quantum leaps over short periods. Rather, it goes through a series of up and down curves, as we fix old deficiencies while new ones pop up. Accident investigators will have to make every effort to ensure that safety communications reach all those affected by the risk. We must learn to think globally instead of locally. We must, therefore, standardize our approach to safety communications—that is develop coherent related internationally recognized policies and standards. FOQA data will be of limited use if gathered threshold information is not investigated properly, or if the results are not passed to others who can learn from other's mistakes. Investigating authorities must become more active in advocating safety action, and those responsible for effecting changes to improve safety must show diligence in mandating those changes.

Ladies and gentlemen, our challenge is clear: each safety deficiency that we conclude must be addressed, and we must write clear, convincing safety communications, and it is imperative that these be targeted at the appropriate audience. If we fail to do this, our message will not get the attention it deserves and others will not learn about these identified risks. Finally, unless we as investigators make vigorous efforts to track responses to communications and critically assess action taken as a result of these communications, those risks will remain. The tragedy will be that we will know that we could have done more to prevent a catastrophic recurrence of a serious accident, but did not. We will have to live with that knowledge. The alternative, advocating safety at all levels, requires more work and dedication on our part, but is much more rewarding in the end. As I said at the beginning of this paper, the traditional role of organizations is advocacy. So let's do some hard thinking among ourselves as to how we can best advocate out there! Surely, we can improve our track record, but it will require constant effort, innovation, and dedication toward the aim. Any bright ideas out there? ◆

Past, Current, and Future Accident Rates: Achieving the Next Breakthrough in Accident Rates

By Dr. Robert Matthews, Federal Aviation Administration, U.S.A.

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Introduction

A common consensus among aviation professionals holds that fatal accident rates have stabilized at such low levels that additional improvements in the rate will be more incremental than in the past. Even when we define air carrier operations broadly enough to capture aircraft with just 15 passenger seats, the rich countries of the world now combine for an average of just two major fatal accidents each year, despite more than 50,000 flights per day. Today's low accident rates often lead us to conclude that we simply do not have much arithmetic space for dramatic improvement.

However, this paper argues that we have entered another period of significant reduction in the fatal accident rate, and the improvement will accelerate over the next decade or more. This improvement has been, and will continue to be, driven by major changes in the air carrier fleet and by the application of new technologies, some of which are already coming on line and some of which soon will do so. These changes will be built on technology and will be connected by two primary themes.

- Ever-increasing precision—in navigation, aircraft handling, engine tolerances, etc.
- Economic benefits—Technological breakthroughs in safety have always been implemented most quickly and pervasively when the economic benefits are so compelling that carriers must incorporate them to compete on important routes. Soon airlines will be compelled to have the precise navigation capabilities associated with GPS and "required navigation performance" if they hope to compete in key markets. This, in turn, will encourage carriers to accelerate the modernization of their fleets.

To build its case, this paper first reviews several past breakthroughs in accident rates. Part Two then addresses significant changes in the civil aviation system that are under way, or will soon be under way, and outlines how those changes will lead to sustained improvements in fatal accident rates. Note that the data and examples used in this paper come primarily from the United States. This is for the sake of convenience. However, since no meaningful differences exist in long-term air carrier accident rates among the world's richer countries, the story outlined in this paper applies elsewhere in the world as well.

Part One: Past Breakthroughs in Aviation Safety

While many incremental improvements have helped to deliver today's low fatal accident rate, a relative handful of major technological innovations explains most of the advances that have transformed aviation from a relatively risky post-World War II system into today's very safe system. Part One outlines several sudden advances in the accident rate that share a number of basic characteristics with changes that are under way today or soon will be under way.

Changes in the air carrier fleet and navigational aids

From 1946 through 1950, U.S. air carriers averaged a major accident[1] every 16 days and a major CFIT accident every 12 weeks. If such frequencies had continued, the industry could never have evolved into the industry that we know today. However, as Figures 1 and 2 illustrate, accident rates fell by half over the next several years. The same figures illustrate that other rapid and significant improvements would follow.

That first breakthrough, from the late 1940s to the early 1950s, was driven by major changes in the civil fleet and by the deployment of new navigational aids (navaids). In the immediate postwar years, larger aircraft and, more importantly, pressurized aircraft entered the civil fleet in large numbers. The Lockheed L-049, with up to 81 passenger seats, entered service in February 1946. In April 1947, the DC-6 (up to 52 seats) entered service, and the Boeing 377 (up to 112 seats) entered service in April 1949. These aircraft instantly extended flight ranges from 350 or 400 miles that typified the era of the DC-3 to 750 and 1,000 miles.

Because they were pressurized, the new aircraft also could fly up to 20,000 feet, which put them above much of the terrain and much of the weather, at least while enroute. The longer range of this fleet also opened new markets to nonstop service, thereby reducing the number of landings and takeoffs required for a typical city pair. Though older aircraft remained in the fleet for some time, the pace of change was dramatic. In just 3 years (June 1950 to June 1953), the number of aircraft in the U.S. fleet increased by 17 percent, but lift capacity increased 42 percent.[2]

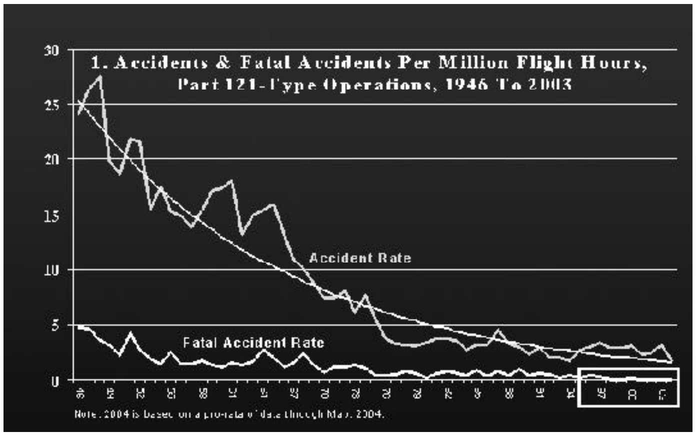


Figure 1

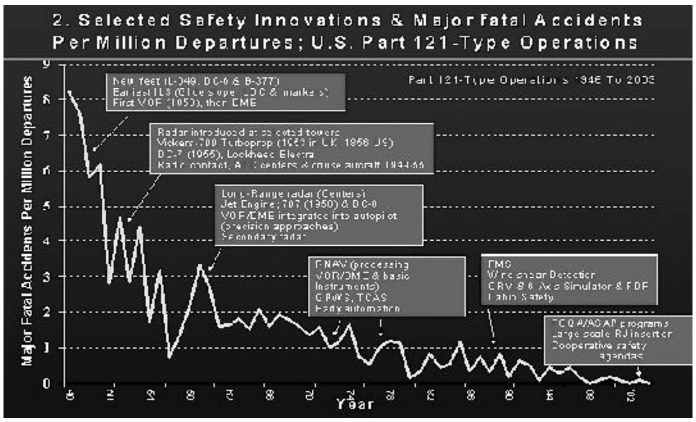


Figure 2

Navaids also changed rapidly and accelerated the pace at which new aircraft penetrated the fleet. In April 1947 the U.S. CAA, a predecessor of the FAA, introduced instrument landing systems (ILS), which included a VHF directional localizer, UHF glideslope transmitters, and, usually, outer, middle, and inner beacons. The CAA said that with an ILS, properly trained crews in properly equipped aircraft could make approaches when ceilings were 100 feet below minimum (then normally 400 feet) and when visibility was 3/4 of a mile (versus a minimum of 1 mile at the time). After an airline had 6 months of satisfactory experience with ILS, minima could drop to 200 feet and a half mile.

The new aircraft and ILS provided a quantum leap in safety by reducing the frequency of controlled flight into terrain (CFIT), inflight loss of control, and approach and landing accidents. Though all three of these accident categories remained far too common, their frequencies fell sharply at the time.

Pressurized aircraft and ILS are good examples of safety improvements that airlines could not afford to be without. The increased power, range, and comfort of the new aircraft opened a matrix of new, nonstop city pairs and introduced a level of service that made aviation much more attractive for intercity travelers. To compete in important markets airlines had to have the new aircraft, even though a glut of military versions of less-capable civil aircraft was available at bargain prices. Economic benefits also made ILS equipment and ILS training a must if a carrier was to remain competitive. No airline could afford to be frequently locked out of key airports due to weather while competitors maintained reliable access. The new fleet was instrumental in the growth of aviation in the U.S. For the first 10 years after World War II, revenue passengers increased by an average of 19 percent per year. [3]

ILS and pressurized aircraft can easily be taken for granted today or even overlooked as major safety advances. In their time, however, as illustrated in Figures 1 and 2, their impact was dramatic and immediate. Yet the new, larger aircraft had some tradeoffs in public perceptions of safety. First, though these aircraft in fact improved safety, their accident rates remained remarkably high by today's standards. Second, their increased size suddenly introduced a quantum leap in the number of fatalities associated with any single accident.

Before the introduction of pressurized aircraft, accidents rarely involved more than 20 to 25 fatalities. Then, in October 1946, a CFIT accident in a DC-4 killed 39 people. The following spring, three major DC-4 accidents occurred within just 15 days. On May 29, 1947, a DC-4 crashed on takeoff at La Guardia in New York, killing 43 occupants. The next day, a DC-4 crew lost control on decent toward Washington; 54 people died. Two weeks later, another CFIT in a DC-4 killed 50 people. Later that same year, an onboard fire killed 52 people on a DC-6. In short, fatal accidents on pressurized aircraft suddenly involved unprecedented numbers, and despite improvements compared to the preexisting fleet, those accidents remained alarmingly common.

Also in 1947 the CAA commissioned its first very-high frequency omnidirectional beacon (VOR) at Nantucket, Mass. This was a significant improvement on the non-directional radio beacon (NDB), which was the only common navaid system at the time. A VOR was more accurate and less prone to interference. The VOR signal was transmitted to a 360-degree universe from a particular angle to magnetic north. Pilots could determine bearings and "home" on the station. The pilot also could determine how far the aircraft was off a proper course. The CAA followed the VOR with a program to deploy 425 distance measuring equipment systems (DME). Procurement began in 1950 and installation began in 1951. Now a flight crew not only knew the proper heading to a signal relative to magnetic north, but the crew also knew the distance to that signal.

The combination of VOR/DME improved safety through more reliable navigation. However, substantial time was required before receivers for this equipment, especially DME equipment, penetrated the fleet. They help to explain the sharp decrease in accident rates experienced in the mid-1950s more so than the sharp decrease that began around 1948 (see Figures 1 and 2).

Again, new technology is incorporated most rapidly when it provides a compelling economic benefit. As that economic case weakens, implementation slows down and the likelihood of, or the need for, regulatory action increases. However, DME lacked the compelling economic case of new fleets and ILS. Though airlines began adding DME receivers in some aircraft, many aircraft in the fleet did not have DME receivers. The FAA later mandated DME equipment. Effective July 1, 1963, DME equipment was required for all jets and any other aircraft capable of operating above 24,000 feet. One year later, DME was required on all aircraft operating in the IFR system and all aircraft more than 12,500 pounds. By November 1964, the FAA commissioned its first ILS-DME combination at JFK in New York.

By the late 1960s and early 1970s, the VOR evolved into the first RNAV systems, which became widely available in the fleet in the 1980s. On properly equipped aircraft, crews could create waypoints using a VOR radial and DME distance. A waypoint is defined by latitude and longitude coordinates and is most often used to identify a point at which a crew begins to change direction, speed, or altitude. The VOR quickly became and remains the backbone of the enroute IFR system. Essentially, an enroute IFR aircraft flies to a VOR, and then makes any required change in direction required to reach the next VOR. This system of navigation provided the first real analogy to a highway in the sky.

Eventually the VOR would be adapted to area navigation (RNAV), as discussed below. RNAV enabled the ATC system to offer "direct to" clearances, letting crews define and fly the shortest distance between two points, rather than flying less-direct routes to and from interim waypoints.

Even without these later evolutionary developments, the new post-war aircraft and the introduction of ILS provided a quantum leap in safety by reducing the frequency of controlled flight into terrain (CFIT), inflight loss of control, and approach and landing accidents. Though all three of these accident categories remained far too common by today's standards, their frequencies collapsed in relative terms.

Improvements in air traffic control (ATC)

Post-war ATC, communications, and navaids

The post-war era in the U.S. began with a very rudimentary ATC system. The system, such as it was, relied primarily on standard procedures, such as landing aircraft had the right of way, see and avoid, etc. The relatively few ATC towers that existed were limited to visual fields of about 1 mile. The enroute system was even weaker. Prior to the war, the federal government had just begun to operate three "air traffic control stations" formerly operated by a consortium of large air carriers. Pilots could get weather information and could report their positions, as determined by the crews. Controllers separated enroute aircraft flight strictly by complex manual computations based on locations, headings, and airspeeds that pilots had reported some time earlier.

This system of telephone-radio-blackboard separation was labor intensive, and could not hope to make efficient use of the airspace. The system was too much of an art to be safe, and it, too, was quickly overwhelmed with continued growth and technological changes in commercial air travel. Clearly, the new aircraft coming on line and the rapidly increasing volume would require more viable ATC technology.

The technical innovation, developed by Great Britain during World War II, was radar. For the first time, ATC could separate aircraft based on **actual** radial position. This would immediately increase airspace efficiency and greatly improve safety by anticipating conflict between enroute aircraft without waiting for complex manual computations based on locations and headings that had been reported some time earlier.

The technical innovation came from Great Britain in World War II: radar, which determines a target's location by measuring the time needed for the echo of a radio wave to return, and by identifying the direction of the return signal. Radar would allow controllers to separate aircraft based on **actual** position. This would increase airspace efficiency and greatly improve safety by anticipating conflict between enroute aircraft.

However, implementing radar nationwide took years. The CAA first demonstrated civilian use of radar at Indianapolis in May 1946. It would be 3 more years before the first radio contact was established between an ATC center and an enroute aircraft. Six more years would pass before all enroute centers even had direct radio contact with aircraft. By mid-1956, the U.S. had radar at just 32 towers and long-range radar at only two centers.

Post-war midair collisions

Radar was first used in terminal airspace at major airports, where the technical demands were less complex. However, rapid growth in air travel, without the benefit of enroute radar, quickly led to an eruption of midair collisions, which created intense and sustained concern by the public and Congress.

The first post-war fatal midair collision occurred in April 1947 over Columbus, S.C., as a Delta DC-3 and a Piper approached Columbus. The Piper turned onto final and struck the tail of the DC-3. The DC-3 went full power to climb, then crashed with the Piper embedded in the DC-3's tail. All 7 people onboard the DC-3 and the lone pilot on the Piper were fatally injured. This was followed by three more midairs in 1949 and three in 1951, one of which involved 15 fatalities on a commercial aircraft, while others involved fatalities on general aviation (GA) and military aircraft. Public concern quickly led to congressional hearings on midairs. Two more midairs with GA, 1 each in 1952 and 1954, saw both air carrier aircraft land safely but two people were killed in each of the two GA aircraft.

Then came the June 30, 1956, midair over the Grand Canyon; everything changed—fast! A TWA L-1049 (Super Constellation) and a United DC-7 had left Los Angeles 3 minutes apart on eastbound flights. The L-049 was at 19,000 and the DC-7 was at 21,000, as assigned, when the L-1049 crew asked for clearance to climb from 19,000 over turbulence. Shortly before both aircraft were about to leave controlled airspace, the L-1049 crew was advised that the DC-7 was nearby, but the DC-7 crew was not advised of the Constellation's climb. Both aircraft then left the airspace controlled by the Los Angeles ARTCC and entered uncontrolled airspace near the Grand Canyon. At that point, the flights were VFR and were not under positive control, since only two ARTCCs had long-range radar. The aircraft struck at about 21,000 feet. All 58 occupants on the DC-7 and all 70 occupants on the Constellation were killed. The total of 128 fatalities was nearly twice the largest number of fatalities (66) in any previous accident.

The numbers truly shocked both the public and Congress. Within weeks of the Grand Canyon accident, Congress had funded 82 long-range radars for centers. The first of these second-generation radars came on line in September 1959, with 20 new tower radars on line by May 1960.

Yet the rash of midairs continued, with one each in 1957 and 1958 between airliners and military aircraft. They took the lives of 58 people on air carrier aircraft, 1 military pilot and 1 person on the ground. These accidents not only sustained public apprehension about aviation safety, but also brought public attention to long-standing disputes between CAA and the military about jurisdiction over airspace.

The same midair also led directly to the Federal Aviation Act of 1958 and the creation of the Federal Aviation Agency (FAA), later changed to the Federal Aviation Administration. Aviation responsibilities had been divided between the Civil Aeronautics Board (CAB) and the Civil Aeronautics Administration (CAA).

The CAB was responsible for rulemaking, accident investigation and economic regulation. The CAA was responsible for enforcement of CAB rules, certification, and ATC. The 1958 Act assigned CAA's functions to the FAA, added the CAB's safety rulemaking function, and made the FAA solely responsible for civil and military air navigation and ATC.

The primary focus of the 1958 Act was to establish a national system of positive ATC. By making the FAA solely responsible for the management of domestic airspace, the 1958 Act resolved a long-standing jurisdictional dispute between the CAA/FAA and the military. Positive air traffic control would separate IFR traffic from VFR traffic, and fast traffic from slow traffic. Positive control was established over all continental airspace above 24,000 in 1957.

In June 1958, the CAA established the first three positive control routes on designated airways between 17,000 and 22,000 MSL. Airways were 40 miles wide and excluded all VFR traffic. Since these altitudes required pressurization or oxygen, this was no burden to most VFR aircraft, but it forced carriers who wanted to use less-crowded airspace to fly IFR. When this narrowly defined system of airways showed serious operational limitations, FAA went to area control. By October 1971, all airspace between 18,000 and 60,000 MSL was reserved for IFR aircraft with transponders.

Midairs continued after 1956 and 1958, with four more in 1960. The first three that year involved no fatalities on commercial aircraft but did involve fatalities among military and GA pilots. Their real effect was to keep midairs before the public as a major safety issue. Then the New York midair in December 1960 put the issue back on page one.

A United DC-8 and a TWA Constellation were on approach to Idlewild Airport (now JFK) and La Guardia, respectively. The ground controller instructed the DC-8 to hold near a navigation fix until he could be cleared to Idlewild. However, the DC-8 had lost much of its navigation equipment, and could not establish its fix. The DC-8 then entered its holding area at too high a speed, overshot its designated airspace and, over Staten Island, struck the Constellation that was awaiting clearance to La Guardia. All 44 people on the Constellation and all 84 on the DC-8 died. Five more people on the ground were killed—a total of 133 fatalities. The Staten Island accident quickly shifted the focus on midairs from the enroute environment to the terminal environment, where IFR and VFR aircraft mixed in close quarters.

Though the commercial system got a 3-year reprieve from fatal midairs after Staten Island, midairs resumed in February 1965, with a non-fatal midair over Long Island. This was followed in December by a fatal accident with 84 fatalities due to an evasive maneuver by an Eastern DC-7 trying to avoid a midair 7 miles off Jones Beach in New York. In that accident, a Pan Am B-707 captain, inbound to JFK from Puerto Rico, advised ATC of a near miss and reported that the other aircraft had "winged over" and "it looks like he's in the bay."

In 1967, a midair over west central Ohio between a GA aircraft and a DC-9 (26 fatalities) and then a midair in North Carolina between a GA aircraft and a Piedmont 727 (82 fatalities) kept the midair issue before the public. Three more midairs followed in 1968 with no fatalities on the commercial aircraft, but seven fatalities on GA aircraft, and two more non-fatal midairs in 1969.

The FAA responded to midairs by developing the ATC Radar Beacon System, starting in the late 1950s. The CAA/FAA understood as early as 1950 that positive control based on radar soon would fall short of the system's needs. The shortcoming was that primary radar simply "painted" a target on a given radial. Altitude could not be identified, nor could the aircraft or, therefore, the aircraft's capabilities. A second-generation radar system would be required, particularly with the birth of the jet age. The desired system would be based on an airborne transponder that transmitted unique signals from which ground interrogators could display aircraft identity on an ATC screen.

FAA clearly needed a new-generation ATC system to reduce or eliminate midairs and to manage the growth in traffic efficiently. That new system would have to be based on computers. It would have to identify each aircraft and display each aircraft's identity, speed, and altitude on ATC screens. The new system also would have to anticipate conflicts with traffic or terrain, **and** perform all these tasks quickly and accurately. Simultaneously, the new system would reduce ATC paper work, which, as late as 1965, still consumed 75 percent of a controller's time.

Terminal automation would be less complex than enroute automation, so the FAA began its automation program in terminal areas in 1965 with the Area Radar Terminal Systems. These systems combined radar and mode C in order to paint and identify aircraft. The system later added conflict-alert software and altitude-warning systems to warn controllers if aircraft were too close to terrain or to each other. Nevertheless, in September 1969, while the new terminal system was being implemented in stages, an Allegheny DC-9, descending from 6,000 to an assigned altitude of 2,500 feet, collided over Indiana with a student pilot in a PA-28. All 82 people on board the DC-9 and the GA pilot died. This was followed by still more midairs, including a midair between a DC-9 and a military F-4B over Duarte, Calif., in June 1971, with 50 fatalities.

All these fatal midairs, from Staten Island in 1960 to Duarte in 1971, occurred in terminal airspace. The sustained frequency of midairs led FAA to restrict access to airspace around the busiest terminals. On Sept. 29, 1969, the FAA proposed to establish Terminal Control Areas (TCAs), later Class B Airspace, around selected airports. Implementation began in May 1970. The rule initially required two-way radio, a beacon transponder, and a VOR or TACAN receiver in order to enter a designated TCA. The FAA then added an altitude reporting transponder requirement in 1974. (See Figure 3, page 26.) The objective was to limit the mixing of VFR with IFR traffic, and small aircraft of limited capability with faster jets in congested terminal areas (as the Safety Board, then still part of CAB, had been recommending since Staten Island).

Simultaneously, the entire enroute system was being upgraded. Automation of enroute ATC began with the installation of IBM's prototype 9020 system at the Jacksonville Center in 1967. The system was designed to provide automated flight data processing and radar tracking at all enroute centers and major terminals. The system was delivered behind schedule, which created significant frustration within the FAA, the aviation community, and IBM. The system would not be in place at all 22 enroute centers until the end of the 1970s. However, indicative of the complex nature of automating the enroute environment, the 9020 system proved to be the most complex computer application in the world at the time. IBM more than doubled the amount of memory first estimated in order to handle the program's half million commands.

Since the 1971 midair over Duarte, only one large American passenger aircraft has been involved in a midair in the United

States (San Diego in 1978). The only other midair involving a large passenger aircraft in U.S. airspace occurred in August 1986 when a GA aircraft and an Aeromexico DC-9 collided over Cerritos, Calif. That accident led to an expansion in the number of TCAs, plus the requirement for a Mode-C transponder on board before entering a TCA. Upon implementation of TCAs, the altitude-reporting transponder in 1974, and a Mode-C transponder, the number of midairs immediately collapsed. (See Figure 3.)

Midairs involving large commercial aircraft, which were the driving force that led to the creation of today's ATC system in the U.S., have changed from relatively common events to extremely rare events. Yet, the risk is not zero, as illustrated by the midair in December 1996 in India between a Saudia B-747 and a Kazakhstan IL-76 with 349 fatalities, or the July 2002 midair over Germany between a DHL B-757 and a Bashkirskie TU-154, with 73 fatalities. Yet these two exceptions help to prove the rule: when aircraft are properly equipped and when crews respond to TCAS alerts (rather than possibly conflicting directions from ATC), midair collisions have become very rare indeed, as illustrated in Figure 3.

The jet

The jet is often cited as the single-most-significant improvement in airline safety, though the earliest years of civilian jet travel were difficult. British Overseas Airways (BOAC) introduced commercial jet travel with the Comet in the early 1950s, only to suffer three especially puzzling accidents in which Comets seemingly disappeared from the sky. On May 2, 1953, a BOAC Comet took off from Calcutta with 43 occupants and disappeared in flight after passing through 19,000 feet. Eight months later, a second BOAC Comet disappeared at 26,000 feet after takeoff from Rome (35 fatalities). The United Kingdom then grounded the Comet, but, under intense pressure, the government allowed the Comet to resume service on April 1, 1954. One week later, another BOAC Comet disappeared at 35,000 feet (21 fatal), also after departing Rome.

These events led to what many people recognize as the birth of modern accident investigation. Investigators in the U.K. employed the scientific method in various experiments to establish that the Comets in fact had broken up in flight. The U.K. investigators established that, as the Comet operated at unprecedented altitudes, the aircraft's frame expanded and contracted during every pressurization cycle, which caused metal fatigue. Designs changed abruptly to avoid points of added stress, such as sharp corners or square openings, and included fewer but stronger joints.

The next generation of commercial jets, such as the Boeing 707 and the DC-8, were the primary beneficiaries of this knowledge. When Pan Am introduced revenue jet service to the U.S. industry in October 1958, BOAC was still operating jets in its fleet, and Aeroflot already had 62 TU-154s.[4] Nevertheless, it was the Boeing 707 and then the DC-8 a year later that truly established the jet age.

Piston engines had continued to improve through the 1930s and 1940s, with much more powerful engines entering the civil fleet after World War II in the DC-6, the Constellation, etc. Yet, even by the standards of the time, the most sophisticated piston engines did not offer the reliability the industry sought. Most of those engines were developed during the war for military use.

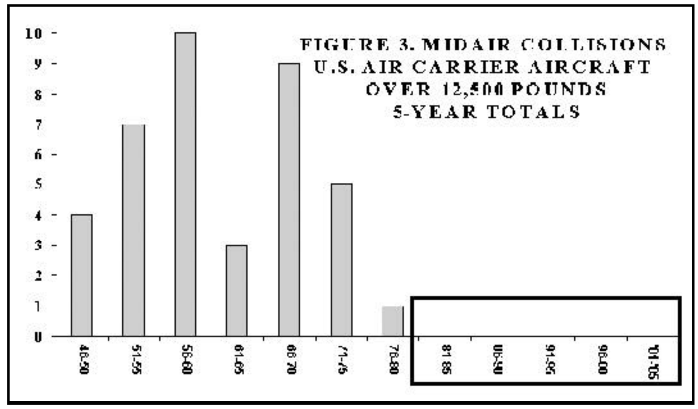


Figure 3

They were built with a conscious notion of "use it and throw it away." Performance and power, not reliable endurance, were the wartime objectives.

In fact, as piston-driven aircraft increased in power, the rate of engine failure often increased. At their peak, 4-engine piston air transports in effect operated with four rows of seven pistons. All those moving parts invited some degree of common failure. By the early 1950s, the top-of-the-line piston engines could run a maximum of only 1,500 hours time between overhauls (TBO). In practice, TBOs of 800 hours were a luxury.

At such levels, arithmetic suggests that every flight had a very real risk of losing an engine, especially on a four-engine aircraft. The chances of losing two engines also were real on every flight. From 1946 to 1958, U.S. air carriers averaged four and a half major accidents and about 50 fatalities in engine-related accidents. On average, one of these four and a half involved the failure of two engines. Due to the frequency of piston-engine failure, in 1953 the U.S. prohibited twin- and triple-engine commercial airliners from flying routes that were more than one hour from an adequate airport.

The earliest turbofans quickly extended the TBO from about 800 hours to 6,200 hours, then trebled the TBO again to 18,000 and 20,000 hours by the early 1960s. Soon the FAA abandoned the TBO as a meaningful regulatory standard and replaced it with a standard of "on condition." By that standard, an engine can be operated indefinitely, provided that it satisfies certain performance criteria, though various parts of the jet engine still have defined life cycles. Less than 6 years into the jet age in the U.S., the FAA in 1964 exempted the three-engine B-727 and Trident from the limitation of having to remain within 60 minutes of an alternate airport.

Of necessity, technological advances in materials accompanied the introduction of the jet. The industry moved to nickel alloys and titanium for greater strength under heat, then to composites, such as spun glass and resins, to resist impact and stress. Fiberglass resins and reinforced plastics followed, and by the mid-60s aircraft manufacturers began to incorporate developments in carbon fiber (graphite) and graphite-reinforced plastic. Similarly, the jet demanded a quantum leap in manufacturing processes to ensure the precision that jet engines required.

In the latter 1980s, the FAA clearly recognized a new order of magnitude in engine reliability when the agency began approving extended-range twin-engine operations (ETOPS) over water for two-engine aircraft, based on performance requirements.

Multiengine aircraft had been required since 1936 to demonstrate that, with one engine out, safe flight could be continued long enough to reach an alternate airport. However, that requirement had been set in an era when commercial aircraft could not be more than 100 miles from an alternate airport at any time during a flight. Though the rule was amended over the years, the rule continued to exclude two-engine aircraft from oceanic flight (defined as flight for at least 1 hour over water).

In 1983, discussions began to ease the 60-minute rule for twin-engine jets such as the A300, B-767, and B-757. In 1985, the FAA amended the rule to permit selected aircraft to operate 2 hours from an alternate airport that could handle the aircraft, provided that carriers and engines met performance parameters over 12 consecutive months of operations. Aircraft also had to be fitted with additional back-up systems. ETOPS was extended to 3 hours from an airport in 1988 as turbofan engines were demonstrating reliability 50 times that of piston engines. As stated in a subsequent advisory circular on Dec. 30, 1988, the FAA based that action on the reliability achieved by newer generation aircraft, and by the use of propulsion systems that had established an inflight shutdown rate of just one per 50,000 hours in the preceding 10 years. The FAA's advisory circular of Dec. 30, 1988, went on to add

Some of the new generation [two-engine] airplanes have a range/payload capability equivalent to many previous generation three- and four-engine airplanes. The demonstrated range/payload capabilities of the new generation airplanes, including their provisions for achieving a higher degree of reliability,):*clearly indicates there is a need to recognize the capabilities of these airplanes* and to establish the conditions under which extended range operations with these airplanes can be conducted over oceanic and/or desolate land areas. (Emphasis added.)

To illustrate the reliability of today's jet engines, by early 2004, the FAA's Engine Directorate reported an average of just .09 serious engine failures (high-risk outcomes) per million flight cycles for the preceding three years, or an average of just one per 11 million cycles. The objective now is to reduce the rate of serious engine failures from .09 per million cycles by half, to .045 or 1 per 22 million cycles, by 2007.

In the past 20 years, the U.S. air carrier industry has had just two fatal jet accidents that can be attributed directly to engine failure: uncontained engine failures at Sioux City, Iowa, in July 1988 (111 fatalities) and at Pensacola, Fla., in July 1996 (two fatalities). Today most engine failures are inherently low-risk events, as aircraft can function well enough on a single engine to make a safe return or safe diversion to an airport. Even if an engine fails on initial climb after takeoff, a crew simply continues to apply full power, completes the climbout, and then returns to the airport. In fact, the primary safety threat from an engine failure now is the risk that a crew might respond improperly to a perfectly survivable event. For example, a crew might turn into the failed engine or become so preoccupied with the engine that they fail to fly the airplane. The bottom line is that engine failure, by itself, is no longer a common cause of catastrophic accidents in commercial aviation.

Automation

At their core, automation and other cockpit advances assist pilots in flight by enabling the aircraft to perform maneuvers automatically and precisely, and by providing more information to the crew on the status of the flight, the aircraft, and the environment. When the jet age abruptly introduced aircraft that were much faster and that operated at much higher altitudes than all preceding civil aircraft, the need for such information instantly increased by orders of magnitude.

In the era of the DC-6, the Constellation, and Boeing Stratocruiser, the most sophisticated piston-powered aircraft had one or two analog computers that controlled pressurization or heaters. Even the autopilot was analog and rudimentary. In comparison, the first Boeing 777 had 1,000 digital computers, and then the Airbus A320 family and subsequent aircraft exceeded that level. In short, we not only have more computers on board to automate more and more functions, but each computer is immeasurably more powerful than either the old analog systems or the earlier digital systems.

In the enroute environment, primary flight information had been limited to just six instruments: airspeed indicator, artificial horizon, three-pointer altimeter, turn and bank indicator, directional gyro, and vertical speed indicator. The basic display and range of information available remained essentially static for years preceding the introduction of the jet. Because routine events occur much more rapidly in jets than in earlier fleets, more information and more precise information was required on the state of flight, especially at high altitudes and on approach.

Electromechanical and analog devices were used through the 1960s to automate a number of aircraft functions. In the 1970s, the use of digital electronics in the design of avionics systems enabled more aircraft functions to be automated with higher levels of reliability. However, automation did not come into its own until the 1980s, when the microcomputer and cathode ray tube (CRT) displays were introduced into cockpits. This was the era in which automation first provided optimized flightpath control, engine power control, and aircraft subsystem control.

TCAS and GPWS: early safety breakthroughs from automation

As outlined earlier, TCAS was a major defense against midair collisions. The first-generation TCAS identified and aurally warned pilots when separation from another aircraft was inadequate. Since the introduction of TCAS, midair collisions have virtually ceased with large American commercial aircraft operating in the United States.

The Ground Proximity Warning System (GPWS) emerged in the same era as a defense against controlled flight into terrain (CFIT). GPWS brought even greater advances in safety than did TCAS, if only because CFIT was a far more common accident scenario than were midairs and because severe outcomes were even more likely in CFIT accidents than in midairs.

Today we can easily forget just how frequently major CFIT accidents occurred. For the first decade after World War II (1946-1955), Part-121-type operations in the U.S. averaged three and a half major CFIT accidents per year, or one every 15 weeks, with nearly 750 fatalities. The pace slowed to "only" two such accidents per year for the next two decades with the improvements that already have been noted, such as the post-war fleet, the jet, improvements in ATC services, etc. Nevertheless, at a steady average of two major accidents per year, and a total of 1,900 fatalities among U.S. operators, CFIT remained a critical safety issue.

The major change in the risk of CFIT began to change on Dec. 1, 1974, when a TWA B-727 approached Dulles Airport in heavy rain on an absolutely miserable day. The approach seemed normal to the crew, but the aircraft slammed into Round Hill about 35 miles northwest of Washington, killing all 92 people on board. That accident involved several key causal factors, one of which was the absence of a definitive alerting system to warn the crew that they were dangerously close to terrain.

As a result of that accident, in 1975 all commercial aircraft with more than 30 seats were required to operate with GPWS. The system sounded an alert whenever an aircraft was flown too close to the surface. Since then, no large U.S. passenger aircraft have had major CFIT accidents in airspace with radar coverage, though three such aircraft have suffered fatal accidents elsewhere in the world where terrain precluded radar coverage. Those three exceptions were: Eastern Airlines in Bolivia on Jan. 1, 1985, with 29 fatalities; Independence Air at Tenerife on Feb. 8, 1989, with 144 fatalities; and American Airlines on Dec. 20, 1995, with 160 fatalities.

The three exceptions noted here are rather clear indications that GPWS cannot reduce the risk of CFIT to zero. GPWS had an important shortcoming, as it was limited to looking ahead of the aircraft. Enhanced GPWS (EGPWS), or the "Terrain Alert Warning System" (TAWS), adds the capacity of vertical sensing. In addition, the eventual adaptation of GPWS and the development of extensive onboard topographical databases have reduced the risk even further.

Note, too, that CFIT accidents continued in smaller passenger aircraft and in cargo aircraft, which were not addressed by the 1975 requirement to have GPWS on board. In March 1992, the FAA required that all aircraft with more than 20 seats and all turbine-powered aircraft in air taxi or commercial service be equipped with GPWS by April 1994. Once again, CFIT virtually disappeared as an accident scenario.

Finally, both TCAS and GPWS support the theme of safety advances being incorporated most quickly when they provide a compelling economic case for operators. Unlike most other advances in automation, TCAS and GPWS were designed explicitly to improve safety. Each had been strongly resisted for years and the resistance continued for several years after each was required. The use of VOR/DME equipment in the cockpit also was resisted into the early 1960s and briefly after that, when the equipment was required in the cockpit. These examples suggest that the coercive power of government to require certain equipment or practices remains an important tool in safety.

In the end, GPWS has proven itself to be an enormously important tool in safety. Again, the risk of CFIT is not zero, as we have been reminded by American Airlines at Cali in 1995 and by Spain's Paukn Air in 1998. Nevertheless, CFIT has become a very rare event, at least among the world's richer countries. Yet, CFIT consistently remains among the top several fatal accident scenarios elsewhere in the world.

Engine power

Automatic propeller feathering systems, introduced after World War II, were the first significant automatic control of engine power. The autofeather was made obsolete by jet engines, which include autothrottle systems to control fuel flow. By the 1980s, this had evolved into full-authority digital engine control, which has further improved the precision with which jet powerplants can be controlled. Autothrust systems now set engine power to automatically determined parameters even during takeoff roll.

Information on engine power and performance was first displayed in the cockpit on electromechanical instruments. This has since been replaced with easier-to-read electronic displays. Since then, variations in the display formats have been added, including analog tapes and alphanumeric data.

Aircraft systems

In the earlier commercial jets, a variety of lights and gauges monitored aircraft subsystems (e.g., electrical, hydraulic, pneumatic, and fuel) and showed the configuration of landing gear, flaps and slats, control surfaces, aircraft doors, and other flight-critical systems. Pilots needed rather detailed knowledge of all onboard systems to ensure that they understand that a certain reading on some gauge indicated a problem or a failure.

This became a problem when subsystems failed or when gauges began to produce unusual information. Pilots had to interpret readings quickly, had to integrate those readings with their own understanding of the various onboard systems, and then had to act quickly enough to reconfigure the aircraft safely.

In the early 1980s, CRT displays of systems information were guided by a less-confusing "need-to-know" principle; the early CRTs would display pictorial and alphanumeric alerts in the cockpit. For example, if a particular failure did not require reconfiguration, or if the pilot could not respond to a failed light on the wing, the pilot received no indication of a problem.

By the late 1980s, CRTs added synoptic diagrams that provided a picture of the aircraft and showed the location of problems within aircraft subsystems more accurately and more succinctly. In today's aircraft, flight management computers and CRTs offer a display of aircraft configuration, along with additional flight planning and navigational information. These systems simplified the information pilots need and provide a resource in times when the aircraft needs to be operated in abnormal conditions.

Flightpath

In the 1970s, onboard computers began using data from static and dynamic air pressure to control aircraft speed and altitude, thereby permitting precision climbs and descents. Flight directors were added to provide computerized pitch and roll commands on displays that were much easier to fly than the VOR/DME/ILS displays. The inertial navigation system (INS) also was added in the 1970s for precision navigation over the ocean and other areas outside the range of ground-based navaids. Other advances of the 1960s and 1970s reduced aerodynamic drag (trim control) and adverse yaw (yaw damper). The first systems were built of mechanical gyros, which required complicated constructions and substantial power supplies, all of which were prone to failure. Later on "solid state" solutions employed discrete integrated electromechanical or electro-optical sensors. These solid-state systems had no moving parts, but consisted of expensive laser-gyros and integrated sensor devices in micro electromechanical systems.[5]

Important as these advances were, the pace and scope of automation and simplified cockpit displays took off in the late 1970s and early 1980s with the introduction of the cathode ray tube

(CRT) into the cockpit, along with onboard computers that quickly processed new information as a flight progressed. Today, large commercial jets have automated flightpath and aircraft management with up to 100 high-speed computers and CRTs that are reconfigured in flight to display different types of information. Visual displays show bearing and distance to specific "fixes," visual information on deviations from localizer and glide slope centerlines on approach, actual versus planned route of flight, weather, traffic avoidance information, systems updates, etc.

Primary flight information first was integrated on several electromechanical displays. By the late 1980s, all primary flight information, such as the location of navaids, actual versus planned route of flight, and weather, was displayed on a single CRT to increase situational awareness and reduce pilot workload.

Flight management system

Many of the advances noted above, plus additional advances, evolved into or have been incorporated into the flight management system (FMS), which was first introduced in the early 1980s. The FMS is a system of airborne sensors, receivers, computers, and a navigation database that integrates the control display unit with raw navigation data and inputs from multiple sources such as DME, VOR, localizers, and, now, GPS. These systems now also provide performance and RNAV guidance to displays and automatic flight control systems. The FMS then soon added the capability of detecting and isolating faulty navigation information.

The FMS provides strategic control of the overall flight and overall aircraft performance rather than tactical control. The system is loaded with data files on airport locations, VOR locations and frequencies, specific ATC constraints, and aircraft operating characteristics, so the aircraft **knows** when flaps can be up or down, etc. The pilot then adds data for each flight, including winds, temperature, standard temperature deviation, whether the pilot wants a full flap takeoff, desired cruising speed, etc.

The FMC computes the rest (maximum gross weight, center of gravity, flightpath with climb and descent profiles, pitch and thrust commands that control aircraft speed and altitude, etc.). The system also adjusts all these computations if necessary during the flight, based on data gathered from onboard sensors (for example, actual winds may differ from the data on winds entered by the pilot).

These advances, in fact, have changed the pilot's basic role on an aircraft. Today's pilot becomes a strategic planner and flight manager, rather than a traditional "stick-and-rudder" operator. As manager and monitor, the pilot has time to anticipate problems, and enjoys the benefits of onboard back-up systems that accurately, dependably, and safely operate the aircraft.

In the end, automation enables the aircraft to perform routine maneuvers more precisely and more safely than those maneuvers might have been performed in the past. Automation has further evolved to include flight envelope protection, which maintains flight controls, speed, and attitude within certain profiles. Envelope protection restricts the aircraft to remain within maximum and minimum speeds, avoid excessive g loads, and minimizes risk of stall, excessive pitch or bank, etc.

Automation has introduced some tradeoffs. So-called mode confusion can get crews into trouble. Crews may expect the aircraft to perform in a specific way that is associated with the logic of one mode, but the mode of automation that actually has been selected may use a different logic from that which the pilot anticipates. For example, depending on the software logic, if a pilot selects flaps at too high a speed, the aircraft may default to a go-around, which the crew does not anticipate. Pilots also must understand the basic design of some automation subsystems. For example, if the captain's pitot static tube is blocked, the crew must understand that the back-up airspeed indicator (ASI) in some aircraft reflects data received from the captain's system. Consequently, the crew must recognize that they need to use the first officer's ADI, since the back-up system would provide the same erroneous data that the captain's ADI displays.

Pilots also must recognize the conditions under which they should disengage the autopilot. The risk is that the crew fails to recognize when the autopilot adjusts to inflight problems without informing the crew, then reaches one or more maximum parameters and suddenly disengages. The crew then may be unprepared to respond properly and quickly, as all the correcting configurations selected by the autopilot suddenly disengage, and the aircraft is thrown into some severe maneuver. In the end, automation often requires that pilots combine basic flying skills with the skills of a systems analysts, and can combine those sometimes disparate skills in an environment that might require instant decision-making. These issues remain real, but they have been reduced by concentrated training and by the benefits of time, which has increased pilot experience with automation and has made pilots much more comfortable with contemporary systems. Those systems have evolved from the glass cockpit to fly-by-wire aircraft, as aircraft increasingly manage flight controls electrically, without the use of cables and pulleys.

In the end, the net benefit to safety has been substantial. To appreciate the scope of advances and their meaning for safety, we need only to look at the cockpit of a DC-7 or Constellation, or even that of a first-generation jet. We would see remarkably stark cockpits that offered limited information and even less assistance to crews. Automation has improved safety by increasing position awareness, by making more precise maneuvers and operations possible, and by eliminating numerous factors that once were common in accident scenarios, such as CFIT, midairs, running out of fuel, getting lost, losing control in flight, landing short, etc. While the risk of such events is hardly zero today, their frequencies have collapsed, as indicated earlier by Figures 1 and 2.

Survivability and cabin safety

Engines, airframes, ATC technology, onboard automation, and avionics have clearly improved the ability to avoid aviation accidents. Not only have we reduced the rate and number of accidents, **but also** more people can expect to survive the rare occurrence of certain kinds of events due to aggressive changes in regulations governing cabin safety.

Large numbers of people have survived several accidents in recent years that would have been deemed "nonsurvivable" just a few years earlier. In August 1988, a B-737 was destroyed by fire after an aborted takeoff; 94 of 108 people on board survived the intense fire. In its investigation of the accident, the NTSB officially found that the 94 survivors were saved by the benefits of new cabin safety regulations that required fire-blocking seats.

On March 17, 1991, an L-1011 carried 231 passengers and crew on a transatlantic flight. In mid-flight, a fire started beneath the cabin floor. The crew used a Halon 1211 extinguisher to fight the fire through the air-return grill. The Halon penetrated hidden voids and spaces beneath the floor to extinguish the fire. Those spaces would have been inaccessible with other equipment, and the aircraft would have been lost. Instead of resulting in a catastrophe, the aircraft completed the flight with no injuries among the 231 people on board. Though Halon has been replaced with other fire-extinguishing agents due to concerns about the ozone layer, the benefit of such systems has been demonstrated several times since the 1991 incident.

Perhaps the most dramatic evidence of the positive effects of changes in cabin safety came from the accident at Sioux City in July 1989. A DC-10 lost an engine that severed the aircraft's hydraulic systems, limiting the crew's control to the use of thrust from the remaining engines. The DC-10 crew became national heroes, as did some air traffic controllers. The crew nearly made a miraculous landing, but the aircraft banked before touchdown and cartwheeled into a ball of fire, which was caught on camera and replayed around the country for days. Tragically, 111 people died in the accident, but, remarkably, 185 people survived what everyone just a few years earlier would have recognized as a nonsurvivable crash.

The list of heroes could have included the FAA and other safety advocates who had worked to increase seat strength, to reduce the speed at which fire could spread through seat materials, to reduce toxic emissions from cabin materials, etc. Other heroes could have included the FAA and other safety advocates who were responsible for tougher emergency preparation standards at the nation's airports.

The three events cited above (Sioux City, the L-1011 transatlantic fire, and the August 1988 accident) took a total of 125 lives. However, the 510 people who survived those events offer tangible evidence of the benefits that came directly from improvements in cabin safety.

For years, aviation accident investigators and safety analysts had recognized that people often survived an accident's impact but then succumbed to post-crash fire or smoke. This led to major efforts to improve cabin safety and give crews and passengers crucial extra seconds to evacuate safely after an accident.

Top on the list was the need to reduce the rate at which fire and toxic smoke spread through an aircraft. FAA first targeted seat cushions in 1984 by requiring for more-demanding flammability tests on seat bottoms and back cushions. This led to new seat materials and fire-blocking layers that slow the speed at which fire can spread <u>and</u> reduce the emission of toxic smoke. In 1986, then again in 1988, the FAA built on these new flammability standards for seats by requiring more demanding flammability tests for all aircraft interiors, such as wall panels, overhead bins, floors, etc.

Seats also have been strengthened to withstand greater impact forces. All seats on aircraft manufactured after June 16, 1988 must withstand an impact of 16 g's, versus the old standard of 9 g's. The 9-g seat had performed well, but the 16-g seat established a greater safety margin for passengers.

In December 1984, the FAA took a related step by requiring fire-resistant emergency slides on air transport aircraft and set radiant testing procedures for that purpose. Two years later (Nov. 26, 1986), the FAA required all air-transport aircraft to be fitted with emergency floor lighting to lead passengers to emergency exits in the darkness that can accompany emergency evacuations.

Other efforts to slow the pace at which fire or toxic smoke can spread in an aircraft involve some obvious steps: state-of-the-art fire extinguishers and smoke detectors. The FAA began upgrading those requirements in 1986 and 1987. For example, at least two hand-held Halon 121 fire extinguishers were required in the cabin of all aircraft as of April 29, 1986. Lavatories were required to have smoke detectors as of Oct. 29, 1986, and lavatory waste receptacles had to have built-in fire extinguishers as of April 29, 1987. Finally, the FAA required protective breathing equipment, such as smoke hoods, for flight attendants as of July 6, 1989.

Beginning in 1986, the FAA took action to strengthen fuel tanks and reduce the risk of rupture in on impact, then began work on standards for more heat-resistant liner panels in cargo and baggage compartments so fires erupting in cargo bays could be better contained. The objective was to replace less heat-resistant aluminum and glass-fiber-reinforced resins with more fire-resistant materials. All subject aircraft had to comply by March 20, 1991.

Other recent improvements include restrictions on the amount of carry-on luggage to reduce injuries from debris and the danger of tumbling, heavy objects during an evacuation (1987). The FAA then established a maximum distance of 60 feet separating any seat from an exit (July 24, 1989), and required an independent power source for public address systems in large aircraft to ensure communication with passengers in an emergency (November 1990).

Though the efforts to improve cabin safety have proven their value, they also offer good examples of how regulatory proposals generate legitimate and politically sensitive differences in perceptions and preferences. Some in the industry criticized the FAA for going too far too fast on too little definitive evidence. Simultaneously, some safety advocates criticized the FAA for not going far enough fast enough on what they perceived to be compelling evidence.

Yet few now dispute the net benefits from most of the advances made in cabin safety from the mid-1980s through the mid-1990s. Advances admittedly have slowed since that period, but new efforts continue, with attention focused on evacuations, the circulation of potentially noxious fumes within the aircraft, etc. The strength of seats also continues to get some attention. The debate wrestles with a desire for still stronger seats than today's 16-g standard versus the possibility of strengthening seats beyond any meaningful benefit to an occupant.

However, the net result of the advances in cabin safety, again, have been tangible. Many more people survive the increasingly rare life-threatening accident when it occurs.

Simulation and training

Advances in simulators have been the single-most-important safety advance in the field of training. Basic simulators have been in fairly common use since World War II, when the military developed them to help train large numbers of new pilots quickly. However, at their best, early simulators gave pilots very limited practice in prescribed procedures for selected maneuvers and emergencies, and did so, under sterile conditions,.

The first modern simulators essentially were boxes with single-channel, three-axis systems (pitch, yaw, and roll). This first generation could try to replicate only a fixed airport and fixed terrain, and could not realistically replicate a given approach path and landing. Visual scenes, based on movies of final approaches, were greatly improved with the introduction of video map models. This began the representation of "real" terrain. However, the scanned map projected TV screen images, which were less than sharp, and they provided only limited depth perception by presenting the image with angular mirrors. This system was followed with digitized visual systems, which created more accurate and varied visual fields, but the system was limited to lighted points in a nighttime field.

This was the state of aircraft simulation as recently as the second oil crisis in the late 1970s. "Training" still meant preparing for flight checks that included several steep turns, some engine-out procedures, and other limited exposure to prescribed procedures. However, pilots could not gain airborne experience either in training or in a checkride in the more challenging and more dangerous scenarios, such as windshear, severe wake turbulence, or serious events close to terrain. Those pilots who had experience with such events got it for the first time in normal air carrier operations with people on board.

However, the second oil crisis and a long list of flight training accidents stimulated the demand for more capable and realistic simulators. With fuel prices abruptly doubling for the second time in just four years, the airlines sought some cost relief by petitioning the FAA to substitute certain simulator training for the required airborne training. The FAA agreed that this made sense, **provided** that simulators accurately represented real aircraft behavior in actual line operations. Disciplined testing quickly revealed they did not. The FAA then identified the standards that a simulator would have to meet in order for a pilot to receive full training credit in a simulator. The FAA established three phases of capability in which simulators that included an increasingly comprehensive range of real aircraft behavior in real scenarios could satisfy different levels of training. The requirements went well beyond the state-of-the-art in simulators at the time but created a set of performance requirements that simulator manufacturers around the world immediately scrambled to meet with new product development.

As a result, the regulatory process proved to be the catalyst that transformed simulators and training. In order to realize the efficiencies associated with reduced training costs that simulators might offer, air carriers immediately negotiated orders for increasingly sophisticated simulators that would meet the next increment in accurate aircraft simulation.

This required a burst of research into actual aircraft behavior in all flight conditions needed for training. The massive effort, accompanied by rapid advances in computer technology, led relatively quickly to the upgrade of late-model existing simulators. These Phase I simulators (later called "Type B") included improved aerodynamic modeling and six-axis motion systems that more accurately replicated **real** aircraft behavior in many line operations.

These Type B simulators were a major advance in training technology, but still were quite limited as substitutes for airborne training requirements. Accredited training in this generation simulator was limited to landing and approach maneuvers necessary for pilots to meet currency requirements. All other airborne training previously required for a pilot to be rated in a new aircraft, to upgrade from the right seat to the left seat in an aircraft type, still had to take place in an airborne aircraft.

The air carriers' desires to substitute simulator training for more training requirements, and eventually a full range of requirements, led to the development and purchase of new "advanced simulators." These simulators (later "Type C") included dusk vision with actual terrain, and actual runways, complete surface conditions, structures, and other ground obstacles. Type C also added weather conditions and other environmental factors, such as ice on runways, variations in wind velocity and direction, windshear, etc., plus a comprehensive range of other emergency scenarios.

This was the leap in realism the industry sought. Type C simulators were authorized to substitute for most training requirements, **except** initial training. That is, a pilot would still have to learn to fly an aircraft type by indeed flying it. Nevertheless, all other training requirements could be met in a Type C simulator, which achieved substantial savings for the carriers. In addition, pilots could gain real experience in actually handling various emergencies; actual experience with windshear, for example, would no longer have to wait for the pilot's first airborne encounter in a real aircraft with real passengers on board.

Type D simulator, the most advanced as of this writing, has reached the goal of substituting for **all** training requirements, including initial training. Pilots no longer must learn to fly in real aircraft, which would carry real risk. Instead, pilots can learn to "fly" a simulator, and can gain a full range of first-person experience with a whole host of actual emergencies.

Type D simulators also have added more realistic, digitized daylight views of airfields around the world. The remaining challenge in simulators rests with "fidelity," or the assurance that the simulator can reproduce actual aircraft behavior in all scenarios. Simulators are routinely auto-checked to test their fidelity, and the fidelity in fact is excellent for most scenarios. However, some issues remain beyond the reach of simulators, such as the sensation of g-loads, extreme scenarios for which actual data have not been or cannot be captured, etc. Nevertheless, with precious few exceptions, flying a simulator is like flying the aircraft; the cockpit of a simulator *is* the cockpit of an aircraft.

The real impact of Type D simulators is the realization of the fundamental goal that helped to drive the remarkable advances in simulation: the simulator has **replaced** the airplane as the vehicle for flight training. Simulators provide a safe and very realistic laboratory for new approaches in crew resource management. Today, every common aircraft in the commercial passenger fleet is simulated, including regional aircraft with fewer than 30 seats.

Equally important to the flying skills that could be taught in a simulator, the safe laboratory also revolutionized the way in which crews were trained to work together. Because real aircraft had to be used prior to the modern simulator, training programs reflected broader cultural traditions in the industry at the time. Captains were trained only with other captains, while first officers were trained only with other first officers. Flight attendants were not even part of the conversation at the time.

Everyone consciously hoped or subconsciously assumed that these separately trained crewmembers would work well together. However a long history of accidents clearly indicated that crews did not always work well together. At least in selected cases, accident histories identified two extremes in the relationship of a captain and first officer during an accident flight. Some first officers were found to be so passive and/or some captains were so domineering that the first officer provided little or no help, and may even have been an added burden during an emergency. At the other extreme, first officers had provided accurate assessment of emergency situations and had recommended appropriate corrective action during an accident flight but were utterly ignored by the captain.

When crew dynamics broke down, the failure essentially was accepted as something about which we could do very little. That passive acceptance changed with simulators. Pilots now are trained to fly aircraft **and** to work with crewmembers. The effort began in earnest in the late 1970s through the 1980s with crew resource management (CRM), as captains and first officers were trained together and trained to work together. By the early 1990s, the "C" in CRM had changed to "crew" and reflected a broader recognition that entire crews, including cabin crews, needed to work together. With accurate simulation, trainers suddenly acquired a realistic laboratory in which to address the psychology of safe flight in a realistic operating environment.

The change in cultural values displayed in the cockpit and in the interaction of all crewmembers cannot be overstated. This does not mean that all captains and all first officers now work well together all the time, or that all flight crews work well with all cabin crews. The change, though, indeed has been enormous. captains no longer are expected to know everything about everything, while first officers and cabin crews are expected to contribute real skills and judgment to the operating environment. Though issues of crew coordination still appear in accident scenarios, their frequency has collapsed.

Today, crews, get hands-on experience with real-time problems, complete with acceleration, full motion sensations, and real aircraft behavior. Simulators let us practice and train in maneuvers and scenarios that really happen but would be far too dangerous to practice in a real aircraft, such as getting out of windshear, losing one or more engines on rotation, etc.

Simulators also have added a realistic laboratory to accident investigation. With the use of digital flight data recorders, accident flights can be recreated and "flown" in simulators. Actual flight behavior and conditions then can be analyzed to identify chains of events we might never have considered before, or at least never have been able to confirm in the past. The result for accident investigation has been that simulators offer the best source in some cases for testing or even discovering how accident chains can be broken.

Windshear

A 1975 accident at JFK was the definitive accident in which the aviation community established the way in which windshear interacted with large aircraft. Windshear had been a primary factor in at least two other hull losses involving large passenger aircraft (a Pan Am B-707 in January 1974 at Pago Pago, with 97 fatalities, and a non-fatal DC-9 accident at Chattanooga in November 1973). Other examples may have existed, but windshear was seldom identified with accidents at the time, because the aviation community had only a limited understanding of precisely how windshear and, especially, microbursts interacted with large aircraft. Investigation of that accident eventually established the scientific evidence that significantly improved the understanding of that interaction.

However, windshear accidents continued to occur. Just 11 days after JFK, Continental Airlines lost a DC-9 at Denver in a non-fatal windshear event. The following June, an Allegheny DC-9 was destroyed on approach to Charlotte in another non-fatal windshear event. Several years later, in July 1982, Pan Am lost a B-727 on takeoff from New Orleans with 145 fatalities. The watershed event, however, occurred in Dallas on Aug. 2, 1985 (134 fatalities). That accident led to immediate and sustained efforts to develop or to accelerate ground-based and onboard windshear detection systems, Doppler radar, better weather forecasting and dissemination of weather information, plus windshear escape procedures and training programs.

While each of the improvements was significant in its own right, together they illustrate the potential benefits from coordinated and focused actions by government and industry. That is an important idea in current and future efforts to drive the fatal accident rate even lower than it is today. The procedures and training programs also illustrate the significance of contemporary simulators, which enabled crews to experience how real aircraft behave in real windshear and to experience real escape maneuvers. Such realistic training would not have been remotely possible just a few years earlier.

Conclusion, Part One

If accident rates of just 20 years ago had remained in place, let alone those of 40 years ago, the demand for public action would have been so great that governments would not have been permitted to let the industry develop to the state that most of us take for granted today. Instead, the advances noted above, plus steady and on-going incremental improvements over the past five or six decades, have brought us to today's low accident rates. The challenge now, of course, is to achieve major and sustained reductions in an already low rate.

Part Two: Recent and Future Improvements in Air Carrier Safety

The challenge now is to ensure a sustained decrease in the already low fatal accident rate in much of the world. The reasons are both complex and simple. The simple reason is the self-evident value and virtue of saving lives. The more complex reasons ironically are the result of the aviation community's past success. Major accidents have become such rare events that they are no longer acceptable to the public. The public assesses the safety of commercial aviation by a de factor standard of zero accidents. Both industry and governments must respond to that de facto standard. At the same time, when the rare major accident does occur, it can threaten the survival of any air carrier. As a result, everyone in the aviation community, whether in government or industry, is damaged when a single carrier suffers a single major accident. Everyone in the industry is truly a hostage to everyone else.

So, how do we drive the already low rate even lower? One answer will be the cumulative effects of incremental improvements, such as a new or revised rule procedure or piece of equipment here and a revised rule there. That has always been the source of significant progress, at least in the long-term aggregate. However, the challenge is to achieve a significant and sustained reduction in the already-low fatal accident rate rather than imperceptibly gradual improvements. At least four factors may produce just such a reduction: (1) fleet turnover, (2) new analytical capabilities with routine operational data, (3) a change in the industry-government relationship that enables the entire community to focus on those areas with the highest risk, and (4) perhaps most revolutionary of all,

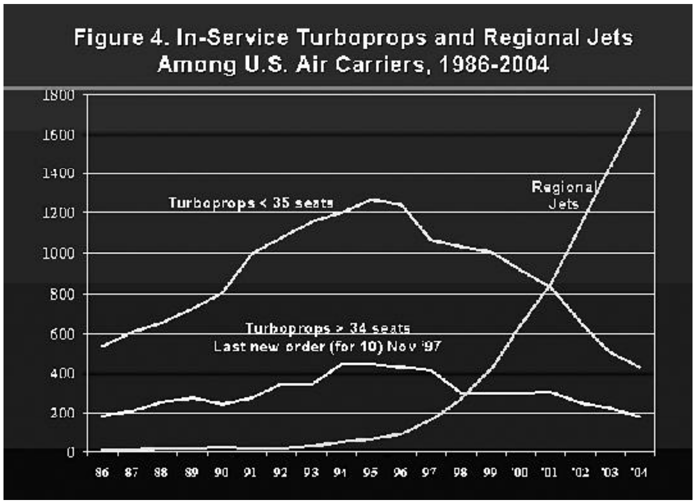


Figure 4

required navigation performance. Each of these changes is already under way to varying degrees. The sum of their impacts have begun and will continue to accelerate the next significant reduction in the fatal accident rate.

One Level of Safety and the regional jet revolution

As of the early 1990s, the "commuter industry" (FAR Part 135) was dominated by turboprop aircraft with 30 or fewer seats. That segment suffered an unusually high number of major accidents from the late 1980s through 1992. This led the FAA in 1994 to mandate that all scheduled passenger operations on aircraft with 10 or more passenger seats would be subject to the more demanding rules of Part 121 operations as of spring 1997. The rationale was twofold. First, the FAA asserted that any passenger buying a ticket on a scheduled air carrier was entitled to the same level of effort by the federal government. Second, that year had witnessed the growth of codesharing between established mainline operators and less well-known regional operators in which the regional airline operated under the name of the better-known mainline carrier. More than a few passengers were buying tickets with the assumption that they indeed would be flying the mainline carrier for their entire trip, only to discover that they were not. Though the regional carriers were inherently quite safe, a significant share of the traveling public felt something was amiss.

One of the effects was to eliminate what had been an unintended distortion of the older regulatory regime. Under FAR Part 135, training requirements were less demanding and, therefore, less costly, and aircraft could operate without certain equipment. Carriers also could operate without dispatch services and other requirements faced by carriers that operated under FAR Part 121.

Given the criterion of 30 seats, carriers typically operated aircraft at or near 30 seats, or aircraft with a minimum of 40 or more seats. The marginal benefit of operating aircraft with a capacity in the low to mid 30s would be more than offset by the increase in costs. In the end, the former regulatory regime had posed an economic disincentive against upgrading the commuter fleet.

Since the One Level of Safety rule went into effect in spring 1997, the frequency of accidents among the operators who were forced to migrate into FAR Part 121 has collapsed. Presumably the required changes in training, operating procedures, and the like explain much of the improvement. However, much of the improvement also can be explained by a revolution in the fleet that was partly under way of its own weight, but which was greatly accelerated by the removal of an inadvertent regulatory distortion of the industry's structure. The bottom line has been an explosion in the number of regional jets (RJs) in the U.S. fleet and the simultaneous collapse of the turboprop fleet. The scale and speed of the change in the fleet is hard to overstate, as illustrated in Figure 4.

The net effect has been a thorough change in the structure of the so-called regional industry, to the point where the very label of "regional" is somewhat outdated. Much like the fleet revolutions of the late 1940s and then the jet era, the extended range of the RJ fleet has opened a matrix of new city pairs to nonstop service and has made travel on existing "regional" city pairs faster a somewhat more comfortable. In short, the RJ revolution has changed the structure of the air carrier industry.

It also has influenced safety. Though turboprops are sophisticated, safe aircraft in their own right, and constituted a major improvement in regional safety from the piston-powered fleet it replaced, RJs indeed are jets. As such, their powerplants are more reliable as they simply have few moving parts, with no props and related transfers of power to the props. RJs also have more sophisticated avionics than the aircraft they are replacing.

Skeptics can note that RJs also brought some tradeoffs in new safety challenges, such as an unprecedented number of pilots from upgrading all at once into jets, or the use of "hard wings" on first-generation RJs (i.e., no forward-edge slats), which experience had shown were vulnerable to icing. Nevertheless, the net effect of the fleet change has been a significant improvement in safety.

Fleet changes among large jets

Changing fleets always have been persistent sources of improved safety, with the RJ adding just one more example. As already noted, the post-war fleet improved safety significantly. Shortly thereafter, the jet utterly revolutionized the fleet and safety. Every generation of jets since the Boeing 707 and DC-8 has improved safety even further with advances in avionics, engine reliability, automation, etc.

Though each new generation of jets has a relatively high accident rate early in its service life, Figure 5 (page 34) illustrates that each new generation of jets enters service with a lower initial accident experience than each preceding generation. In addition, the learning curve is shorter lived for each new generation compared to preceding generations. Each generation then reaches a stable accident state more quickly and that stable state is lower than for each preceding generation. Note that Figure 5 (page 34) is a product of Airbus, but Boeing has published comparable charts for years that illustrate the same points.

The bottom line has been that fleet turnover, by itself, typically has led to a reduction of about a third in fatal accident rates over each 10-year period since the start of the jet age, and even before the jet age. With fourth-generation jets already in service, such as the A320 family and the Boeing 777, other fourth-generation jets will be entering the fleet in the next several years, including the A380 and the Boeing 7E7. At the same time, the Boeing 737-800 and 900, which are recent arrivals, will rapidly increase their presence in the fleet. All these makes/models will constitute the most automated aircraft in aviation's history, only to be surpassed eventually by the next generation of new designs.

Analysis of routine operational data

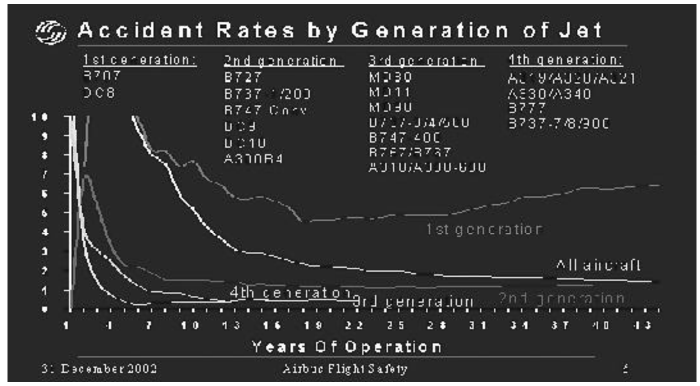
For several decades, the aviation community in the U.S. used operational data only as part of an accident or incident investigation. With cockpit voice recorders and flight data recorders (FDRs), operational data on accident or incident aircraft was relatively complete and helped the community to learn a lot about what went wrong in accidents and incidents. We could study FDR parameters in extreme events, and we could review design criteria that identified the edge of the envelope, which is not unlike knowing the extreme. However, we knew far less about how aircraft were flown on normal flights, on normal approaches or normal departures to and from runways under normal or at least common circumstances. In short, we knew little about what constituted a normal flight.

Though Japan and much of Europe had been using FDR data on selected parameters from normal, safe flights as part of their routine safety analysis for years, several factors precluded that practice in the U.S. until the late 1990s. One major factor was a litigious legal tradition in which the safety data might be obtained and then misrepresented by litigants. Carriers were weary of collecting data that might be used against them in a civil court. Similarly, a traditional of adversarial relations between the government and industry made the carriers weary of collecting data that the FAA might use against them in the enforcement of regulations. Finally, an equally adversarial tradition of industry-labor relations made pilots very suspicious of exactly how their employers might use operational data from routine downloads of FDR data.

However, this began to change with rapid advances in the number of parameters that could be recorded and in the frequency with which parameters could be sampled, then equally rapid improvements in tools that were available to analyze this new quantity of data—this new avalanche of data. Early FDRs had a relatively few basic parameters, such as speed, time, altitude, pitch, magnetic heading, and climb rate. By the early 1990s, FDRs in the third generation of jet aircraft were recording up to 125 channels. Knowledge about accidents and incidents suddenly got much better, but knowledge about routine flights did not improve.

In May 1995, the FAA first began to advocate systematic use of FDR data and voluntary reports from crews when Administrator David Hinson delivered the keynote address at the annual Wings Club meeting in New York.[6] Hinson argued not only that the industry and government needed to make better use of routinely available data, but that the basic premises in the industry-government relationship needed to change. The basic argument was that the command-and-control model of mandating safety improvements by regulation and then inspecting to ensure that those regulations were being followed had produced nearly as much safety as they would ever produce. Conversely, the industry's self-interest in reducing the accident rate made the adversarial relationship between the FAA and the industry obsolete. Hinson concluded by arguing that a new model was needed.

The basic premise was that systematic use of operational data from everyday flights that ended safely could define "normal" in a statistically meaningful way. Only then could "abnormal" be identified from the same data source, via statistical outliers or by



Note: B-737-800/900 added by author.

Figure 5

identifying events that exceeded defined ranges of acceptable performance. The notion came to be identified in the U.S. as Flight Operations Quality Assurance (FOQA), while other regions of the world identified the notion as Operational Data Analysis (ODA).

Regardless of the preferred term, to be most useful, the data would need to be shared system-wide, among carriers and between carriers and government. Ideally such data could be strengthened with the use of comparable data from the ATC system and by voluntary crew reports. The key though, as Hinson noted then, was to ensure that the data could not be used for punitive purposes by the FAA, employers, or even by civil courts and that it would not be vulnerable to popular misrepresentation.

This stimulated a debate within the U.S. aviation community that only recently approached resolution. Though few challenged the intellectual case that Hinson had presented, debate and opposition were often intense due to the core issues identified above: a lack of trust between employers and employees and a lack of trust between pilots and FAA and between carriers and FAA. The only "technical" objection focused on the capacity to analyze the mountains of data that daily operations could generate. However, rapid improvements in computer capacity, analytical software, and data displays resolved that issue and moved the possibilities well beyond the practices in place among some non-U.S. operators.

CAST

In the interim, the industry and the FAA entered several significant efforts to build trust by jointly analyzing historical accident data and to identify a single set of accidents that needed to be targeted to reduce the accident rate even further. Efforts were undertaken with engine manufacturers and then airframe manufacturers. However, the major advance came in the creation of the Commercial Aviation Safety Team (CAST).

CAST started in 1997 and quickly included representation from the FAA and NASA, as well as major carriers, major aviation labor organizations, aircraft manufacturers, engine manufacturers, avionics manufacturers and the International Civil Aviation Organization. Corporate members typically were at the level of vice president, while FAA membership was at the level of associate or assistant administrators.

CAST then employed a structured mechanism, with explicitly defined procedures for joint analysis of selected accident types, then joint assessment and endorsement of interventions, complete with jointly developed **and** jointly endorsed implementation plans. Teams with professionals from all interested CAST organizations have conducted the analyses and developed proposed interventions and implementation plans. CAST members then review the products and vote yes or no. Unanimous votes are required to endorse plans.

Given the level of these members within their respective organizations among unions, operators, manufacturers, and government, unanimous endorsement makes actual implementation a realistic expectation. Though many ad hoc efforts with similar intentions had been initiated for years, this was the first such effort that included a credible mechanism for implementing the results of joint analysis and jointly developed plans, with the respective obligations of all parties clearly identified.

The industry recognized that it needed government involvement to accomplish many of its objectives. Similarly, government recognized that, if indeed the old regulatory model had yielded nearly all it could yield, government needed to work through and with the various segments of the aviation industry to improve safety. Granted, early progress was slow as industry and government officials worked to build trust among themselves, and as competitive rivals got used to sharing what was once considered sensitive corporate information. However, those growing pains subsided and CAST has since evolved into an effective mechanism that indeed has produced results.

All CAST members have taken some risk in cooperating with each other. The FAA risks being criticized for being too close to the industry it regulates. Officials from pilot unions face a similar risk of being perceived as too close to management or to the FAA. Companies risked airing some of their dirtier laundry with competitors and with the FAA. Everyone risked having priorities rearranged. Yet, the effort has been successfully addressed CFIT accidents, loss of control, approach and landing accidents, turbulence, and runway incursions, with work under way on maintenance, near midair collisions, and issues that are unique to cargo. In 7 years, CAST has managed to build both intellectual and professional trust that simply did not exist in the past between the FAA and the industry.

FAR 193 and FOQA

CAST added both some level of trust and its own analytical findings to the case for FOQA and ASAP programs. Simultaneously, with improvements in analytical tools, the economic benefits of using FOQA data became self-evident. Carriers could now monitor the health of various aircraft systems and perhaps reduce premature replacement of parts and systems. Carriers could also hope to manage inappropriate and inefficient use of control surfaces in flight (such as high-speed slat deployment during approach) or the use of approach profile that regularly resulted in high g-loads at landing, or inefficient flight profiles that needlessly burned fuel, etc.

Efforts to use FOQA data internally within various air carrier properties (not among air carriers) started to build some level of trust with pilot groups. Typically, carriers and their pilot unions entered formal agreements on exactly how such data could be used and typically ensured a role for the unions in analyzing the data and/or in recommending any remedial training, but with the absolute assurance that the data could not be used for punitive purposes. However, efforts to get carriers to share the data among themselves and with the FAA progressed much more slowly.

Finally in April 2003, under statutory authority granted by Congress and after several years of negotiating with the industry to ensure a workable system, the FAA issued a new rule (FAR Part 193). The rule protected any data voluntarily shared with the FAA from punitive uses, "discovery" during litigation, or from public disclosure under Freedom of Information requests. Yet, exact procedures for sharing the data with the FAA remained the subject of negotiation for another year.

As of this writing, the carriers and the FAA are about to implement an agreement by which the carriers can share data with each other (which some carriers had already been doing) and with FAA through NASA as the honest third-party broker. Integration with voluntary crew reports, typically known as an Aviation Safety Action Program (ASAP), which is also protected by FAR 193, and operational data from ATC could augment existing databases to provide a truly comprehensive understanding of risks in the system and offer the opportunity to resolve them before they lead to accidents.

Early efforts to use FOQA and ASAP data cooperatively and without threat of punitive misuse have produced some positive early results. ATC data have been integrated with FOQA data to identify several approaches and departure routes where TCAS resolution alerts were especially common and, therefore, where the threat of midair collisions was unusually high. Similarly, operational data have been used to identify particularly difficult approaches where flight crews must remain high until very close to the runway, then descend quickly to the runway. Though each case thus far has been localized and not exactly page-one news, the improvements in systems safety have been real.

Similarly, many carriers have used FOQA data to analyze unstable approaches, a key precursor in CFIT and approach and landing accidents. Based on these analyses, the carriers are emphasizing standard procedures during approach in their training programs and in their safety education efforts, in cooperation with their pilot unions. More challenging issues likely will emerge as candidates for joint analysis with the use of data from FOQA and ASAP programs, and from ATC data.

The potential for long-term safety benefit is enormous. Eventually, the knowledge gained on normal ATC operations could lead to new system models that account for different weather conditions, seasonal variations, unique (and newly recognized) characteristics of different aircraft types, etc. Ultimately, the knowledge gained from analyzing operational data could be added to the next generation of aircraft, ATC software, and air-ground-air digital communications to account for any newly defined interrelationships. At the same time, everyone understands fully that the system must remain non-threatening to the sources of the data. If the system is misused just once, or if it comes to be perceived as threatening by any of the interested parties, it will be doomed to fail.

Required navigation performance (RNP)

Notwithstanding all the advances noted above, required navigation performance (RNP) may be the best example of a contemporary safety advance that will offer compelling economic benefits to carriers. Consequently, the technology will penetrate the fleet rather rapidly.

RNP is an evolution of area navigation (RNAV). Consistent with the International Civil Aviation Organization's (ICAO) definition of RNAV, FAA defines RNAV as "a method of navigation that permits aircraft operation on any desired flightpath within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these." RNP applies to "self-contained aids, or a combination" of self-contained and ground-based navaids.

With RNP, an aircraft essentially brings its own self-contained ILS system to all phases of flight and to any point in the world. Any airplane with dual inertial navigation, dual GPS and dual FMS will be able to go anywhere, **provided** the aircraft has an adequate database. Conceptually, the airplane will be able to find a prescribed piece of sidewalk, **provided** that the database has the sidewalk incorporated or the flight crew knows the precise coordinates for locating it. If the crew must enter coordinates, the aircraft basically will fly "dead reckoning" with its inertial system (i.e., the aircraft will know how long it has been flying various headings from a starting point and at what speeds and, therefore, will be able to compute its precise position).

The existing ground-based system has been improved incrementally over the years to deliver huge improvements in safety. Nevertheless, the system remains expensive, demands effective security, and still has relatively high failure rates. RNP allows the civil aviation system to reduce or, at some point, even eliminate its dependence on ground-based navigational aids.

In the terminal environment, the ground-based system is restricted by runways that are not equipped with ILS, and by the large, cone-shaped containment zones that spread out as we move back from the runway in order to ensure safe separation in lieu of possible navigational failures. As a result, maximum runway capacity remains relatively modest.

The enroute environment faces comparable limitations on accuracy and dependability. Aircraft still basically fly fixed routes from one navaid to the next. This is true, at some point, even with direct routing. Those limitations put enroute aircraft on fixed paths that require significant separation. This is especially true in the oceanic environment, which is beyond the service range of ground-based systems and, therefore, requires enormous separation. Without RNAV and its next iteration of RNP, the efficient use of airspace in much of the world approached its conceptual limits several years ago.

At its core, RNP provides more precise navigation and tight "containment" within the airspace. An aircraft's capacity to take advantage of RNP will depend on the specific navigation sensors and equipment on the airplane, the precision and dependability of that equipment, plus the type, accuracy, and dependability of ground-based systems.

ICAO has defined various RNP values for oceanic, enroute, terminal, and approach and expresses "RNP level" or RNP type as a function of navigational precision (nautical miles from the intended centerline of a route, or flightpath) and reliability. The required RNP level is shown on navigational charts and procedures. For example, an RNAV departure procedure may define eligible aircraft by citing "RNP-0.3" or "RNP-10." As the number associated with the RNP level decreases, the required precision and reliability of onboard equipment and ground-based systems increases. A fully equipped aircraft can be expected to execute CAT III approaches to a decision height (DH) of 100 feet if the precision criterion satisfies .003 nautical miles (18 feet) and meets a reliability criterion of 99.999 percent of the time with RNP/RNAV.

RNP also is consistent with and supported by several key actions led by CAST. For example, CAST and its members, along with the Flight Safety Foundation, have focused on stabilized approaches, minimizing the use of non-precision or step-down approaches, establishing constant-angle approaches where precision approaches are not available, and establishing go-around gates in which the failure to meet several basic criteria will require the crew to go around rather than to continue and try to recover what is likely to be an unstable approach.

RNP is the product of innovations in communications and computing capacity. The communications link, of course, is based on satellite technology. However, changes in computer capacity help to explain the rapid onset on RNP. Computer capacity required for the on-board database and data processing of GPS signals, FMS data, etc., would have precluded an aircraft from getting off the ground just 15 years ago. Instead, the fleet already includes aircraft that are fully RNP capable.

Yet some barriers could limit or delay the full benefits of RNP. For example, large segments of the aviation community will still require ground-based navaids. This will hardly stop RNP, but it will limit the fiscal benefits for air traffic service providers. In addition, concerns about wake turbulence will limit the application of RNP on closely spaced parallel runways with simultaneous operations. Similarly, some controls may be required to ensure that a light jet does not position itself behind and below a heavy jet on approach or departure.

Perhaps the most significant barrier or source of delay could be the pace at which some carriers incorporate RNP requirements into their fleets. If a majority or even a significant minority of the fleet were to have limited RNP capability well into the future, the mix of traffic could restrict the availability of RNP procedures in the airspace system. This, in turn, would negate benefits to carriers that are anxious to use RNP procedures and thereby perhaps slow the pace at which those carriers choose to add RNP capabilities. In the end, this domino effect would substantially slow the pace at which airspace efficiency improves.

In the end, civil aviation authorities (CAA) may have to exercise their regulatory powers to ensure that the economic incentives inherent in RNP remain compelling. At busy airports during periods of congestion, CAAs may have to limit access to aircraft with RNP capability. For example, landings and departures at, say, Chicago O'Hare or San Francisco between 0600 an 1000 or 1530 through 1930 might be restricted to aircraft that meet a specific level of RNP capability. Carriers that expect to compete at such airports during peak periods then would indeed have a compelling economic interest in RNP.

However, none of the above barriers will stop RNP and very likely will not be permitted to cause significant delays in the application of RNP. In fact, RNP is already under way. ICAO and some member States have designated a number of RNP procedures. For example, RNP-10 routes have been established in the north, central-east, and the South Pacific in which lateral separation of flight tracks has been reduced to 50 nautical miles. Granted, 50 miles of separation remains a lot of airspace, but it is a major improvement in the efficient use of oceanic airspace. States in Europe also have designated RNP-5 procedures, and most arrivals in many countries already have designated RNP levels.

When RNP is fully implemented, it will establish precise lateral and vertical guidance to and from any runway or any other targeted spot in the world. It will improve situational awareness for pilots and ATC, and it will smooth out traffic flow even while significantly reducing required separation buffers. It will reduce workload for both pilots and controllers as pilots and, more significantly, the aircraft will know precisely where the aircraft is within a tightly defined three-dimensional piece of airspace.

The changes will greatly improve stabilized approaches, reduce the need for ATC to issue close-in changes in speed or heading, and will reduce the need for keeping aircraft high until they are close to the runway in order to keep traffic moving. Time and time again, a flight crew can expect to touch down with the nosewheel splitting the centerline. Yet, impressive as the arrival, approach and landing functions are, the precision that RNP brings to departure procedure is equally impressive. Departure becomes very precise as, in effect, aircraft climb out on a reverse glide slope.

In the not-too-distant future, RNP will open huge portions of terminal airspace that is now obligated to separation. As a result, terminal capacity will increase by orders of magnitude, as will air carrier access. Simultaneously, carriers can expect more precise flight profiles, fewer go-arounds, etc. The promise of fuel savings, schedule reliability, consistently lower g loads, less-frequent deployment of flight controls at inappropriate speeds, less-frequent efforts to capture a glide slope or localizer at the last minute, plus the benefits of accident avoidance already have made many air carriers anxious to implement RNP. Safety benefits will include lower risk of CFIT, loss of control, or other types of approach and landing accidents, as well as accidents on takeoff and climbout. In short, RNP is on its way.

Conclusions

The fatal accident rate has undergone several sharp and sudden reductions in the past half-dozen decades. Most of those sudden and sustained reductions have been driven by technological innovation, including constant fleet turnover, improvements in navaids, automation, etc. The fatal accident indeed has reached such low levels that trying to push it even lower can sometimes seem impossible or at least very challenging.

However, the next significant and sustained reduction in the fatal accident rate in fact is already underway and it will accelerate over the next decade or so. The sources of that reduction will include some factors that are familiar in their core attributes: technology and fleet turnover. However, some new factors also will help to drive the fatal accident rate ever lower, including fundamental changes under way in analytical tools and in the relationship between the industry and regulators.

Footnotes

1 "Major accidents" involve (1) either a hull loss or multiple fatalities, or both; *and* (2) a scheduled passenger flight with 10 or more seats, or a non-scheduled passenger flight with 30 or more seats, or a cargo aircraft with at least 7,500 pounds of payload.

2 *FAA Historical Chronology*, page 51.

3 Civil Aeronautics Board, U.S.A.

4 Fleet data from Airclaims.

5 Description adapted from Electronics Laboratory of the Swiss Federal Institute of Technology, Zurich.

6 See "A New Paradigm for Aviation Safety," FAA Administrator David Hinson and Robert Matthews, Wings Club of New York, May 1995.

New Opportunities and New Boundaries: Accident Investigations Involving Engine Consortiums And Alliances

By Michael Bartron and Mike Gamlin, Pratt and Whitney, U.S.A., and Rolls-Royce, U.K.

Michael Bartron, manager of Flight Safety Investigations, has worked for Pratt and Whitney for the past 12 years. From applied mechanics activities through airplane performance analysis, Bartron gained an appreciation for the complexity of today's jet engine technologies. For 1 year, he was assigned to the U.S. National Transportation Safety Board to support transportation safety initiatives, while providing an industry view to the Board. For the past 5 years, he has worked as an investigator within P&W's Flight Safety Office and has participated in several major aircraft investigations. Bartron holds a bachelor's degree in mechanical engineering from Lehigh University and a masters degree in mechanical engineering from Rensselaer Polytechnic Institute.

Mike Gamlin is an air safety investigation manager for Rolls-Royce plc, responsible for the investigation of accidents and serious incidents involving airline and defense engine types designed and manufactured by Rolls-Royce in Europe. He has worked for Rolls-Royce for 30 years, initially in the Bristol Engine Division, Defect Investigation Department, as a quality engineer. He has been involved in the investigation process and multinational consortia projects for more than 20 years and has a wide range of investigative experience covering all of the company's defense products. Involved in air safety investigation since 1990, he has led the air safety investigation team, responsible for European products since 2000.

Abstract

Aircraft accidents of decades ago are often looked upon today as much simpler than contemporary investigations. As aircraft designs grew in complexity and number, the related accident investigations also grew from component or hardware concerns to include complex systems and company processes. Over time, many propulsion system original equipment manufacturer's (OEM) products also moved from in-house design and manufacturing to outsourced and vendor-supplied equipment, finally assembled, tested, and shipped from the OEM. All along, the investigative approach still relied on the interested party members to gather and sort through their respective product.

Today, the lines between supplier and partner have blurred. Engine manufacturers have partnered and aligned with one another in order to share both costs and rewards in the highly competitive propulsion marketplace. While these partnerships consider the entire engine program life cycle, the activity of accident investigations and safety processes across the partnership provides numerous challenges, new boundaries, and opportunities.

Investigations of consortium and alliance products face hurdles with on-scene investigator staffing, challenges with post-scene investigation of company-sensitive hardware, and barriers of proprietary product information.

This paper offers a look at the challenges of investigation from within a consortium and from the investigative authority, as well as the opportunities of communication and education toward safety processes. Ultimately, the success of accident investigations and safety actions within these alliances and consortiums rely heavily on communications across these new and sometimes-blurred boundaries.

Intent

This paper is intended to provide insight to the challenges and opportunities of the investigative roles and functions resulting from the increasing variety of OEM arrangements. The authors offer that investigative agencies and authorities, which have not yet worked with consortium or alliance OEM arrangements, may benefit from this familiarization to the subtle differences between these new organizations and the more traditional company participants to investigations. Additionally, these evolving company arrangements offer several opportunities to foster communication and education toward aviation safety concerns.

Participants to air safety investigations

During the inception of powered flight, the early pioneers had their share of accidents and incidents. At that time, the investigations were focused on improvements in fundamental design and operations. These investigations helped propel powered flight into a commercially viable enterprise and forever changed the world. As the aviation industry grew and businesses began to compete for equipment sales and passenger and cargo revenue, aviation accidents continued to influence the existence of these companies. The revolutionary but ill-fated Comet pressured the de Havilland Aircraft Company's survival, but also brought about new approaches to accident investigation and aviation safety.

Recognizing the growing aviation industry, governments around the world identified both the need and benefits to either regulating or monitoring aviation operations. Consequently, in 1944 an international aviation conference was held in Chicago, attended by 52 "States," and as a result the International Civil Aviation Organization (ICAO) was founded and a convention on international civil aviation drafted. This draft convention was ultimately ratified in 1947, securing future cooperation across international civil air transport operations through 96 articles. ICAO continues this work today based in Montreal, as a United Nations agency.

Subsequent to the ratification of the Chicago Convention articles, 18 annexes, known as standards and recommended practices (SARPs), were produced, which detail specific areas of operation. The SARP relating to aircraft accident investigation, designated as Annex 13, was adopted in 1951. Aircraft accident investigation activity continues today under the organizational structure outlined by Annex 13 (now in the ninth revision and agreed to by nearly 200 States).

The context of Annex 13 provides contracting countries or States the opportunity to identify a national (government) investigation agency to lead an investigation, if they are the State of occurrence, or to represent their State as an accredited representative should the accident occur in another State. Additionally there is provision for the representation of national (State of) design or (State of) manufacturing organizations, by competent experts, through nomination by the national agency, for advice and consultation. Traditionally, the interested party's (technical advisors) were quite simply a single company, agency, or organization. But in today's world, it may be necessary to recognize that individual companies within consortia and alliance companies may have the necessary expertise required to provide the best support for an investigation.

To preserve control of an investigation, it is understandable that national agencies may want to minimize the number of people involved through party status at any investigation. Conflict may, therefore, arise as the OEMs attempt to provide support from different parts of their organization. This paper considers the issues and implications that arise with consortia support for the national agencies during an investigation.

The changing face of air safety investigation

Aircraft accidents of only decades ago are often looked back upon today as having been much simpler than contemporary investigations. A review of investigation reports of the earlier era provides today's engineers with an insight to many of the design and safety requirements in place today. However, the reports belie the engineering efforts required to reach the conclusions and identify the solutions that bought about many of these safety improvements (and all done without the "*tools*" we now take for granted). The learning curve for early investigators must have been immensely rewarding, as investigations led to fundamental understanding, recommendations, changes, and actions.

So, in themselves the investigations may seem to have been easier, but the solutions rarely were. Often the boundaries of knowledge were pushed to identify new and innovative fixes to what were often "simple problems." In parallel, the solutions to the problems presented by the growing industry and the need to push the boundaries for bigger, faster, and heavier aircraft have led to today's complex and efficient designs and systems.

As aircraft systems grew in complexity and number, the related accident investigations also grew from component or hardware concerns to include these complex systems as well as company procedures and organizational arrangements. In 1994, with the loss of USAir Flight 427, the investigative activity extensively considered systems design and operations, as well as maintenance procedures. The investigation continued for nearly 4 years and involved tests of components, systems, as well as flight tests. Today, we can expect accident investigations to consider aircraft and maintenance systems, as well as personnel actions and the related company procedures and policies. Having been prompted by the evolution from specific hardware designs to systems evaluations, today's investigators, similar to 100 years prior, help to feed continued improvements in aircraft design and operations.

Aerospace globalization

The aerospace business, like many others, has changed significantly in recent years. Technology advancements in materials, design tools, and complex systems, which ultimately lead to more efficient airplanes, were driven by business requirements and opportunities. By the same rationale, efficiency improvements within aerospace companies have been sought after through changes to organizational structures, from subtle reorganizations to mergers and partnerships. The companies have evolved, like those in other high-technology, capital-intensive manufacturing sector businesses, to become functionally integrated as well as globally aligned. Continued evolution and globalization of the aerospace business is resulting in the growth of collaborative alliances and contracting partnerships across North America, Europe, the Far East including the Pacific Rim, and Latin America as companies seek to maximize the benefits of global markets, industrial capabilities, and systems integration.[1] These partnerships, alliances, joint ventures, and other arrangements involve both modest and dominant companies. They can often occur when an independent approach to a multibillion dollar program becomes financially unreasonable or where partnerships offer companies new entrances to a market.

The advent of the consortium brings a problem that impacts not only the consortium companies but also the investigation agencies. It is in the interest of the consortium, for many reasons, to be involved in any accident or incident investigation. But the primary reason for any company to be involved in an investigation is the same as that of the investigation agencies—none of us want to have a second event. We all want to get to the root cause as expeditiously as possible. So when an accident involving a consortia product happens, who do the agencies want to act as advisors? One thing is for sure, they will not want representatives from all of the partners behind the consortium looking to join the investigation as advisors…whomever they are.

Collaboration agreement

Partnerships are not new; they have existed in aviation for nearly as long as powered flight. 2004 sees the celebration of the 100th anniversary of the first meeting of Mr. C.S. Rolls and Mr. F.H. Royce, who were later to form a partnership that is today the continuing venture of Rolls-Royce plc. Today, Rolls-Royce, operating in a vast global market, finds partnerships and collaboration an integral and important part of its business. It is involved in many joint ventures, collaborative research programs. and risk- and revenue-sharing agreements.[2] Unfortunately. but ironically related to this subject, Charles Royce was killed in a French-built Wright aircraft in 1910 and became the first Englishman to die on an aviation accident, only 1 month after becoming the first Englishman to fly across the Channel and back again in one trip.

A current consortium, IAE International Aero Engines AG, was formed to produce the V2500 engine family. International

Aero Engines (IAE) is a collaborative effort between Pratt and Whitney, Rolls-Royce, MTU, and the Japanese Aero Engines Corporation, which is much like a consortium in itself. Within IAE, these collaborative members are otherwise referred to as "partner companies".

IAE was formed in 1983, based on a 30-year collaborative agreement, registered in Zurich, with its corporate headquarters in East Hartford, Conn., U.S.A. Pratt and Whitney and Rolls-Royce each hold a 32.5% share in the company, with JAEC and MTU holding 23% and 12%, respectively.

Each of the partner companies took responsibility for one of the engine modules. JAEC is responsible for the fan and LP compressor, Rolls-Royce the HP compressor, Pratt and Whitney the combustor and HP turbine, and MTU the LP turbine. Engine assembly is the responsibility of Pratt and Whitney and Rolls-Royce. Figure 1 depicts the allocation of responsibility of the V2500 engine.

For such an alliance to succeed, it was imperative that there were clearly defined responsibilities and resources if the desired results were to be achieved. A strong and well-organized company was created that established its own matrix structure able to function autonomously. IAE focused on achieving a seamless operation from IAE headquarters operations through the partner companies, irrespective of cultures, geography, or time zones. The partner companies, in agreeing on the division of hardware responsibility, also agreed that the proprietary concerns or intellectual property of each partner company's designs would not be disclosed to the other partners. This is an important point during the accident or incident investigation, as the responsible technical advisor supporting the investigation would be representing IAE as the engine manufacturer, rather than an individual partner company.

The U.S. FAA issued the type certificate and production certificate for the engine in 1988, and the first V2500 aircraft was delivered early in 1989 following a successful 8-month flight test program. Subsequent development of the engine saw it installed on a range of Airbus and Boeing aircraft. IAE has now produced more than 2,000 engines. The production of a highly successful engine is testimony to the management of the consortium, the engineering skills based in the partner companies, and the critical evaluation of managerial and professional challenges associated with an international aerospace project throughout its life cycle. This demonstrates the ability of the consortium to challenge the more traditional, single-company approach and successfully coordinate the design and manufacture of such a high-technology product.

However, even with the strengths arising from such alliances, unfortunately problems can and do arise. Eventually an accident or serious incident may occur and the investigation process would be invoked. The executive team of IAE and the partner companies were aware of this likelihood and set out in its collaboration agreement the way IAE would manage its involvement in any major accident or incident involving a V2500 powered aircraft. Pratt and Whitney, having an established flight safety investigation organization, accepted the investigation lead role, while also holding the responsibility for interfacing with the FAA on certification and continued airworthiness issues. Further development within IAE found that a shared responsibility for safety investigations would benefit this consortium. Coordinating this development proved to be the genesis for the topics of this paper. Currently, both Pratt and Whitney and Rolls-Royce safety offices work in concert to support incident and accident investigations.

Safety organizations

Just as we might look back on earlier accident investigations as having been easier, company organizational structures may have been "simpler" as well. Original equipment manufacturers quite often structured their organizations in a simple, hierarchical system, delineated by technical or financial disciplines.

More recently, organizational structuring has moved to a more complex arrangement of integrated engineering, manufacturing, and support functions in order to increase operating efficiencies across each company. When combined with globalization efforts, today's aerospace companies offer tremendous reach and capability but may resemble little of their former operations. This provides an added burden to the investigative offices, which have remained in many cases, tied to both the traditional external investigative systems as well as the contemporary company organizations.

Each of the major manufacturers maintains individual safety offices complimented by accident investigations disciplines. The overlap and potential conflicts of interest between the individual organizations require investigators and investigative authorities to recognize the position and boundaries of company representatives and technical advisors participating in air safety investigations.

Aviation safety offices have generally been support organizations to the company's core products, helping the company provide safe aviation products while also offering help to identify and direct product integrity concerns. Today, many safety offices maintain positions that can significantly affect a company's activity.

The IAE consortium offers to its customers one company in IAE, even though the support functions come primarily from the partner companies. This places organizational and functional challenges inside both the consortium and the partner companies. For the partner company, the manner in which safety efforts are managed within their respective company helps determine this organizational challenge. In a general view, there are essentially three models that are employed in the industry:

- Safety is managed through a central safety or airworthiness office, with safety personnel having visibility across all programs/projects and inserting themselves as needed within each program/project. This centralized approach tends to follow more closely the former organizational structures delineated by disciplines, which goes against the drive for operational efficiencies. However, this approach offers independence to the safety organization by removing program/project motivations from influencing safety office functions, and provides a path for visibility across problems and solutions identified during investigations.
- Safety is managed through a decentralized safety role, and safety personnel are positioned within each project/program. This approach ties the safety activity close and continuous to each program, which can lead to a reduced vision across programs as well as taxing the independence of the safety discipline. This arrangement could also restrict the ease with which lessons learned are cross-fertilized into other projects. However, safety personnel can focus on their specific project without the distractions of cross-program influences.
- Safety is managed through a combination of the two preceding approaches. However, with the continued focus on cost re-

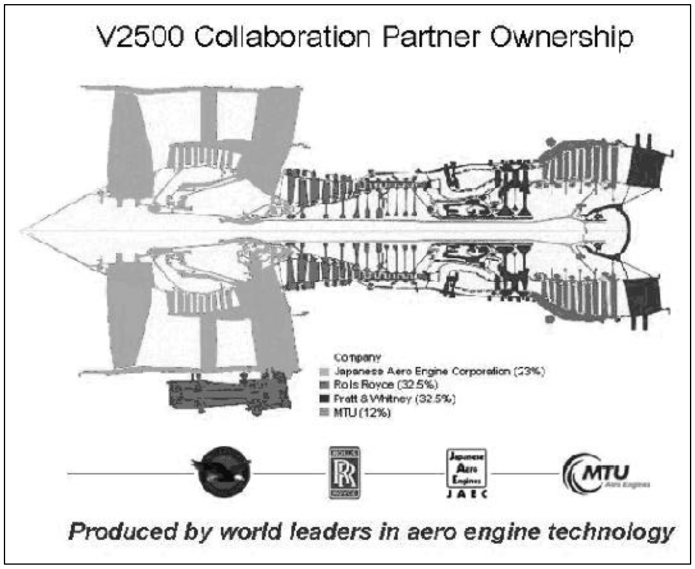


Figure 1: Share of responsibility of the IAE V2500 engine.

ductions and operating efficiencies, companies may find difficulty in maintaining the combined approach, which also requires additional support staff and communication activity to ensure that both program-specific needs as well as cross-program issues are addressed.

Companies may attempt to emulate the combined approach through the use of specialized safety offices and safety reviews, allowing staff to address program-specific concerns, while management or executive personnel review and respond to cross-program issues.

The importance of understanding these approaches arises as the consortium, in supporting an investigation, attempts to function across partner company boundaries, namely in the manner that information flows between companies, which can impact the larger safety processes. These approaches, and their contributing factors, should be recognized in advance to maintain effective operations especially during an accident investigation. The least-desirable situation may find the investigative authorities identifying concerns with a company's organizational structure, safety culture, or practices.

During an accident or incident investigation, the investigating authority has then the challenge to interface with several personnel, most of whom come from one of these corporate safety offices, with the goal of gaining an understanding for the cause and contributing factors behind an accident. From the perspective of the investigating authority, one point of contact—an accident coordinator and one or more accident investigators from each company—provide the necessary support to their party-system approach.

Challenges—investigative activity

Investigations of consortium and alliance products face hurdles with on-scene investigator staffing, challenges with post-scene investigation of company-sensitive hardware, and barriers of proprietary product information. Working with the guidance of ICAO Annex 13, IAE have looked at the challenges of its consortium in responding to and supporting these investigations. As a result, IAE has enhanced its procedures and awareness efforts across the consortium.

IAE is permitted to participate in an investigation as a manufacturer. However, since it is often not clear at the outset of any investigation where the thrust of the investigation may lead, it was originally possible that a representative from each of the partner companies would want to attend the accident scene—recalling that each partner company retains responsibility and propriety for its respective engine hardware. This was the first of several challenges identified by IAE in response to accident investigation procedures.

Ron Schleede, international affairs advisor and retired from the NTSB having been deputy director of the Office of Aviation Safety, offered, "private sector organizations, such as airlines, manufacturers, and insurers, have an enormous stake in the results of an aircraft accident investigation. Consequently, the private sector plays a large role in the ability of States to meet the intent of Annex 13."[3] With some of the engine company partnerships, consortiums, or alliances, the participating companies exist in different countries. Beyond the geographical challenges of having partners spread around the world, during the initial response to an accident, the partner companies may seek inroads to the safety activity of the investigation. As an example, IAE maintains type and production certificates issued by the U.S. FAA, making the United States the State of design and State of manufacture. During an investigation, Annex 13 offers that the U.S. NTSB would be the investigative agency or accredited representative depending on the location of the incident or accident. However, with four companies each having a primary responsibility in the design of a significant portion of the engine, at the start of an accident investigation it can be expected that each company would want to participate in the on-scene activity. Would the authorities in charge of an investigation permit or even want investigators from each parent company to arrive at the scene?

Clearly, the consortium needs to identify the accident response team members, but then also needs to gauge the reaction level of each of the partner companies. An agreement is required between the consortium and partner companies that details the participation and responsibilities during the initial phase and throughout the complete accident investigation.

Communications requirements, starting with the creation of a control room within which a core company response team could meet and talk with on-scene personnel all the way through reporting and documenting investigation findings, presents further challenges for developing accident response procedures.

Another challenge comes from appreciating the requirements of the other investigation participants. A primary concern originates with the airline or operator who experienced the accident. As well as expecting a level of support as a "customer," the operator will also be a "party member" during the investigation. However, during the investigation, the operator will be interacting with the engine company through both the official investigative team as well as its normal field service representative, as both investigation and business requirements dictate. The challenges and requirements placed on field service representatives then uncover a series of additional challenges.

Field service representatives for the consortium company may likely be employees of one of the partner companies and, as such, could be responsible for supporting products of both their parent company and those of the consortium company. To best supply their customers with company support, an OEM will usually issue to each field service representative a handbook of company procedures. This handbook becomes the essential reference tool for field representatives when they find themselves in rare or unsettled situations with their customer, i.e., immediately following an accident. Each handbook often dedicates a chapter or section to the procedures and policies of the company and more specifically the reactions of a field service representative to an accident or incident occurrence.

Because of the competitive nature of the aviation business, where customer accounts often translate into substantial dollar value, the field service representatives are expected to provide continuous support to their customers, as many airlines also move to redistribute tasks that are outside their core business of passenger or cargo air transportation, many functions are being moved to their suppliers, i.e., engine companies. Therefore, company field service representatives are adapting to provide nearly seamless support to delight their customers and help their employers succeed.

In the moment of an airplane accident, the airline operator is quite often leading the response activity, with the most relevant information concerning flight operations, accident location, persons on board, manifests, etc. The company field service representative, working so closely with their customer, can also provide an early access to vital information. However, as the field service representatives work to support their customer, and their customer works to sort-out the early understanding of the accident, neither group may have the appropriate background to comprehend the magnitude and subtleties of their involvement. Until the formal (Annex 13) accident response system has been initiated and the hierarchy of responsible investigation personnel are positioned, including the OEM air safety investigators, it is imperative that the company representatives demonstrate appropriate behavior. Nonetheless, their actions can be expected to reflect primarily the behavior that has been so strongly engrained in them by their day-to-day functions and relationships. The representatives may refer to their handbook for accident procedure information, but may, in all likelihood, respond to their customer's requests as they have been conditioned to do. To this end, both repetitive awareness training and periodic updates to the field service representative's handbook have shown to help guide representatives when responding to their customers in times of accidents or incidents.

Challenges—national investigative agencies

In a paper titled "Accident Investigation Assistance: What Should the State of Occurrence Expect from a Manufacturing State?" Robert M. MacIntosh, chief advisor, International Safety Affairs at the NTSB, has laid out the framework in which the investigator-in-charge (IIC) of a State of occurrence can reasonable expect to work with the State(s) of manufacture.[4]

The paper reflects the requirements of Annex 13 and importantly identifies that a key driver in the successful engagement of support from the State of manufacture accredited representatives and manufacturer's advisors is timely notification of accidents in accordance with the procedures defined in Annex 13. MacIntosh considers the dynamics of the party system and points out the hierarchy of responsibility between the State of occurrence, the State of manufacture (accredited representative), and the technical advisor (industry specialist).

Recognizing the uncertainty that exists at the outset of an investigation into an accident or serious incident, an IIC understandably has to judge what is considered to be a reasonable number of persons (technical advisors) invited to aid the investigation process.

All of the leading companies in the aerospace industry, and a large proportion of smaller companies, have trained personnel able to support national authorities when the need arises. The paper suggests that an IIC, through an accredited representative, would prefer to have a single point of contact or focal point for specific disciplines. This fits well in the party system and working group framework often employed by IICs.

The national safety agencies then often prefer a single point of contact within the technical advisors from each manufacturer. In the case of a consortium or alliance, a look at current OEM practices offered guidance to this need of support. Rolls-Royce experience has started to identify benefits to the investigation process of having more than one person attend during the early phase of the investigation. Often this has been an experienced air safety investigations team member supported by a field service representative, or specially trained project personnel also termed technical support. The fully trained investigator understands the organization and protocols that surround an investigation, provides direct support to the IIC or accredited representative, and in the case of a consortium works as the representative for the consortium, and not the parent company. The field service representative/technical support person, on the other hand, brings specific product knowledge or skills but may not fully appreciate the requirements and constraints of the arena into which they are now participating. This arrangement has been shown to bring both focus and seamless support to the investigation. This seems to address the State of occurrence and industry's needs, from both sides.

Discussions with investigators from both the U.S. NTSB and the U.K. AAIB have offered very logical perspectives. Tom Haueter and Jim Hookey from the NTSB headquarters in Washington, D.C., suggested that the IIC wants one coordinator from each party. "You can coordinate however you wish within your company team, but we [NTSB] need one person representing your party," Hookey explained. This follows normal NTSB protocol. With the consortium arrangement however, one person may not be able to represent each of the partner companies. Haueter added, "With agreement from the IIC, the accident coordinator can change during an investigation. We can also add or remove investigators and even parties to the investigation as the investigation unfolds."[5] This flexibility permits these new organizational arrangements to work within the current party system. Although the challenges continue well after the on-scene activity has been completed, consideration must be given to limitations of the organizational arrangement.

From challenges to boundaries

Selected hardware recovered from the accident or incident scene may be subject to further examination at maintenance shop or laboratory locations. With consortium hardware rather than traditional OEM hardware, the investigative participants must recognize and respect new boundaries within the consortium parties. The concerns for intellectual property arise immediately, given that the partner companies retain design expertise. It is quite likely that the named accident coordinator from the consortium cannot completely represent the partner company responsible for the design of the selected hardware. In these cases, additional representation would enter the investigative effort and need to be recognized and accepted by the investigating authorities.

Considerable effort has been made in defining the working level arrangements between party companies of consortiums, alliances, and joint ventures. Where hardware design responsibilities, equipment part numbers, personnel ID badges, and even pay checks can easily establish proprietary boundaries, the investigation of the engine systems quickly crosses into partner company responsibilities. An accident investigation needs to respect these boundaries, in line with what would be normal working conditions. The investigative team must recognize that the available data to support the investigation can be gathered; however, access to the data may require additional formal requests and administration than occur during a more traditional company arrangement.

Within the traditional investigation framework, working through a party system, the party members cannot share proprietary information across the investigative team. Thus, the onus is on the company to establish and inform the other investigative parties when proprietary concerns are being broached. When this occurs, the investigative authority can discuss the concerns in a confidential manner with the specific party member owning the concern. In the consortium, the investigative authority, as well as the other parties, must again appreciate that discussions may require a change of personnel within the investigative team for the consortium.

Moving inside the consortium, the issue of proprietary information is handled in much the same way. Although, the partner companies maintain technical responsibility for their hardware, the partner companies can and often do assemble to discuss whole engine concerns while maintaining confidentiality of partner company information by limiting the scope of the discussions. To the investigative authority and other parties to the investigation, recognition of these limitations and the related administrative requirements can help guide progress of the investigation, while avoiding potential conflicts and delays.

Subsequent to the specific accident or incident investigations, the consortium must manage the same high level of integrity and recognition throughout the discussions, resolutions, and closure of the resulting safety concerns.

Practical example

Anne Evans from the Air Accident Investigation Board (AAIB) of the U.K. explained a recent experience with a consortium organization. A particular occurrence found the AAIB responding to an incident scene in the U.K., where representatives from only one of the parent companies from the consortium arrived on scene, along with other parties to the investigation. The investigation progressed through the on-scene activity as needed. The on-scene team identified hardware that required further examination and evaluation. However, a different parent company within the consortium maintained responsibility for this hardware, and this company resided in another country. Importantly, the consortium not only kept effective communications between their parent companies from the start of the investigation, but also kept their respective ICAO representatives informed as well.

Following the decision to further examine hardware, the AAIB utilized the Annex 13 principles and forwarded responsibility of the hardware to the States' government agency of the other parent company. Only the hardware crossed international boundaries, while investigators of the respective States and resident companies completed the hardware examination and reported back to the AAIB. In this case, effectively the States' government investigative agencies operated more like the consortium.

During the same investigation, discussions with both the airframer and the airline representatives found that the approach of the consortium, in this case, fit well into the normal party system. However, the participants acknowledged that they were unaware of the organizational structure behind the consortium. "From our position, the investigation worked like most others, except that there were a few more levels of participation with the engine hardware," commented an airline representative.

Opportunities

From the perspective of a national agency investigation, the activity involving consortium or alliance companies essentially becomes a party system within a party system, with the consortium administering the roles and responsibilities of the investigation among the partner companies and then participating at the Annex 13 level as a party to the investigation.

For the consortium, the on-scene investigators may be from one or more partner companies, but would be responsible to the consortium through the consortium coordinator. With the appropriate permissions, the on-scene team would provide daily communications to a team within the consortium office. The coordinator will share with the consortium only the information that is dependent upon actions from the consortium or partner companies. Issues of proprietary concerns would be handled through standard consortium business practices.

With the examination of hardware related to the investigation, the responsible partner company rather than the consortium needs to provide an important role. At this point, the onus falls to the investigating authority to decide the level of oversight and involvement with the partner company, which may be located in a country that is not officially involved in the investigation. Recall that the country(s) that granted the type and production certificate would be the State of design and State of manufacture, respectively, and may not be the same country(s) in which the partner companies reside. This presents the situation in which the investigating authority, when desiring to return hardware to the responsible partner company that resides outside the State of design (from a type certification perspective), may need to modify the boundary of the definition used for participants under ICAO Annex 13.

Each partner company then maintains proprietary information and offers investigation results to consortium-level review. If necessary, the partner company may provide confidential information to the national investigation agency, with the restriction that the information does not get distributed to other consortium companies. However, the agency must be aware of these limitations, as well as the organizational arrangement, in order to prevent inappropriate distribution of such data.

It is important during the later phase of the investigation activity that the responsibility for delivery of reports and other evidence required by the investigation agency be adequately coordinated. At this time the coordinator should act as the focal point for the consortia and the investigation agency alike. There should be clear recognition of deliverables and time scales agreed by both sides to ensure such requirements are not compromised.

As the investigation draws to a close, the comment periods for draft reports may require additional administrative coordination, as the parent companies need to formulate and approve their comments prior to assembly and final approval of the consortium's response to the investigative authority. Satisfying the added coordination requirements, which stem from the alliance and consortium arrangements, may be helped through effective development and execution of procedures that not only address safety activities of the consortium but also match the partner companies of the alliance or consortium. Developing these procedures offers the opportunity to generate example scenarios and test cases, which may identify many overlooked details. Executing within these defined procedures would then maintain consistency across the partner companies as well as with the investigative agencies.

Periodic reviews of these procedures and of personnel changes at the consortia level and into the partner companies may help drive lessons learned from each investigation back into the procedures and processes of all the participants. Introducing the lessons learned from each investigation into the activities of the consortium and further into the parent companies promotes the ultimate intention of investigative activity—safety information gets shared and utilized between organizations as part of normal business operations. Furthermore, training topics and activities can be a natural extension of the procedures and periodic review findings.

Training

The value of training company personnel at all levels, to understand the framework of the investigation process and its protocols, cannot be understated. In today's highly dynamic organizations, it is increasingly difficult to establish points of contact that are likely to remain in position for much more than 5 years. There is a tendency, particularly in shrinking companies, for personnel to be more mobile. With the rarity of aviation accidents, it is not uncommon for employees at all levels to cycle through the consortium or partnership without having experienced the activity and demands of an investigation.

One stable element in the process appears to be the safety investigation teams, where continual challenges presented by investigations tend to keep the investigative personnel in place. This stability can offer an invaluable pool of knowledge and experience, which as a result of the recent and significant evolution of the aerospace business is proving difficult to replace.

Planning and training activities should identify safety personnel required to support both external and internal company activities. External activities would be primarily focused on the on-scene response and subsequent hardware examinations, meetings with government agencies, and document and report coordination. The internal activities would include data gathering and analysis, hardware examinations, technical reviews, and management briefings and communications. We believe that there is a tremendous benefit to training personnel who may never attend or interact with investigative authorities on the investigative process and protocols. On more than one occasion, one well-intended but misdirected communication or lack of understanding has jeopardized a party's involvement with an investigation.

Training activity among engine manufacturers has tended to be limited to training with airlines and airline authorities. With these new organizational arrangements, interactions between personnel across the partner companies are vital to exercising the response and planning of the individual companies. Opportunities for scenario training, including the involvement of other potential investigative participants such as airframers and national authorities, have proven very successful to our consortium.

Conclusions

As the corporate environment continues to change in response to the business demands of the aviation marketplace, accident investigation functions must continue to adjust accordingly. These changes must be recognized by each countries investigative agency in order that subsequent accident investigations activities do not fall victim to organizational conflicts and difficulties.

An airframe manufacturer offered that these partnerships and consortiums shouldn't offer any additional challenges to the party system, as flexibility exists in membership participation. It is not uncommon to change participants during an investigation, due to changing requirements and personnel changes.

National investigative agencies should recognize and appreciate the subtle differences presented by involvement with an alliance or consortium venture. One agency offered its appreciation of the nature of the consortium arrangement and viewed its role as accredited representative to include working as an endorsement for the consortia participation into foreign investigations, in the same manner as it would a more traditionally organized company.

Consortiums and alliances—an evolving industry

As the business of aviation changed during the latter decades of the 20th century, (alternate) forms of organizations were created. Consortiums such as International Aero Engines, and other partnerships were born into the aircraft engine OEM arena. Where once aircraft engines were designed, manufactured, assembled, tested, and shipped from primarily one location, has today become a myriad of contractual agreements representing a cost-effective sharing of technical and program risks as well as business rewards. Today, the lines between supplier and partner may seem blurred. But the trend will continue nonetheless. In fact, the latest jet engine programs offered by a single OEM have established or continue to seek risk-sharing agreements for a majority of each engine program.

The recent trends in organizational structuring show a more complex arrangement of integrated engineering, manufacturing, and support functions. These trends have played out through years of mergers and reorganizations.

With the move to matrix-type organizational integration, partnerships and alliances, combined with the low number of aviation accidents, companies may benefit from a close review of the fundamental requirements of the investigative process and product integrity concerns.

Employees who are successful working within these partnerships provide a marked value to their parent company as well. The increased perspective of the joint venture or partnership allows employees to gain direct insight to alternate approaches and business practices, to continuously benchmark their parent company against their partners, and forces a teaming environment not always available in any one company.

Ultimately, the success of accident investigations and safety actions within these alliances and consortiums rely heavily on communications across these new and sometimes blurred boundaries.◆

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Airborne Collision Avoidance System: ACAS/TCAS from the Accident Investigation's Point of View

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On July 1, 2002, a collision between a Tupolev TU154M, which was on a flight from Moscow, Russia, to Barcelona, Spain, and a Boeing B-757-200, on a flight from Bergamo, Italy, to Brussels, Belgium, occurred north of the city of Ueberlingen (Lake of Constance). Both aircraft flew according to IFR (instrument flight rules) and were under control of ACC Zurich. After the collision, both aircraft crashed into an area north of Ueberlingen.

A total of 71 people were on board the two airplanes, none of whom survived the crash.

The BFU investigation team identified the following immediate causes:

- The imminent separation infringement was not noticed by ATC in time. The instruction for the TU154M to descend was given at a time when the prescribed separation to the B-757-200 could not be ensured anymore.
- The TU154M crew followed the ATC instruction to descend and continued to do so even after TCAS advised them to climb. This maneuver was performed contrary to the generated ACAS/TCAS RA.

The following systemic causes have been identified:

- The integration of ACAS/TCAS II into the system aviation was insufficient and did not correspond in all points with the system philosophy.
- The regulations concerning ACAS/TCAS published by ICAO and as a result the regulations of national aviation authorities, operations, and procedural instructions of the TCAS manufacturer and the operators were not standardized, incomplete, and partially contradictory.
- Management and quality assurance of the air navigation service company did not ensure that during the night all open workstations were continuously staffed by controllers.
- Management and quality assurance of the air navigation service company tolerated for years that during times of low traffic flow at night only one controller worked and the other one rested.

Investigation

An essential part of the investigation done by the German Federal Bureau of Aircraft Accident Investigation (BFU) was the investigation of ACAS/TCAS. The accident was not prevented even though both airplanes were equipped with ACAS/TCAS II, Version 7. One of the major questions in this investigation was: Why was ACAS/TCAS not able to prevent the midair collision?

ACAS/TCAS system description

ACAS/TCAS operates by interrogating Mode C or Mode S transponders installed in other aircraft, and uses the responses to identify traffic conflicts within a protected volume of airspace around the aircraft. The system generates traffic advisories (TAs) to assist the flight crew to locate and monitor other traffic that may present a collision hazard. If ACAS/TCAS determines that an intruder aircraft will enter the protected airspace around the aircraft, the system generates a resolution advisory (RA). The RA provides the crew with collision-avoidance guidance.

ACAS/TCAS data recovered from internal processor card

To rule out a technical malfunction of the ACAS/TCAS computer, it was a most important aim to read all data stored by the computers.

The ACAS/TCAS computer of the B-757-200 was completely destroyed by impact forces and fire. Some data could be deter-

The damaged ACAS/TCAS computer of the TU 154M.

mined by reading the TU154M computer because each ACAS/TCAS computer of the airplanes involved stored data of the other.

The non-volatile memory of the ACAS/TCAS computer of the TU154M was read at the ACAS/TCAS manufacturer under supervision of members of the BFU investigation team.

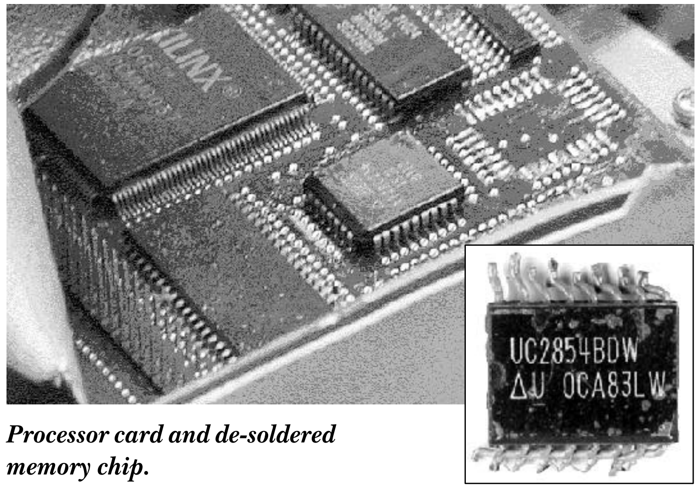
The recovered ACAS/TCAS computer of the TU154M had been crushed during impact, and the faceplate was partially detached from the processor chassis. Because of the damage to the computer, the unit was not benchtestable. The processor card was not in a condition to be placed into another intact unit in order to download the contents of the memory chips into an serviceable unit. The two identified chips were cleaned and then removed (de-soldered) from the processor circuit card. The chips were placed into a microchip reader and the contents downloaded into a 3.5" floppy disk.

The downloaded data were then imported into a software package called TRAFFIQ System (Traffic Resolution Advisories and Fault Failure Inspection and Query System). The event history file was opened and the resultant data examined by the investigation group. There were two situations during the flight for which the ACAS/TCAS computer generated event numbers and stored the course of events in the data memory.

The data included the measured values of own aircraft (altitude, bearing, distances) and the altitude information of the intruder received via the transponder. ACAS/TCAS calculated the values for the rate of climb and descent from the received altitude information and stored them. This data could also be analyzed. Therefore, important information for the reconstruction of the flightpaths of both airplanes was available.

The following ACAS/TCAS data of the TU154M was extractable from the memory:

Time (UTC)	Altitude (feet)	V/S (ft/min)	Intruder Range (nm)	Bearing (deg)	Advisory
21:34:32	35968	217	11.97	325	-
21:34:34	35968	140	11.56	326	-
21:34:36	35968	45	11.16	326	-
21:34:38	35968	49	10.75	328	-
21:34:40	35968	-70	10.31	328	-
21:34:42	35968	-101	9.94	328	TA
21:34:44	35968	-66	9.53	328	TA
21:34:46	35968	-62	9.12	328	TA
21:34:48	35968	-13	8.69	328	TA
21:34:50	35968	42	8.31	328	TA
21:34:52	35968	-65	7.88	329	TA
21:34:54	35968	-166	7.48	328	TA
21:34:56	35968	-155	7.11	326	RA Climb
21:34:58	35968	-168	6.69	325	RA Climb
21:35:00	35968	-451	6.31	323	RA Climb
21:35:02	35968	-705	5.91	322	RA Climb
21:35:04	35840	-1072	5.48	322	RA Climb
21:35:06	35840	-1117	5.09	323	RA Climb
21:35:08	35840	-1421	4.69	323	RA Climb
21:35:10	35712	-1871	4.30	322	RA Climb
21:35:12	35712	-1841	3.91	321	RA Climb
21:35:14	35584	-2025	3.52	321	RA Climb
21:35:16	35456	-2227	3.12	321	RA Climb
21:35:18	35456	-2347	2.73	319	RA Climb
21:35:20	35328	-2377	2.34	316	RA Climb
21:35:22	35328	-2212	1.96	315	RA Climb
21:35:23	35200	-2152	1.77	316	RA Climb
21:35:25	35200	-1920	1.40	315	RA Climb
21:35:27	35072	-1766	1.00	315	RA Climb
21:35:29	35072	-1957	0.63	314	RA Climb
21:35:31	34944	-1841	0.24	307	RA Climb
21:35:33	34944	-1335	0.00	162	RA Climb
21:35:34	34944	-1335	0	152	-



Processor card and de-soldered memory chip.

Note: Instead of the relative time scale of the ACAS/TCAS devices (elapsed time), the UTC time was included by the BFU.
Altitude: Resolution 128 ft, truncation, calculation based on a source with 25 ft resolution
V/S: Calculation based on altitude, resolution 25 ft
Intruder Range: Distance from the B-757-200 in nm
Intruder Bearing: Angle to the B-757-200 related to the longitudinal axis of the TU154M
The advisory "increase climb" was stored in the memory and the time of storage determined on the basis of the raw data was 21:35:24 hrs.

The following information (Altitude, V/S, and Advisory) is ACAS/TCAS data of the B-757-200 interrogated and stored by the TU154M computer:

Time (UTC)	Altitude (feet)	V/S (ft/min)	Advisory
21:34:32	35968	0	-
21:34:34	35968	0	-
21:34:36	35968	0	-
21:34:38	35968	0	-
21:34:40	35968	0	-
21:34:42	35968	0	-
21:34:44	35968	0	-
21:34:46	35968	0	-
21:34:48	35968	0	-
21:34:50	35968	0	-
21:34:52	35968	0	-
21:34:54	35968	0	-
21:34:56	35968	0	RA Descent
21:34:58	35968	0	RA Descent
21:35:00	35968	0	RA Descent
21:35:02	35968	0	RA Descent
21:35:04	35968	-377	RA Descent
21:35:06	35840	-624	RA Descent
21:35:08	35840	-1222	RA Descent
21:35:10	35840	-1462	RA Descent
21:35:12	35712	-1541	RA Descent
21:35:14	35712	-1987	RA Descent
21:35:16	35584	-2047	RA Descent
21:35:18	35456	-2640	RA Descent
21:35:20	35456	-2617	RA Descent
21:35:22	35328	-2700	RA Descent
21:35:23	35328	-2535	RA Descent
21:35:25	35200	-2370	RA Descent
21:35:27	35072	-2452	RA Descent
21:35:29	35072	-2422	RA Descent
21:35:31	34944	-2392	RA Descent
21:35:33	34816	-4260	RA Descent
21:35:34	34688	-4260	-

Note: Instead of the relative time scale of the ACAS/TCAS de-

vices (elapsed time), the UTC time was included by the BFU.
Altitude: Resolution 128 ft, truncation, calculation based on a source with 25 ft resolution (transponder reply of B-757-200)
V/S: Calculation based on altitude, resolution 25 ft
The advisory "increase descent" as an individual command was not transmitted to the TU154M. This command was recorded on the CVR at 21:35:10 hrs.

The ACAS/TCAS investigation team also examined the maintenance fault information from the processor card. The following six faults were recorded:

1. XT bus 2 failure
2. Radalt failure: no radalt #2 found
3. CFDS bus fail
4. XT bus 1 fail label error
5. XT bus fail no active XT
6. TA display 1 failure

Design engineers from the ACAS/TCAS manufacturer indicated that there was no current method to correlate the maintenance fault information to the event flight history information.

ACAS/TCAS operational findings

Based on the recovered data, the following time line shows the functions of the ACAS/TCAS computers after the identification, the positioning and the transponder interrogation:

21:34:32 hrs
The airplanes flew at FL360 (altitude difference was approximately 50 ft) and at a distance of 11.97 nm.
The ACAS/TCAS of the TU154M localized the B-757-200 at an angle of 325° (-35° related to its own longitudinal axis).

21:34:42 hrs
The ACAS/TCAS devices of both airplanes generated a TA simultaneously. The distance between the two airplanes was 9.94 nm.

21:34:56 hrs
The ACAS/TCAS devices of both airplanes generated an RA simultaneously because they continued to fly at the same altitude. The distance between the two airplanes was 7.11 nm.
The RA in the TU154M was "climb," "climb"
The RA in the B-757-200 was "descend," "descend"
(FDR data showed that both airplanes started to descend at 21:34:57 hrs.)

21:35:10 hrs
The distance between the two airplanes was 4.3 nm.
The ACAS/TCAS of the B-757-200 generated the advisory "increase descent."

21:35:24 hrs
The distance between the two airplanes was 1.54 nm.
The ACAS/TCAS of the TU154M generated the advisory "increase climb."
Both airplanes were still in descent with almost the same rate of descent and an altitude difference of less than 100 ft.

21:35:34 hrs
Collision of the airplanes.

Evaluation of the collision avoidance system logic (CAS logic)

Prior to the issuance of the RAs, the airplanes were in cruise flight with a vertical speed of almost zero and an altitude difference of approximately 50 ft.

Both airplanes reported their altitude in 25-ft increments. They tracked an altitude difference of one or two increments, whereas the B-757-200 was below the TU154M. Thus the altitude difference was the decisive factor for the selection of the direction of the RAs, CAS logic avoids crossing trajectories.

Following the RAs and the initiated avoidance maneuvers the calculated distance at the CPA (closest point of approach) normally increases until the ACAS/TCAS computer generates the aural annunciation "clear of conflict."

Due to the contrary reaction of the TU154M crew, the calculated distance to the B-757-200 at the CPA did not increase. 14 seconds after the initial RA the CAS logic of the B-757-200 generated an RA "increase descent" (increase the rate of descent from 1,500 ft/min to 2,500 ft/min) in order to resolve the persistent conflict.

The CAS logic of the TU154M also generated an RA "increase climb" (increase the rate of climb from 1,500 ft/min to 2,500 ft/min) 28 seconds after the initial RA.

The "increase" advisories are not coordinated between the ACAS/TCAS computers of airplanes involved in the encounter. ICAO Annex 10 states that CAS logic computes an extrapolated trajectory instead of using real tracked values. This leads to different times for the issuance of strengthening RAs in the airplanes involved.

When the crew of the B-757-200 complied with the advisory "increase descent," the altitude difference between the two airplanes decreased.

ACAS/TCAS II, Version 7, is capable of generating a reversal RA, i.e., a coordinated RA into a direction contrary to the initial RA. The reversal is a way out, if during the avoidance maneuver an inversion of the original geometrical situation of the flightpaths occurred. This situation will arise in particular if the crews respond contrary to the initial RA.

Eurocontrol ACAS/TCAS II analysis

A Eurocontrol ACAS/TCAS specialist team has analyzed the accident based on three ACAS/TCAS simulations. Three different data sources and two different analysing tools for ACAS/TCAS II were used.

It is the BFU's opinion that the following important insights can be drawn from the Eurocontrol study:

- The analysis confirmed that the TAs and RAs in both airplanes were triggered according to the design of the CAS logic.
- The simulation and the analysis of the alert sequence showed that the initial RAs would have ensured a safe vertical separation of both airplanes if both crews had followed the instructions accurately.

Moreover, Eurocontrol conducted a further analysis how TCAS II would have reacted in this case with the modification CP 112, which had already been developed prior to the accident. According to the results provided, ACAS/TCAS would have generated a reversal RA after the initial RA, which would have led to a sufficient vertical separation of both aircraft if the Boeing B-757-200 crew would have reacted according to the reversal RA.

Regulations and procedural instructions
As ACAS/TCAS II, Version 7, is designed as a semiautomatic system that shall serve as a "last line of defense" in collision avoidance, clear and unambiguous procedural instructions for the crews are an essential prerequisite. This prerequisite is so important because the system philosophy of ACAS/TCAS II, Version 7, provides only one procedure after the issuance of an RA and that is to follow the generated RA.

The decision to follow an RA without reservation could mean that up to the resolution of the conflict the crew has to divert from other obligatory standards, for instance, from instructions for vertical separation issued by ATC and from other general right-of-way rules.

Regulations of the International Civil Aviation Organization (ICAO)
In view of the international importance of ACAS/TCAS, the establishment and publication of standardized procedures by ICAO are an essential requirement.

ACAS/TCAS has been mandatory in the U.S.A. since 1993 and in Europe and the Middle East since 2000 but is not yet required in other parts of the world. Thus the installation of ACAS/TCAS was one prerequisite the operator of the TU154M had to fulfil in order to be allowed to fly to European destinations. For domestic flights within the Russian Federation, ACAS/TCAS is not presently required.

The publications of the ICAO concerning ACAS/TCAS are evaluated by the BFU as follows:

Annex 2:
In Annex 2 (Rules of the Air) procedural instructions for the utilization of ACAS/TCAS are not taken into account sufficiently. Though the wording, "*The aircraft that has the right of way shall maintain its heading and speed, but nothing in these rules shall relieve the pilot-in-command of an aircraft from the responsibility of taking such action, including collision-avoidance maneuvers based on resolution advisories provided by ACAS equipment, as will best avert collision.*" (Rules of the Air, Chapter 3. 3.2.2 Right–of–way), allowed a deviation from the right-of-way rules in case of a ACAS/TCAS RA. It did not make clear, however, the required consequent action to be taken by the pilot in case of an RA.

Annex 10:
The note, "*Contrary pilot response*" *[…]* was adequate and clear; however, its placement in Annex 10 was unfavorable as this Annex contains mainly technical specifications. A better place for this instruction would have been Annex 2 or Doc. 8168.

Doc. 8168, PANS-OPS:
In Doc. 8168 the "Operation of ACAS Equipment" was to be described. These objectives have not been achieved as the descriptions of the procedures were insufficient and unclear. With the statements, "*assists pilots in operation of the aircraft*" and *"Nothing in the procedures shall prevent pilots-in-command from exercising their best judgement and full authority in the choice of the course of action to resolve a traffic conflict.*" (3.1.1. and 3.1.2 of Doc 8168) The pilots were given freedom of decision, which according to the ACAS/TCAS philosophy must not be granted. The procedural requirement to comply with an RA and to immediately report the avoidance maneuver advised by ACAS/TCAS to the controller responsible for the vertical separation was not described clearly enough in the Doc. 8168. Thus the situation of a coincidence of an RA with an instruction given by the controller had not been dealt with either.

Doc. 4444, PANS-ATM:
With the publication of the Doc. 4444 a procedural description (15.6.3.2) has been issued for the Air Navigation Services pursuant to which the controller should not influence the flightpath in case the pilot reports a ACAS/TCAS RA, until the conflict has been resolved.

A prerequisite for the effectiveness of this procedural instruction is the timely report of a ACAS/TCAS RA via radio as an automatic transmission from the aircraft to the ground is not provided.

State Letter AN 11/19-02/82:
In the state letter dated Aug. 8, 1997, the procedures to react to an RA and the necessary training procedures were described much more clearly. The wording, however, did not comply with the procedural descriptions in Annex 2 and Doc. 8168, partially the interpretation was even contradictory.

TCAS 2000/TCAS II traffic collision and avoidance system pilots guide
The specifications of the ACAS/TCAS manufacturer's pilots guide regarding the ACAS/TCAS system philosophy and the necessary procedures that ensure a safe function were not described distinct enough. The wording "*TCAS 2000 is a backup to the ATC (air traffic control) system and the see-and-avoid concept*" could be interpreted that ATC takes priority over TCAS and that TCAS is designated to be implemental or a substitute. It was not made clear in the description of the system philosophy that ACAS/TCAS is exclusively meant as a "last line of defense" for the avoidance of a collision and that in this stage ACAS/TCAS advisories must be disconnected from instructions given by ATC controllers.

The TCAS 2000 pilots guide does not state clearly enough that the safe separation accomplished through ATC and the tasks of ACAS/TCAS are two different functions. It is not clear that ACAS/TCAS is not part of the conceptual design of ATC.

In the chapter "Pilot Responsibilities," a sufficient directness is missing. On one hand it talks about "backup for ATC," and on the other uses the following wording by contrary instructions of ATC and ACAS/TCAS.

- Must not delay in responding to the RA.
- Must not modify a response to an RA.
- Must follow the RA maneuver, unless invoking "Emergency Pilot Authority."

The descriptions in the TCAS 2000 pilots guide were the basis of ACAS/TCAS trainings within the operator companies and for the procedures in the S.

TU154M flight operations manual
The passage: *For the avoidance of inflight collisions is the visual control of the situation in the airspace by the crew and the correct execution of all instructions issued by ATC to be regarded as the most important tool. TCAS is an additional instrument that ensures the timely determination of oncoming traffic, the classification of the risk, and, if necessary, plan-*

ning of an advice for a vertical avoidance maneuver. Made clear that ATC has the highest priority in the avoidance of collision risks.

Regulations from Eurocontrol

All Eurocontrol publications for ACAS/TCAS introduction, training, and utilization have a recommending character.

All Eurocontrol documents expressed a clear ACAS/TCAS philosophy and clear rules of action and procedural instructions following the issuance of an RA.

Regulation from the JAA

The JAA Leaflet No. 11 had no legal significance in the accident as the States of registry and the States of the operators of both airplanes were not JAA member States.

National regulations and procedures

Aeronautical Information Publication (AIP) Germany:
The explanations in the Aeronautical Information Publication Germany concerning ACAS/TCAS were not up-to-date for ACAS/TCAS II, Version 7. With regard to contents several terms, e.g., "Evaluation of ACAS/TCAS," were related to the introduction phase.

The procedural instruction for the actions to be taken by the pilots in case of an RA was not worded clearly enough.

Luftverkehrsordnung (LuftVO—Air Traffic Order):
Pursuant to § 13 subpara 9 a deviation from the right-of-way rules was possible.

With the wording, "*This also applies to diversionary maneuvers that are based on recommendations given by collision-avoidance equipment on board,*" the pilots are granted a freedom of decision that is not compatible with the system philosophy of ACAS/TCAS II, Version 7. For the purpose of the ACAS/TCAS philosophy, the use of the term "recommendation" is inadequate. In case of an RA, there can be only one reaction of the pilots: to follow the RA.

Furthermore the wording allows two different kinds of interpretation:

The paragraph can mean that independent of the right-of-way rules an RA must be followed in order to avoid a collision.

The paragraph can also mean that the pilots have the option to deviate from the right-of-way rules and the ACAS/TCAS RAs in order to avoid a collision.

In theory it might be possible, in reality not really practicable. In principle it is correct to give the pilot the final power of decision; the pilot, however, has no better basis for his decision than ACAS/TCAS can give.

Advisory circular (AC) by the Federal Aviation Administration (FAA):

In the AC, which had no legal effect on the airplanes involved, the procedures following the issuance of an TA/RA as well as the responsibilities (for the individual flightcrew members) and the training measures were described clearly and unambiguously. The training program of the B-757-200 operator was based on this document.

Safety-related conclusions

- In case of failure by ATC to provide safe separation between aircraft, ACAS/TCAS provides an independent safety net in preventing mid-air collisions.
- ACAS/TCAS is an effective system, but its ability to fulfil its role is entirely dependent on correct and timely flight crew responses to collision-avoidance maneuvers calculated and displayed by the system.
- The procedure for pilots has to include the following elements:

—In the event of an ACAS/TCAS resolution advisory (RA) to alter the flightpath pilots shall respond immediately and maneuver as indicated, unless doing so would jeopardize the safety of the airplane.

—Never maneuver in the opposite sense to an RA, nor maintain a vertical rate in the opposite sense to an RA.

- The regulations concerning ACAS/TCAS published by ICAO and as a result the regulations of national aviation authorities, operational, and procedural instructions of the ACAS/TCAS manufacturer have to be standardized, clear, and unambiguous.

Note: Focus of this paper is an ACAS/TCAS point of view. Further investigation aspects concerning ACAS/TCAS in the BFU final report are human factors (HF) and training. A download of the final report is available at http://www.bfu-web.de/. ◆

The Role of Lessons Learned in The Investigate, Communicate, Educate Cycle for Commercial Aviation

By Dr. Paul Werner and Richard Perry, Sandia National Laboratories, U.S.A.

(This paper was submitted and accepted by the seminar's technical committee; however, because of unexpected circumstances, it was not orally presented.—Editor)

No photo available

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No photo available

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Aviation safety begins with safe aircraft. The safety of large transport airplanes operating in commercial service throughout the world has steadily improved over the last several decades. Nevertheless, accidents still occasionally occur. When they do occur, it is important to identify the root causes, precursors, and lessons learned of these accidents so that appropriate steps may be taken to reduce the risk of their recurrence. Safety lessons learned from aviation now spans several generations of safety managers and engineers. It is no longer possible for comprehensive knowledge to be exchanged from experienced safety individuals to the next generation of safety personnel through on-the-job training alone. The system is so complex that it is unlikely any one individual can possess truly comprehensive system safety understanding. It is necessary to adopt a more rigorous and systematic approach to lessons-learned safety training and management.

When presented with the data, facts, and histories available, it becomes painfully obvious that most, if not all, accidents followed one or more precursors or previous accidents that were not acted on for several reasons. The predominant reason is that those involved were unaware of the significance of what they had observed. This lack of awareness was due to a failure to view the event from the airplane level rather than the aircraft system, subsystem, or component level. Another reoccurring reason is that those involved were unaware of the existence of critical relevant information. These reasons are actually common throughout many industries and tolerated or accepted by most. It is unacceptable in commercial aviation.

The aviation industry cannot afford the time and resource costs, and the loss or non-use of important safety information. Work must go on and airplanes must fly. The lessons learned system must allow individuals to do their jobs more effectively and the aviation system to operate safer and more efficiently.

Such a system does not currently exist in the FAA. The need and urgency has been recognized and action taken to move in that direction. The first step is awareness and a transition to a different way of making decisions for regulatory and industry personnel at all levels doing their job.

Safety standards and the methods used to apply them must continually evolve due to advances in technology and demand for higher levels of safety. Each phase of the product life-cycle continuum impacts safety as information and experience derived from one phase is systemically applied to the other phases. Success of the entire continuum is dependent on effective safety management in each and every phase, capturing and using lessons learned from all phases of a product's life cycle to continuously improve standards, validate design assumptions, identify precursors, mitigate risk in safety related decision-making, and correct underlying sources of problems systemwide. Lessons learned from accidents are perhaps the most costly. It is vital to capture these lessons through investigation, communicate them to the appropriate organizations, and educate people to recognize and use these hard-learned lessons to proactively make commercial aviation safer.

Why lessons learned are important?

Lessons learned are defined as knowledge or understanding gained by experience. The experience may be positive, such as a successful test or mission, or negative, such as a mishap or failure. A lesson must be significant in that it has an impact on safety; valid in that it is factually correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result.

Establishing a culture where we capture and use day-to-day information and experience from certification, maintenance, and operational activities is crucial to improving aviation safety. By

doing so, we can expect to gain benefits that include
• documented guidance, information, and best practices passed on to less-experienced people,
• more-consistent safety decisions,
• improved safety by reducing accidents and preventing any repeat accidents, and
• reduction in safety problems caused by breakdowns in communication between design and maintenance or operation organizations.

The best way to learn and improve is to analyze previous experience and draw conclusions for future direction based on them. One way regulators capture lessons learned is through development of regulations, policies, and procedures. The following is a short and incomplete list of major transport airplane accidents that have helped shape U.S. federal aviation regulations (FARs) and policies:
• Ford Trimotor in U.S.—1930 (engine failure on takeoff)
• TWA L1049/UAL DC-7 near Grand Canyon—1956 (enroute ATC)
• Braniff L-188 near Buffalo, Texas—1959 (propeller whirl mode)
• U.S. operator/Viscount in Maryland—1962 (birdstrike to tail)
• Northwest L-188 near Cannelton, Indiana—1960 (propeller whirl mode)
• Eastern L-188 at Boston—1960 (bird ingestion to engines)
• Pan Am B-707 near Elkton, Maryland—1963 (lightning strike to fuel tanks)
• United B-727 at Salt Lake City—1965 (stretchable fuel lines)
• Pan Am B-707 at San Francisco—1965 (rotor burst)
• Mohawk BAC1-11 in United States—1967 (APU inlet fire)
• U.S. carrier B-727 at Los Angeles Int. Airport—1969 (human factors, cockpit switches)
• Air Canada DC-8 near Malton, Ontario—1970 (human factors, spoilers)
• Eastern L-1011 near Miami—1972 (human factors, ATC)
• VARIG B-707 near Paris—1973 (smoking/waste bin fire in lavatory)
• Turk Hava Yollari DC-10 near Paris—1974 (pressure relief, human factors)
• Lufthansa B-747 near Nairobi—1974 (takeoff warning, human factors)
• TWA B-727 near Berryville, Virginia—1974 (human factors, ground prox.)
• Eastern B-727 near New York City—1975 (windshear)
• KLM B-747/Pan Am B-747 at Tenerife—1977 (human factors, ATC)
• Southern Airways DC-9 near Atlanta, Georgia—1977 (rain ingestion to engines)
• Pacific Southwest Airlines B-727 at San Diego, California—1978 (human factors, TCAS)
• United Airlines DC-8 near Portland, Oregon—1978 (human factors, low fuel warning)
• American Airlines DC-10 at Chicago, Illinois—1979 (system isolation, human factors)
• Saudia L-1011 near Ryiadh, Saudi Arabia—1980 (interior fire, human factors)
• Air Florida B-737 at Washington, D.C.—1982 (human factors, airframe/engine icing)
• British Airtours B-737 at Manchester, England—1985 (fuel tank access covers)
• Delta L-1011 at Dallas, Texas—1985 (windshear)
• Japan Air Lines B-747 near Tokyo—1985 (system isolation, pressure venting)
• Mexicana B-727 near Maravatio, Mexico—1986 (wheelwell fire)
• Northwest DC-9 at Detriot—1987 (human factors, takeoff warning)
• South African Airways B-747 in Indian Ocean—1987 (cargo compartment fire)
• Aloha Airlines B-737 in Hawaii—1988 (structural corrosion)
• American Airlines DC-10 at Dallas/Ft. Worth—1988 (break wear)
• TACA B-737 near New Orleans, Louisiana—1988 (hail ingestion to engines)
• United Airlines B-747 in Hawaii—1989 (structural inspection)
• United Airlines DC-10 near Sioux City, Iowa—1989 (system isolation, engine inspections)
• USAir Jetstream 3100 at Beckley, W. Virginia—1991 (tail plane icing)
• Lauda B-767 near Bangkok, Thailand—1991 (thrust reverser inflight deployment)
• American Eagle SF340 near New Roads, Louisiana—1994 (propeller beta in flight)
• Simmons Airlines ATR 72 near Roselawn, Indiana—1994 (freezing rain)
• ValueJet DC-9 near Miami—1996 (haz. mat., cargo fire protection)

What are the attributes of a successful lesson-learned process?

Development and implementation of an effective lessons learned process is critical for improving aviation safety. Ideally, it would be an integrated, common infrastructure that captures and provides access to lessons learned safety information throughout a product's life cycle. As such, a successful lessons-learned process would have the following characteristics:
• A structured process for incorporating lessons learned into rules, policies, and procedures for certification, maintenance, and operations. The process should ensure that in-service lessons learned are incorporated in design or certification methods of compliance, and results of project-specific decisions are easily accessible by other certification projects.
• Use of a disciplined, data-driven approach to find root causes and determine the best actions to break the chain of events that lead to accidents.
• A process that includes periodic reviews and feedback. This should be a unique task from daily business for a "look back" and should ensure reviews are conducted at regular intervals.
• A process that ensures corrective actions are implemented for all root causes assessed, so that underlying sources of problems are corrected systemwide.

What are the barriers to capturing and using lessons learned?

Several observations have been noted across diverse industries regarding effective capture and use of lessons learned. First, most organizations strive to reuse all kinds of documented experience, but that it is not easy to do so in an effective manner. The reuse is rather ad hoc and unplanned, and it is often hard to know what to search for or how to find useful documents. Another observation is that the "right" knowledge for solving a problem often exists somewhere within the organization, but the challenge is to take the time to search for it, identify it, get access to it, and then learn from it. Due to the fact that experience is represented internally by experts, the major problem is often finding and getting access to the "expert" in order to solve a problem.

In today's complex and fast-moving aviation system, engineers and inspectors often don't have the time to do extensive research and analysis of aircraft accidents and incidents. Instead, they must rely on their experience and training, and possibly the insight of others. So, why are lessons not learned?

- Cultural barriers such as the lack of time to capture or submit lessons and a perception of intolerance for mistakes,
- Organizational barriers such as communication across companies or lines of business is often difficult or nonexistent,
- Lessons are not routinely identified, collected, or shared across organizations and industry due to a lack of communication or other factors, and
- Unorganized lessons are hard to use with too much material to search; it may be formatted differently for different accident reports; the information needed is not available; it's not quickly available; or work pressures don't allow the time or resources.

Critical concepts

The concepts discussed in this section are critical to the identification of design and certification lessons learned from accidents. First, let's look at aircraft-level awareness.

Aircraft-level awareness

When presented with the data, facts, and histories available, it becomes painfully obvious that most, if not all, accidents followed previous events that were not acted upon because someone was unaware of the significance of what they observed. Often this was because they failed to view the significance of the event at the airplane level rather than the system, subsystem, or component level. In most cases, those involved were unaware of the existence of critical relevant information, i.e., lessons learned.

A conclusion from many of the accidents reviewed during the Commercial Airplane Certification Process Study (March 2002) was that adequate processes do not exist within the FAA or in most segments of the commercial aviation industry to ensure that the lessons learned from specific experiences in airplane design, manufacturing, maintenance, and flight operations are captured permanently and made readily available to the aviation industry. Consequently, the failure to capture and disseminate lessons learned has allowed airplane accidents to occur from causes similar to those of past accidents. In response to this concern, Change Area 1.C, Precursor Awareness, was tasked to specifically: *"Develop AVR airplane-level awareness for improved identification and risk assessment of accident precursors. Define methods to capture, share, and use lessons learned information throughout industry and the life cycle."*

Precursors

The role and importance of accident precursor recognition cannot be over emphasized. Precursor data can be a valuable source of information for decision-making, either directly or as a supplement to risk analysis. Moreover, precursor data inherently incorporate the effects of factors such as human errors and intersystem dependencies.

Accident precursor identification should identify latent and potential design, certification, and operational safety issues and correct them before they become accidents through

- comprehensive monitoring, sharing, and use of design and operational safety information and a consequent growth in the understanding of current and emerging accident precursors and direct causes.
- immediate certification and operational interventions at the regional, national, and international levels.

Precursor events can be any service information or experience or test or inspection data that could be interpreted as a predictor that the event consequence could occur if the event conditions were present. Accident precursor data can be from any discipline (e.g., risk analysis, statistics, engineering, ergonomics, psychology, sociology, organizational behavior).

Daniel Cheney of the Federal Aviation Administration suggested the following definitions of Precursor Types:

Type 1: Precursors with no protection or mitigation elements associated with the prevention of the event initiation, progression, or consequences. Types 1 are the most potentially serious of all precursor events.

Type 2: Precursors with no consistent or dependable protection or mitigation elements associated with the prevention of the event initiation, progression, or consequences. Nearly as potentially serious as Type 1, but may have an opportunity for intervention by flight crew, ground crew, or others.

Type 3: All other precursor events—those that have at least one consistent or dependable protection or mitigation element associated with the prevention of the event initiation, progression, or consequences. Type 3 precursors require at least one other condition in addition to the event condition to occur. These represent the vast majority of service information (i.e., data) used in the safety-oversight process.

An example of a Type 1 precursor for the 1979 American Airlines DC-10 crash would be the 1978 pylon flange failure on a Continental Airline DC-10 during maintenance. This incident was essentially masked in trivia in a report circulated to other airlines and did not specifically identify that the failure was related to the method used to remove the pylon.

Precursors are not just technical in nature. The DC-10 example also shows how precursors can be related to procedural/human factors, political events, and decisions. Accident precursor recognition is a vital part of a proactive intervention strategy and needs to be an important part of any safety management program.

Root causes

A driving reason for investigating accidents is to prevent future accidents. By identifying root causes (a cause is a set of sufficient conditions—each is necessary but only together are they sufficient), we can potentially avoid a whole "class" of accidents. Unfortunately, there is significant variation in people's perceptions of accidents. For example,

- viewing accidents as a single event. This often includes regulatory compliance/violation thinking.
- linear chain-of-events thinking, like knocking over a row of dominos.
- statistical analysis methods.
- viewing an accident as a process involving concurrent actions by various actors to produce an unintended outcome.

At the heart of root-cause analysis is the knowledge that things do not just happen. Events are caused to happen, and by understanding the causes we can decide which ones are within our control and manipulate them to meet our goals and objectives. Root causes can be defined as the first factor in a chain of events that can be controlled through a regulation, policy, or standard. It is a point in the chain of events at which internal control can be exercised. Simply put, they can be found by stating the end-result and keep asking "why?" until you have found a factor that can be corrected by the application of a regulation/policy/standard at the governing/management, implementing, or individual level, or you have reached a non-correctable situation. There may also be insufficient data to proceed further.

There is a strong link between root causes, decision-making, and lessons learned, especially in

- establishment and communication of a regulation or policy,
- application of a regulation or policy,
- establishment and communication of monitoring and oversight, and
- enforcement of that regulation or policy, based on monitoring and oversight.

System safety

In commercial aviation, a single accident is often disastrous. One obvious lesson from the short history of aviation is that most accidents are not the result of unknown scientific principles but more likely result from the failure to apply well-known engineering practices. A valuable lesson is that technology alone will not provide a solution; another lesson from history is that the non-technical issues cannot be ignored. Safety requires control of all aspects of the development and operation of a system. System safety covers the entire spectrum of risk management, from design of hardware to the culture and attitudes of the people involved.

Safety is a property of a system. For example, determining whether an aircraft is acceptably safe by examining the landing gear, or any other component, is not possible. Talking about the "safety of the landing gear" out of context of the aircraft and how it operates is really meaningless. Safety can only be determined by the relationship between the landing gear and other aircraft components, that is, in the context of the whole aircraft and its environment.

A systems approach provides a logical structure for problem solving. It views the entire system as an integrated whole. To make the system safe, we must manage safety (risk) and we must assess safety. Management is what is done to ensure safety (limit risk), and assessment (surveillance, in this case) is what is done to determine whether the results are satisfactory. One cannot be practiced without the other to have a positive impact on safety.

System safety is characterized by the systematic identification and control of hazards throughout the life cycle of a system. It calls for the timely identification of system hazards before the fact and emphasizes the designing an acceptable level of safety into the system.

Some basic concepts of system safety are

- Safety should be built into the system, not added on to a completed design.
- Safety is a property of the system, not a component.
- Accidents are not always caused by failures and all failures do not cause accidents.
- Analysis to prevent the accident is emphasized instead of reacting to the accident.
- Emphasis is on identifying hazards as early as possible and then designing to eliminate or control those hazards (more qualitative than quantitative).
- Recognize tradeoffs and compromises in system design.
- System safety is more than just systems engineering.

Design safety concepts

Aviation safety begins with safe aircraft. The safety of large transport airplanes operating in commercial service throughout the world has steadily improved over the last several decades. Many techniques are used to achieve a safe design and include

- design integrity (will not fail or has very high margins, e.g., propellers, landing gears, turbine rotor discs) and quality
- redundancy
- isolation
- reliability
- failure indication
- flight crew procedures
- checkable/inspectable
- damage tolerance
- failure containment
- designed failure path
- margins/factors of safety
- error tolerance

Four basic elements of design safety (U.S. transport-category aircraft)

ELEMENT NO. 1. Basic Design Philosophy and Methodology

The design philosophy governs the overall design approach, establishes design criteria, and dictates failure assumption.

The fail-safe philosophy is the chosen basic design philosophy and from this has emerged the fail-safe design concept; i.e., "no single failure or probable combination of failures during any one flight shall jeopardize the continued safe flight and landing of the airplane."

Design safety precedence:

- Design to minimum hazard—Design the hazard out. If it cannot be eliminated, minimize the residual risk.
- Use safety devices—Do this by incorporating a fail-safe mode, safety devices, or fault-tolerant features.
- Use warning devices—Done through measuring devices, software, or other means. The warning should be unambiguous and attract the operator's attention.
- Use special procedures—Used when the above means are unable to control the hazard.

ELEMENT NO. 2. The Official Code of Airworthiness Design Standards for Transport-Category Aircraft, Engines, Propellers, and APUs. This is the legal codification of Element No. 1 and is usually referred to as the type certification code. The legal design safety code specifies how the design safety methodology is to be applied; what general or specific design safety methods are to be incorporated; what, if any, specific exceptions are to be allowed; and, any specific additions.

FAR Parts 25, 33, and 35 are the legal codifications of the basic "fail-safe design concept" that was developed by the U.S. aircraft transport industry over a period from the days of the Ford Trimotor of the 1920s until the present day.

ELEMENT NO. 3. The Type Design Check.
The purpose of the "design safety check" is to verify or validate that the design does in fact meet the required minimum safety standards embodied in Elements 1 and 2. The "Type Design Safety Check" is formally completed with the issuance of an FAA type certificate. The design safety check also includes the manufacturer's in-house safety assessments, flight, and laboratory test programs, qualification test programs, and the FAA Type Design Certification Program.

ELEMENT NO. 4. The Official Accident Investigation and the Finding of Probable Cause.
This includes an official public report of the accident findings. The knowledge contained in the findings, especially the lessons learned, is used to improve and strengthen the design philosophy, code and checks of Elements 1, 2, and 3.

Safety and reliability

System safety and reliability are often confused. Although similar, it is important to first understand the difference between the two. Fundamentally, the two disciplines ask and seek to answer two different questions about two different concepts. Reliability asks, " How often does something fail?" System safety asks, "What happens (to the system) when something fails or behaves unexpectedly?" Although it is obviously concerned with system failure, reliability is usually concerned with individual parts. Remember, a reliable system is not necessarily a safe system.

As applied to civil aircraft designed to FAR 25, safety is not reliability. As standards, they are related but distinctly different concepts with different objectives. Both are concerned with the causes of failure. The difference is, briefly, reliability is concerned with the frequency of failure and safety is concerned with the impact of failure. An aircraft design can be safe but unreliable, it can be reliable but unsafe, and it can be safe and at the same time reliable. Safety and reliability are essentially related, independent design parameters that tend to complement or oppose each other but one cannot be substituted for the other. The type certification process finds an aircraft design to be in compliance only with safety standards; it does not and cannot establish the reliability level of the design.

Design integrity

The probability of failure of an aircraft component is controlled by its design specification, including its qualification testing, and is a measure of its design integrity. The concept of design integrity is concerned with the quality of the design and its ability to perform its intended functions as required by the design specification and FAR 25.1309(a). Design integrity is generally established through the qualification testing of individual aircraft components to their design specification requirements. Design integrity is an integral part of the basic aircraft safety concept. The achieved reliability of a component in service is a measure of its design integrity. The operator's approved maintenance program and the operator/manufacturers product improvement program control the reliability of an approved aircraft design.

Aircraft-centered system

As discussed earlier, accidents, and consequently the lessons learned, are products of system interactions. Therefore, it is critical to have at least a minimal understanding of all the subordinate elements and how they behave as a system in order to identify, understand, and apply lessons learned.

The hierarchical breakdown used here is consistent with and adds to the Air Transport Association (ATA) index. This breakdown provides a familiar structure and is consistent with normal systems engineering practice. It is convenient for lessons learned because it groups subsystems together technologically. The aircraft is broken down as

Airframe—This element includes wing, fuselage, and empennage.
Mechanical—This element includes landing gear, hydraulics, flight controls, and cargo loading equipment.
Electrical—This element includes electrical power and lighting.
Propulsion—This element includes the engine pod and pylon and their components, fuel components, and thrust management components.
Avionics—This element includes communication, navigation, and aircraft monitoring equipment.
Environmental—This element includes cabin pressure, air conditioning, and oxygen equipment.
Interior—This element includes crew and passenger accommodations.
Auxiliary, other—This element includes auxiliary electrical and pneumatic power supplies.

Other factors in aircraft accidents

Aging aircraft—The average age of the U.S. commercial aircraft fleet today already exceeds 75 percent of the typical nominal 20-year design life of a passenger aircraft. Significant attention must accordingly be given to better understanding and quantifying the mechanisms of aircraft aging. If these failure mechanisms are left unchecked, the significantly longer times in service that can be anticipated could lead to a significant increase in the accident rate.
Human factors—Basic automated flight control systems and electromechanical displays are giving way to new generations of jet transport aircraft equipped with highly automated flight management systems and flat panel or liquid crystal displays. The new technology has significantly changed the work of airline pilots and has implications for all elements of the aviation system, especially design and safety regulation. Air safety investigators and researchers worldwide have witnessed the emergence of new human-factors problems related to the interaction of pilots and advanced cockpit systems.
Environment—This is the environment external to the aircraft. Weather is the probably the most prominent factor.
Maintenance, operations—Maintenance and operational events are the primary source of information for accident precursors and lessons learned.
Regulations, policies, standards—Past lessons learned are often captured in regulations, policies, and standards. Most accidents have factors related to the absence of or misapplication of such guidance and direction. Accident precursor information and lessons learned are a valuable source to aid in interpretation, implementation and certifications decisions.
Software—All commercial transport aircraft designed and built within the last 15 years have some computer technology, mostly in the cockpit. The computers are intended to make flying easier and safer, and in general they do. But when things don't happen

as expected, it can be hard to figure out quickly what's going on, and how to deal with it. The safety of an aircraft depends on designing and building it to the highest standards of safety we know and the same goes for its computer systems. Careful attention must be paid to how well we design and build those computer systems.

Most accidents will have lessons learned in more than one of the elements mentioned above and involve one or more of the concepts and factors discussed.

Conclusion

Lessons learned are defined as knowledge or understanding gained by experience. The lessons learned system must allow individuals to do their jobs more effectively and the aviation system to operate safer and more efficiently. Safety standards and the methods used to apply them must continually evolve due to advances in technology and demand for higher levels of safety. The first step is awareness and a transition to a different way of making decisions for regulatory and industry personnel at all levels doing their job.

The role of lessons learned in the *investigate, communicate, educate cycle* for commercial aviation can not be overstated. It is a necessary part of the organizational safety strategy involving continuously improving standards, validating design assumptions, identifying precursors, mitigating risk in safety-related decision-making, and correcting underlying sources of problems systemwide. ◆

Underwater Recovery Operations off Sharm el-Sheikh

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Abstract

On Jan. 3, 2004, Flash Airlines Flight FSH604, a Boeing 737-300 registered as SU-ZCF, operating as a chartered flight from Sharm el-Sheikh, Egypt, to Paris, France, crashed into the Red Sea approximately 6 nautical miles southwest of the airport.

This article covers the recovery operations that took place after the accident. It encompasses several aspects of these operations, such as:

- the legal and emotional context of the investigation.
- the difficulties related to the undersea environment (1,000-meter depth).
- the strategies developed by the international investigation team with the assistance of the Egyptian and French navies.
- the use of additional resources (boats, ROVs, etc.) needed to cope with the different steps: pinger location, seafloor mapping, tidal survey, etc.
- the chronology of the operation with priority given to the recovery of bodies and the location of flight recorders (FDR and CVR) while mapping the wreckage.

The wreckage recovery was based on the review of the FDR and CVR data undertaken in Cairo. Teamwork proved to be key in the success of this operation with each contribution improving the effectiveness of this joint effort.

Sharing the knowledge gained during this experience will help other investigators facing the aftermath of an occurrence similar to the Sharm el-Sheikh accident.

Introduction

Underwater recovery operations were carried out jointly by Egypt and France following the accident on Jan. 3, 2004, off Sharm el-Sheikh of the Boeing 737-300, registered SU-ZCF, operated by Flash Airlines. This article will outline the strategy that was used for the search and recovery of the flight recorders. The chronology of the search, the wreckage mapping, as well as the recovery of airplane parts will also be discussed. Recovery operations took place from Jan. 3-Feb. 5, 2004.

The initial search for possible survivors and the recovery of bodies were priorities for the rescue and investigation teams.

The accident triggered a lot of emotion in France because of the large number of French victims [1]. The complex international situation and the rather mysterious nature of the accident raised many questions. Speculation on safety (airworthiness of the airplane) and on security (possible terrorist attack) led to intense media coverage while the initial results of the technical investigation were awaited.

Two judicial investigations, coordinated through an international commission of inquiry, were launched in France and Egypt in the aftermath of the accident. Of course, the investigation of a civil aviation accident comes within the framework of the Chicago Convention, to which both Egypt and France are signatories. Annex 13 to this Convention details the responsibilities of the different States involved in the occurrence.

The technical investigation, carried out by the Egyptian Investigation Commission, with the participation of the United States (the NTSB) and France (the BEA), is charged with finding answers as to why this accident occurred. The investigation team was composed of specialists from the Egyptian CAA, Flash Airlines, the NTSB, the FAA, Boeing, SNECMA and the BEA.

The salvage operation was the first step in the investigation, and the underwater recovery operations were undertaken by ships and equipment provided by the Egyptian and French navies. To this end, the French Navy mobilized considerable resources, both human and material. In addition to the frigate *Le Tourville* and the fleet support *La Somme*, two salvage ships (*Ile de Batz, Janus II*) equipped with underwater robots were chartered by the French government to complete the operation. This required a great deal of coordination between the various parties in order to provide rapid answers to the many questions raised by the disaster.

Preparatory work: finding the wreckage depth and recovering the recorders

Before committing the naval resources, it was essential to get more information on the wreckage site. Parts that were found floating on the surface, and the initial witness statements collected were not sufficiently precise to allow the wreckage of the plane to be located. Moreover, the seafloor was not thoroughly charted and varied in depth between 100 and 1,420 meters over relatively short distances.

A flight recorder immersed under water can be located by the signals (1 bip/second with 37.5 kHz (±1 kHz)) transmitted by the beacon (pinger) attached to the recorder. This pinger starts as soon as it is in contact with water and is designed to transmit this signal for at least 30[2] days.

Equipment from the BEA and the French Navy was used. The BEA's portable equipment, consisting of a directional hydrophone, could not pick up any signals.

The French Navy used an acoustic detector assembled on a pole called "Helle," which tracks signals on frequencies ranging from 7 to 50 kHz. This detector has two reception antennae, one omnidirectional and the other directional. It was connected to an audio system that controlled the frequencies and was coupled with a global positioning system.

The first stage in the search consisted of checking signal transmissions and defining an general area using the omnidirectional antenna. Because the seafloor was uncharted, locating the beacons was complicated by possible reflections from the transmitted sound waves and possible secondary echoes. The next stage consisted of taking successive bearings using the directional antenna to get a more precise fix.

This acoustic search determined two possible positions for the beacons: one to the south with a position considered as nominal since it could be picked up from all bearings, but which was transmitting more weakly than the one identified further north. The measurements and calculations performed gave an estimated depth of around one thousand meters.

To confirm these results, the USBL (ultra short base line—acoustic positioning) of the *Ile de Batz* (the first recovery ship on site) was temporarily modified (in coordination with its manufacturer Sonardyne) and adapted to the reception of the signals transmitted by the southern pinger. These results confirmed the presence of a transmission source beneath the *Ile de Batz,* which had been positioned directly above the estimated position.

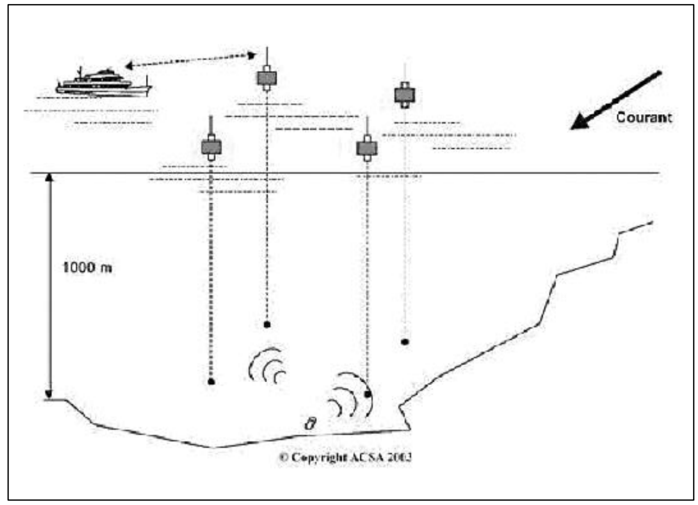


Figure 1: GIB system.

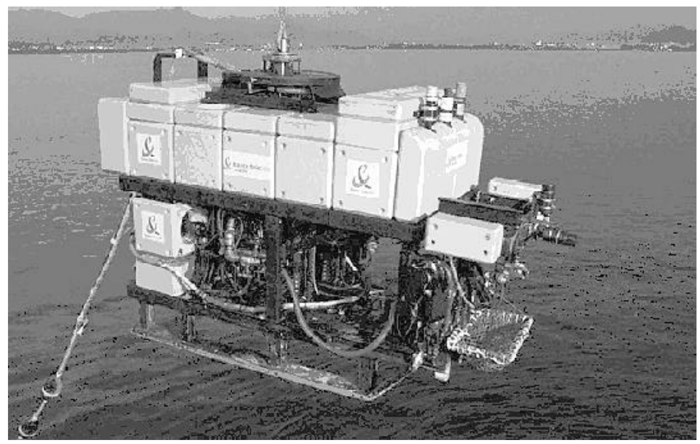


Figure 2: Scorpio ROV operated from **Ile de Batz.**

Use of a GIB system

To narrow the search area, the French Navy contracted ACSA and its partner ORCA Instrumentation to supply a GIB system (GPS intelligent buoys). For the purposes of the investigation, they adapted a network of four acoustic receivers to conduct a search at a depth of around 1,000 meters.

The hydrophones, immersed 450 meters down around the initial identified position, drifted with the current while continuously transmitting information on their position and any signals received (Figure 1). An algorithm integrated all data to determine the recorder's fixed position.

The use of a GIB system proved to be essential in this context since the ROV (remotely operated vehicle) only used visual means to search for the recorders and could not be guided by acoustic information to home in directly on the beacons. The FDR was ultimately found in the area defined by the Navy, just 12 meters from the position computed by ACSA.

Bathymetric data

The French Navy sent the oceanographic hydrography ship, the *Beautemps-Beaupré*, to carry out multi-beam sonar bathymetry of the accident area. It drew up a chart of the seafloor with fifty meter isobath. This knowledge of the topography facilitated ROV operations on the seafloor.

Support ships and ROVs

The *Ile de Batz*, owned by Alcatel (LDA), was designed to lay and maintain submarine communication cables, and is ideally suited for this type of search mission. This powerful ship is equipped with dynamic positioning II (DP II), enabling it to maintain its position at a given point in spite of adverse weather conditions. The *Ile de Batz* is approximately 140 meters long and can operate at great depths. The Scorpio ROV (work class, see Figure 2), provided by France Télécom Marine (FTM), was installed with its 50 tons of equipment on the ship's main deck.

The *Janus II*, owned by Comex, is a 30-meter aluminum semi-swath catamaran equipped with dynamic positioning. This ship can be used to support the Remora 2000, a twin-seat submarine that can operate down to 610 meters, and the Super Achille ROV (observation class), which can operate down to 1,100 meters.

The Super Achille is a light unit and can be remotely controlled via its lifting cable from the *Janus II*. A "garage" cage was lowered vertically from the ship by a winch located on the main deck. Once at its working depth, Super Achille exited the cage attached via a 70-meter floating cable, controlled by a winch at the top of the cage (tether management system). The ROV was equipped with a transponder acoustic beacon controlled through the *Janus II*'s USBL; it was also used as a DP reference and was continuously positioned on the integrated navigation system. A record could thus be kept of the ROVs movements and its position in relation to the garage, which was also equipped with a transponder.

This gave the robot mobility by not hindering its movements through the drag from around a thousand meters of connecting cable.

Procedure for handing over the recorders by the BEA to the Egyptian commission

The readout of the flight recorders was to be undertaken in Cairo, since Egypt had just been equipped with a technical laboratory.

It was important to have an agreed official procedure for handing over the recorders from the French to the Egyptian authorities since the recorders were to be recovered from Egyptian territorial waters (Egyptian jurisdiction) via a ship flying the French flag (French jurisdiction).

It was also necessary to satisfy news media requests for images. An official photographer took photographs of the recoveries of the recorders (which in both cases happened at night). They were quickly put on line on the BEA website.

So as not to hinder salvage operations, the zone had been secured by the Egyptian Navy. The BEA officially delivered the recorders to the Egyptian Commission in Sharm el-Sheikh harbor in the presence of journalists. The Egyptian judicial authorities then affixed seals for their transfer to Cairo.

FDR recovery

The Scorpio robot started searching for the recorders using its cameras based on an initial determination of the position of its beacon. This position was then refined by the ACSA system. That produced a theoretical position with a precision of plus or minus 10 meters over 100 meters.

Squares of 20 x 20 meters were systematically searched by the ROV. While finishing one run, this visual search finally led to the discovery of the FDR, which was in fact located approximately 12 meters from the estimated position.

CVR recovery

The search for the second recorder required making some further tactical choices. Since the beginning of the operations, the echo from the second beacon had appeared to be located a few hundred meters north of the initial search area. At that time, results from ACSA computations were not yet available.

For accidents with high-impact forces, accelerations at the time of the collision may separate the pinger from the recorder case. This assumption was considered plausible on the basis of the initial information gathered.

Two approaches were then possible:

- to wait for the absolute position of the northern echo to be determined on the basis of the ACSA computations processed in deferred time,
- to continue the search in the area where the FDR had been found, supposing that the pinger had been detached from the CVR.

The second option was chosen. On the basis of the initial analysis of wreckage distribution, it was decided to define a zone to the

Figure 3: Investigators' workroom.

Figure 4: Underwater picture taken by Super Achille.

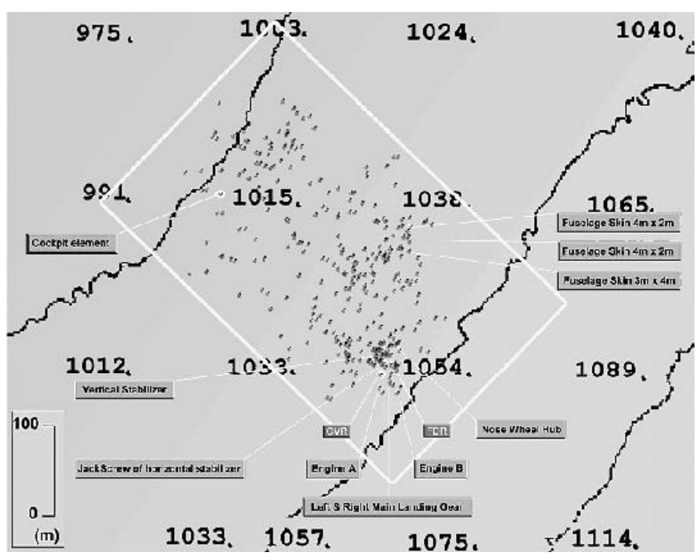


Figure 5: Wreckage distribution.

south of the position of the FDR. The CVR was found approximately 24 hours after the discovery of the FDR just outside the search area designated by the investigators. Its case was damaged more than the FDRs, its reference numbers and the pinger had separated.

The use of a large television screen connected to the panoramic camera helped in identifying its position (see Figure 3) as the CVR was spotted during a 180-degree turn between search lines. The facilities on board the *Ile de Batz*, which contributed greatly to enhanced teamwork and coordination, were a key element in the rapid recovery of the recorders.

Mapping the wreckage

Exploration of the seafloor was organized by defining rectangular zones extending outwards from the central area. Each zone was then divided into grids with the side of each square being 3 to 5 meters, depending on the ROV used and the specific objectives.

During these operations, it was important to have aeronautical specialists who were able to coordinate the search and identify the debris. Each Scorpio and Super Achille ROV dive was filmed. On board the *Ile de Batz*, the workroom was equipped with a video recorder, which allowed some dives to be reviewed during ROV maintenance.

The digital video system on the Super Achille was also able to take digital stills of the airplane parts considered interesting to map and examine (see Figure 4: flight manual) with the still featuring an inset with parameters such as latitude, longitude, depth, heading, etc.

The various parts located and identified during the dives were entered in a database. Parameters such as the date, the position, a brief description, and photographic references provided useful information for the investigation and could thus be easily accessed (this database contains approximately 400 located and identified wreckage parts).

Figure 5 shows the wreckage distribution and the extent of the search area (a rectangle 440 by 275 meters). The Super Achille also traveled on the seafloor towards the location of the northern echo, search a 100 x 100 meter square and did not find any pieces of wreckage nor the pinger.

The wreckage distribution is compatible with the last recorded heading (311°) and the northeast current measured by the *Beautemps-Beaupré*. The heavy parts (engines and main landing gear) were close to the point of impact whereas lighter debris drifted with the prevailing current during their 1,000-meter descent.

Recovery of airplane parts

The strategy for airplane parts recovery was developed after initial flight recorder readouts undertaken in Cairo. All parts related to airplane control surfaces, flight systems, and flightdeck panels were regarded as priorities.

A procedure was developed to record the description, dimensions, and coordinates of the parts recovered by the investigators, following their first observations. A database made it possible to establish the link between these parts and the photographs taken on the ship's deck or on the seafloor.

A specific nomenclature was also adopted:

- FW (floating wreckage) for the floating debris r ecovered in the first few days after the accident,
- SW (surveyed wreckage) for the debris surveyed on the seafloor,

Figure 6: Rudder recovery.

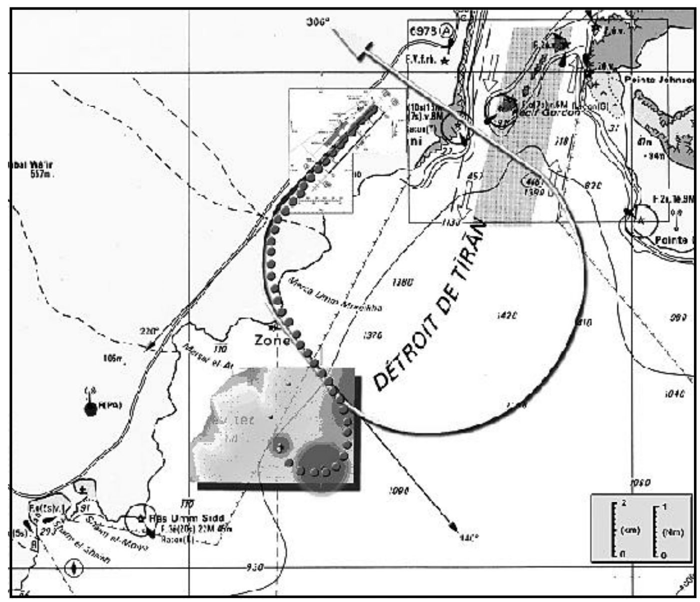


Figure 7: Combined data on one map.

- RW (recovered wreckage) for debris recovered, and
- PE (personal effects) for the personal effects.

Fifty-five items were recovered, identified, and referenced as floating debris and around 50 parts were recovered from the seafloor and in turn referenced.

The work performed jointly by the *Janus II* and the *Ile de Batz* (both with dynamic positioning) made it possible to recover large parts such as the rudder and the elevator (Figure 6).

All salvaged parts were preserved in sea water until unloading at the naval port of Sharm el-Sheikh and handover to the Egyptian authorities.

Recovery of personal effects

Some items of clothing were recovered. On several occasions, they jammed the propellers of both ROVs. Their slightly positive buoyancy made handling and recovery difficult.

Some items fell out of the recovery basket during the 1,000-meter lift to the surface. Personal effects recovered included watches, cell phones, bags, wallets, etc.

When possible, some personal effects were recovered progressively during the search operations. The majority of these personal effects was then recovered by the *Janus II*, which remained at the accident site longer for that purpose.

It covered the central zone where most of the personal effects were located. The *Janus II*'s mission at Sharm el-Sheikh came to an end when everything possible had been recovered.

Conclusions

The recorders were recovered in less than 2 weeks, although they were in a relatively uncharted area about a thousand meters deep. Figure 7 combines a maritime map, airfield data, bathymetric data, and the airplane track from the FDR readout.

The success of the operations was mainly due to the preparatory work undertaken by the Navy, which meant that appropriate equipment and personnel could be sent to the site quickly. The investigation team was then able to define the most effective strategy to find and recover the recorders in the shortest possible time.

The logistical support was a significant part of the success of the operations. The support ships' adaptability and the hard work of their crew made the joint recovery efforts more complementary, and thus more effective. The Navy's decision to deploy the ACSA system also contributed greatly to reducing the amount of time needed for the search. The mobility, adaptability, and the image quality from the Super Achille made it possible to cover the site methodically and to recover many personal effects.

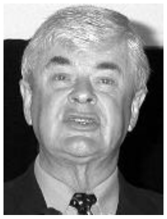
Teamwork proved to be key in the success of this operation with each contribution improving the effectiveness of this joint effort. Sharing the knowledge gained during this experience will help other investigators facing the aftermath of an occurrence similar to the Sharm el-Sheikh accident. ◆

Endnote

[1] Of the 148 people on board, 134 passengers were of French nationality. The last two aviation tragedies involving large numbers of French passengers were those at Mont Sainte-Odile (near Strasbourg, with 87 fatalities in 1992) and the bombing of the UTA DC-10 (171 fatalities in 1989).

ISASI 2004 Theme

By Dr. Rob Lee



Dr. Rob Lee is an international consultant on human factors and systems safety. He was formerly director of the Australian Bureau of Air Safety Investigation (BASI). He is a group captain in the Royal Australian Air Force Specialist Reserve.

I would like to extend to our overseas guests a warm personal welcome to Australia, and to all our delegates from within Australia. The response to ISASI 2004 has been excellent, and a real tribute to the outstanding work of the organizing committee. Since we last held the ISASI international symposium in Australia, in Canberra in 1991, much has changed in aviation, and particularly in the dimension of aviation safety.

Before introducing our speakers for this session, I would like to make a few personal observations to put the theme of this 2004 ISASI symposium into context.

It is important to realize that while air safety investigation is of vital importance, it is but one component of an integrated approach to the systemic management of safety within aviation. Both civil and military aviation are moving rapidly toward a properly structured and fully integrated approach to the management of safety—that is, of organizational risk.

Safety management systems have been contained within the standards and recommended practices set out in various ICAO annexes for some years. IATA has also adopted a systemic proactive approach to safety management—as epitomized by the IATA Operational Safety Audit (IOSA) program.

I am very pleased to observe that Australia's Civil Aviation Safety Authority, CASA, after a lengthy program of consultation with, and education of, our aviation industry will almost certainly become the first aviation regulatory authority in the world to mandate an integrated safety management system as a requirement for the granting of an air operators certificate.

On the military side, the Australian Defence Force launched its new integrated safety management system last December. Integrated safety management systems offer many benefits to an organization. They enhance safety, efficiency, and profitability, and the preservation of assets—in particular, through the prevention of accidents and incidents.

While the specific circumstances of individual accidents may be different, the same underlying systemic factors, such as training or communication, may be common to many different accident and incident scenarios.

It is a tragic fact of life that, all too often, intensive, protracted, and very expensive accident investigations ultimately simply identify the presence of systemic safety deficiencies that were present long before the accident, and were sometimes well-known to sections of the industry.

For example, in the case of major accidents in recent years, such as the B-747 at Taipei, the A320 at Bahrain, the B-757-TU154 mid air collision over Ueberlingen, and the runway collision at Linate, virtually all of the critical underlying systemic factors that contributed to these accidents were known beforehand.

The subsequent thorough and comprehensive investigations of these accidents, in which a number of us at this seminar have been involved—in my case, as an analyst on three of them—showed that all of these tragic accidents could have, and should have, been prevented.

I should emphasize here that I am not making this statement with the benefit of hindsight, or being wise after the event. Proper safety management from an international industrywide perspective would have identified and rectified these preexisting safety deficiencies—they were not exactly invisible.

In other words, the failures of the aviation system to prevent such accidents are in themselves fundamental deficiencies of the international aviation system of which we are all a part, and for which we all must share some accountability.

Recognizing that the process of accident investigation is but one vital element of a total system of safety management means that we must strive to rectify the present situation by working harder to ensure that air safety investigation becomes part of a more integrated and proactive overall approach to aviation safety.

This involves government regulatory and investigation agencies, ICAO, IATA, aircraft and equipment manufacturers, and individual operators. At present, many activities are fragmented, uncoordinated, and occasionally adversarial. Very often, the different components of the aviation system do not speak the same language of systems safety. As a consequence, there are breakdowns of communication in critical areas of safety.

In the words of Don Gunther of Continental Airlines, who I spoke with recently at the August meeting of the IATA Safety Committee in Montreal, "We need to investigate the accidents before they happen."

We then need to make sure that the recommendations derived from such investigations are implemented. This latter process can be very difficult, as the evidence shows that it often takes an actual accident, with many fatalities, before significant and timely change is effected. It is generally far harder to get safety action after a near miss than it is after an accident.

There are some very positive signs of improvement, but sadly for some people it is already too late. Many have died, or have had their lives ruined.

As the theme of this ISASI symposium states, as well as investigating, we need to educate and communicate. This requires industry, public, and, perhaps most importantly, political support. As investigators we have achieved a great deal, but in the brave new world of the 21st century, there is even more we can do, both as individuals, and through our professional association, ISASI. ◆

INVITED PAPER

Latent Failures in the Hangar: Uncovering Organizational Deficiencies in Maintenance Operations

By Dr. Alan Hobbs (MO3425), SJSU/NASA-Ames Research Center, U.S.A.

Alan Hobbs *is a senior research associate with the San Jose State University Foundation in the Systems Safety Research Branch at NASA Ames Research Center, Calif. Before moving to Ames, he was a human performance investigator with the Bureau of Air Safety Investigation and its successor, the Australian Transport Safety Bureau. He has published extensively on the topic of maintenance human factors and is co-author with Jim Reason of the book* Managing Maintenance Error: A Practical Guide. *He has a Ph.D. in psychology from the University of New South Wales.*

Introduction

Accident statistics for the worldwide commercial jet transport industry show maintenance as the "primary cause factor" in a relatively low 4% of hull-loss accidents, compared with flight crew actions that are implicated as a "primary cause factor" in more than 60% of accidents.[1] Yet such statistics may understate the significance of maintenance as a contributing factor in accidents. When safety issues are presented alongside the fatalities that have resulted from them on worldwide airline operations, deficient maintenance and inspection emerges as the second-most-serious safety threat after controlled flight into terrain.[2] According to former NTSB Board member John Goglia, maintenance has been implicated in 7 of 14 recent U.S. airline accidents.[3]

While it may be tempting to consider that the lessons learned about human performance in other areas of aviation will translate readily to maintenance, some of the challenges facing maintenance personnel are unique. Maintenance technicians work in an environment that is more hazardous than all but a few other jobs in the labor force. The work may be carried out at heights, in confined spaces, in numbing cold, or sweltering heat. Hangars, like hospitals, can be dangerous places. We know from medicine that iatrogenic injury (unwanted consequences of treatment) can be a significant threat to patient health. In maintenance, as in surgery, instruments are occasionally left behind, problems are sometimes misdiagnosed, and operations are occasionally performed on the wrong part of the "patient." Aircraft and human patients also have another common feature in that many systems are not designed for easy access or maintainability.

In order to understand maintenance deficiencies, we need to understand the nature of the work performed by maintenance personnel, and the potential for error that exists in maintenance operations. It is relatively easy to describe the work of maintenance personnel at a physical level. They inspect systems, remove, repair, and install components, and deal with documentation. Yet, like virtually every human in the aviation system, maintenance personnel are not employed merely to provide muscle power. They are needed to process information, sometimes in ways that are not immediately apparent. The central thesis of this presentation is that in order to uncover latent failures in aviation maintenance, we must recognize the invisible cognitive demands and pressures that confront maintenance personnel.

In general, line maintenance tasks progress through a series of stages, much like the stages of a flight. The information-processing demands change as the job progresses. The preparation stage involves interpreting documentation and gathering tools and equipment. The work area must then be accessed, most likely by opening panels or removing components. After core activities such as inspection, diagnosis, and repair, the task concludes with documentation and housekeeping, or cleanup tasks. An analysis was conducted of the activities of 25 aircraft engineers at two international airlines. At 15-minute intervals, participants were asked to describe the nature of the task they were performing at that moment, according to whether it was routine, involved familiar problems or involved unfamiliar problems. A total of 666 observations were made of line maintenance activities. The analysis indicated that the preparation stage was not only the most time-consuming task stage, but was also a stage at which personnel must overcome challenges and solve problems (see Figure 1). Between 15 and 20% of their time was spent performing work packages they had never performed before. Diagnosis and functional testing also presented significant problem-solving demands and involved relatively little routine task performance.[4]

The nature of maintenance error

In recent years, analyses of databases of maintenance-related incidents and accidents have revealed some of the more common types of maintenance quality lapses.

In 1992, the U.K. CAA identified the major varieties of maintenance error as incorrect installation of components, the installation of wrong parts, electrical wiring discrepancies (including cross-connections), and material such as tools left in the aircraft.[5] In a recent review of more than 3,000 maintenance error reports, parts not installed, incomplete installation, wrong locations, and cross-connections were the most common error types.[6] The most common airworthiness incidents reported in a survey of Australian Licensed Aircraft Maintenance Engineers (LAMEs) were incomplete installations, incorrect assembly or location, vehicles or equipment contacting aircraft, material left in aircraft, wrong part, and part not installed.[7]

Applying human-error models to maintenance discrepancies reveals that underlying these events are a limited range of cognitive error forms. More than 50% of the maintenance errors reported in the Australian survey could be placed in one of three categories: memory failures, rule violations, or knowledge-based errors.[8]

Memory failures

The most common cognitive failures in maintenance incidents are failures of memory. Rather than forgetting something about the past, the engineer forgets to perform an action that he had intended to perform at some time in the future. Examples are forgetting to replace an oil cap or remove a tool. Memory for intentions, also known as prospective memory, does not necessarily correlate with performance on standard measures of memory.[9] Prospective memory also appears to show a marked decrease with age, a finding that may have implications for older maintenance personnel.

Rule violations

Common rule violations include not referring to approved maintenance documentation, abbreviating procedures, or referring to informal sources of information such as personal "black books" of technical data.

In a study of the everyday job performance of European aircraft mechanics, McDonald and his colleagues found that 34% acknowledged that their most recent task was performed in a manner that contravened formal procedures.[10] McDonald et al. refer to the "double standard of task performance" that confronts maintenance personnel. On the one hand, they are expected to comply with a vast array of requirements and procedures, while also completing tasks quickly and efficiently. The rate at which mechanics report such violations is a predictor of involvement in airworthiness incidents.[11] Violations may also set the scene for an accident by increasing the probability of error, or by reducing the margin of safety should an error occur. For example, the omission of a functional check at the completion of maintenance work may not in itself lead to a problem, but could permit an earlier lapse to go undetected.

The survey of Australian airline maintenance personnel indicated that certain critical rule workarounds occur with sufficient regularity to cause concern.[12] More than 30% of LAMEs acknowledged that in the previous 12 months they had decided not to perform a functional check or engine run. More than 30% reported that they had signed off a task before it was completed, and more than 90% reported having done a task without the correct tools or equipment. These procedural non-compliances tend to be more common in line maintenance than in base maintenance, possibly reflecting more acute time pressures.

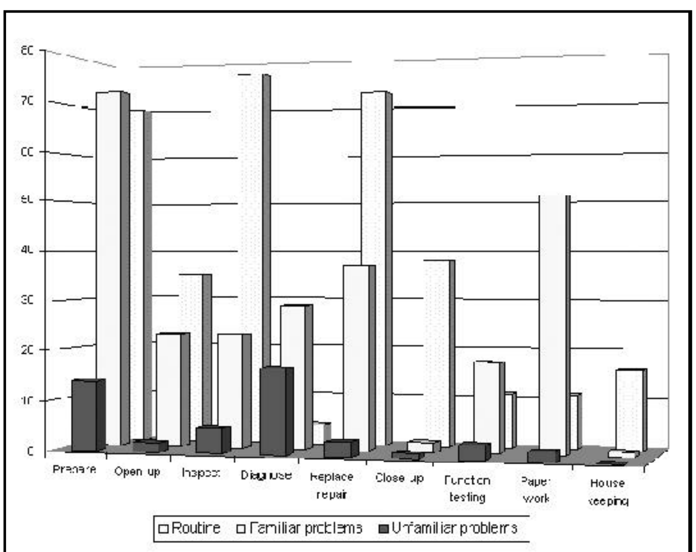


Figure 1. Cognitive demands and job stage in line maintenance (N=25).

Knowledge-based errors

Rasmussen[13] introduced the term "knowledge-based error" to refer to mistakes arising from either failed problem-solving or a lack of system knowledge. Such mistakes are particularly likely when persons are feeling their way through an unfamiliar task by trial and error. Most maintenance engineers have had the experience of being unsure that they were performing a task correctly. In particular, ambiguities encountered during the preparation stage of maintenance tasks may set the scene for errors that will emerge later in the task.

Errors and violations as symptoms of system issues

As Jim Reason has made clear, errors and violations such as those described above may be symptomatic of latent failures in the organization.[14] As such, they may call for responses at the level of systems rather than interventions directed at individuals. System issues in aircraft maintenance can be divided into two broad classes.

The first class of system issues comprises well-recognized systemic threats to maintenance quality. These issues have been so thoroughly identified that they can hardly be called "latent failures." They include broad issues such as time pressure, inadequate equipment, poor documentation, night shifts, and shift handovers. Smart has listed a set of factors that can increase the chance of error, including supervisors performing hands-on work, interruptions, and a "can do" culture.[15] Of these factors, time pressure appears to be the most prevalent in maintenance occurrences. Time pressure was referred to in 23% of maintenance incidents reported in the Australian LAME survey.[8] Time pressure was also identified as the most common contributing factor in Aviation Safety Reporting System (ASRS) maintenance reports received by NASA.[16] This does not necessarily indicate that maintenance workers are constantly under time pressure. However, incident reports indicate that time constraints can induce some maintainers to deviate from procedures. Although these system issues are recognized as threats to work quality, the extent to which they are present will vary from workplace to workplace. Evaluating the threat presented by each factor is an important step toward managing maintenance-related risks.

The second class of system issues can be more truly referred to as latent failures. These tend to be task-specific risks that can remain dormant for a considerable time. There are numerous maintenance tasks that are associated with a recurring error, sometimes due to difficult access, ambiguous procedures, or other traps. Two well-known examples are static lines to an air data computer on a twin engine jet aircraft that must be disconnected to reach another component, with the result that the lines are sometimes not reconnected, and wheel spacers that routinely stick to a removed wheel, resulting in the new wheel being installed without the spacer.

Barriers to uncovering maintenance issues

Despite the extensive documentation that accompanies maintenance, the activities of maintainers may be less visible to management than the work of pilots. A major challenge is to increase the visibility and openness of maintenance operations.

Time

While some maintenance errors have consequences as soon as the aircraft returns to service, in other cases months or years may pass before a maintenance error has any effect on operations. The world's worst single aircraft disaster resulted from an improper repair on the rear pressure bulkhead of a short-range B-747. The aircraft flew for 7 years after the repairs were accomplished before the bulkhead eventually failed.[17]

The passage of time between an error and its discovery can make it difficult to reconstruct events. Despite the extensive documentation of maintenance work, it is not always possible to determine the actions or even the individuals involved in a maintenance irregularity. In the words of one manager, "Most maintenance issues are deep and latent; some items are more than two-and-a-half years old when discovered and the mechanics have forgotten what happened." [18]

Blame culture

The culture of maintenance has tended to discourage communication about maintenance incidents. This is because the response to errors frequently punitive. At some companies common errors such as leaving oil filler caps unsecured will result in several days without pay, or even instant dismissal. It is hardly surprising that many minor maintenance incidents are never officially reported. When Australian maintenance engineers were surveyed in 1998, more than 60% reported having corrected an error made by another engineer without documenting their action.[12]

Outsourcing

The trend toward outsourcing places another potential barrier in the way of open disclosure of incident information. Some major airlines in the U.S. are now outsourcing up to 80% of their maintenance work.[19] Third-party maintenance organizations may be reluctant to draw attention to minor incidents for fear of jeopardizing contract renewals.

Recent progress

In recent years, significant progress has been made in addressing the "not-so-latent" failures in maintenance operations. Several regulatory authorities now require maintenance error management systems that include human factors training for maintenance personnel and non-punitive reporting systems. For example, the U.K. Civil Aviation Authority (CAA) has released Notice 71 that encourages operators to introduce maintenance error management programs. A central part of such a program is a reporting system that allows people to report maintenance occurrences without fear of

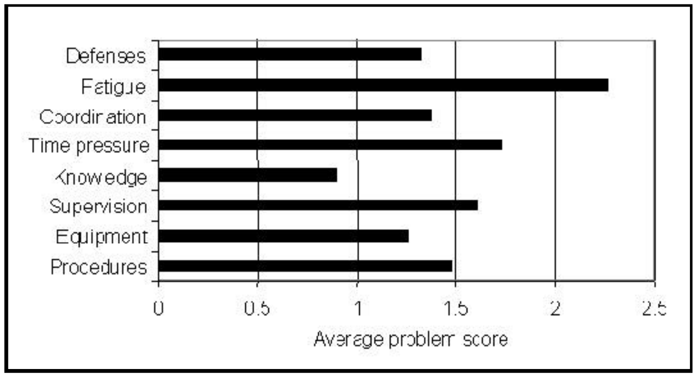


Figure 2. Example of a maintenance environment profile for a line maintenance organization.

punishment. The CAA states that "unpremeditated or inadvertent lapses" should not incur any punitive action. In the U.S., maintenance Aviation Safety Action Programs (ASAP) are being introduced, enabling maintainers to report inadvertent regulatory violations without fear of retribution. The success of such programs will depend on recognizing the spectrum of unsafe acts in maintenance, encompassing errors, violations, negligence and recklessness, and defining in advance the types of actions that can be reported without fear of punishment.[20] Establishing a clear policy on blame and responsibility should be a high priority for companies and regulators alike.

Investigation approaches

Structured investigation approaches are increasingly being introduced within maintenance. Systems include the Aircraft Dispatch and Maintenance Safety (ADAMS) investigation framework[21] and Human Factors Analysis and Classification System—Maintenance Extension (HFACS-ME).[22] The oldest and most widely known system is Boeing's Maintenance Error Decision Aid (MEDA), now used by approximately 50 airlines worldwide.[6] MEDA presents a comprehensive list of error descriptions and then guides the investigator in identifying the contributing factors that led to the error.

Monitoring organizational conditions

In recent years, several proactive systems have been developed to measure safety culture in maintenance organizations. These include the Maintenance Climate Assessment Survey (MCAS)[23], Maintenance Resource Management Technical Operations Questionnaire (MRM-TOQ)[24], Managing Engineering Safety Health (MESH)[25], and the Maintenance Environment Questionnaire (MEQ). The Maintenance Environment Questionnaire was developed in Australia and is based on an earlier checklist administered to more than 1,200 maintenance engineers.[11] The MEQ was designed to evaluate the level of error-provoking conditions in maintenance workplaces. The MEQ evaluates the following seven error-provoking conditions: procedures, equipment, supervision, knowledge, time pressure, coordination, and fatigue. In addition, the questionnaire contains items addressing maintenance defenses, or "safety nets," in the system. The eight factor scores are the main output of the survey. Once the questionnaire has been completed by a sample of maintenance personnel, the ratings are combined to create a profile similar to the example shown in Figure 2.

Conclusion

Advances in technology throughout the last century have enabled the number of flightcrew members to be progressively reduced to the standard complement of two on current aircraft. Developments in UAV technology have already led to unmanned combat aircraft. Unmanned civilian cargo aircraft may be in service before long.

Despite continuing advances in vehicle health monitoring and built-in test equipment, the work of maintenance personnel is unlikely to be automated in the near future because maintenance activities present challenges that, at present, only humans can meet. We may be able to auto-fly but we cannot "auto-maintain."

In order to understand maintenance deficiencies and the conditions that lead to them, it is necessary to appreciate the demands that maintenance work places on the individual maintenance worker, and the types of errors and violations that occur in response to these demands. Memory lapses, procedural non-compliance, and knowledge-based errors are significant classes of unsafe acts in maintenance.

Some of the conditions that promote errors and violations in maintenance have been clearly identified in recent years. For example, fatigue and time pressure are widely recognized hazards. In these cases, policies regulating hours of work and maintenance resource management (MRM) training are potentially effective countermeasures.[26]

Other threats to maintenance quality are harder to identify. These include recurring errors, traps in procedures, and practices that introduce unacceptable iatrogenic risks. The potential for delay between maintenance actions and consequences can present a problem for reactive investigations. The blame culture that pervades much of the industry can make it difficult to proactively identify threats to maintenance quality. One of the most pressing challenges now facing the maintenance sector is not technical in nature, rather it is how to foster a spirit of glasnost to promote incident reporting and the disclosure of incident information. ◆

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Equipment Damage and Human Injury on the Apron—Is It A Cost of Doing Business?

By Bob Vandel, Flight Safety Foundation, U.S.A.

***Bob Vandel** has more than 37 years' experience in both fixed- and rotary-wing aviation, aviation safety, maintenance management, training, and air traffic control. He holds a bachelor of science degree in management and a master of science degree in psychology. He has flown all types of aircraft from small single-engine fixed-wing aircraft and helicopters up to heavy jets. Vandel served in the U.S. Army in various aviation positions for 23 years before retiring in 1988. He spent 4 years in air traffic control work at the Federal Aviation Administration. He was director of technical projects for the Flight Safety Foundation for 10 years. In May 1999, he was elected executive vice-president. During his tenure as director of technical projects, he led studies on the use of onboard recorded data, safety aspects of precision approaches, a windshear training aid, fatigue, and continuing airworthiness risk evaluation. He has organized, conducted, and spoken at safety seminars and workshops all over the world. Vandel was awarded the* Aviation Week and Space Technology *Laurels Award for his work with the Foundation's controlled flight into terrain initiative.*

The Flight Safety Foundation (FSF) estimates that losses from apron damage are costing the world's air carriers in the vicinity of US$4 billion every year. Add to this the costs of apron damage to the corporate and business aircraft fleet and the price tag goes up an additional US$1billion per year. Some U.S.-based operators suggest that for every dollar in apron damage they pay $2 for human injury. Many assume that these losses are insured and so the financial risk has been mitigated or eliminated. This is in fact not the case.

Apron damage did not get to the $5 billion annual loss overnight. There has been a gradual increase in both the number of incidents and in their associated costs over the history of powered flight. According to the late Jerome Lederer, president emeritus of the Flight Safety Foundation, the reason that Orville Wright flew the first flight as opposed to Wilbur was because Wilbur had damaged the fabric on the wing of the Wright Flyer. In response to this damage, Wilbur made the repairs and Orville then flew the first flight. What is significant in this anecdote is the fact that we had damage to the first airplane that was inflicted on the ground, and it occurred prior to the first powered flight. We, therefore, had apron damage before we got the first airplane airborne using its own power.

The problem of apron damage can be traced to the beginnings of aviation, through the era where aircraft were beginning to be flown on a commercial basis, right up to today where we have more than 800 airlines globally and nearly 5,000 operators of corporate aircraft. It was during the early period that pioneers began to find barns or large structures to house the aircraft and to protect them from the elements. Movement of aircraft into and out of these structures, or what became known as "hangars," sometimes inflicted minor damage to the aircraft. This damage was nicknamed "hangar rash" by the early aviation enthusiasts, and that descriptor is still in use today.

Following the example of the Wright brothers, aircraft operators made repairs to their aircraft to correct the hangar rash in order to return them to flyable condition. This concept of repairing the minor damage to aircraft has continued for decades, and today we are still following the example of the Wright brothers by repairing damage as soon as possible thereby returning the aircraft back to service in the most expeditious manner. Wilbur made the repairs in the best manner that he knew and understood in accordance with the aerodynamic principles as he knew them to be. Today we are making far greater repairs and doing so in accordance with guidance from the regulatory authority and the aircraft manufacturer's recommendations, but we are doing so at a greatly increased price.

As airlines began to form and increase in size, they began to suffer hangar rash and at increased rates. In their attempts to remain competitive in the marketplace, they repaired the aircraft damage and brought the airplanes back into service as soon as possible. This process was a natural extension of what probably started with the tear in the fabric on the Wright Flyer's wing and the need to repair it and attain flight on Dec. 17, 1903. As airplanes became larger and more complex the repairs became more complex and the hangar rash costs became more and more significant. Today we are suffering $5 billion annually in what many refer to as apron damage. Today, as we work to reduce apron damage, we must extend the definition of apron damage to include not only the damage to aircraft but also to include injury and death to ramp workers as well as the damage inflicted upon service vehicles and on airport structures.

It is appropriate to pause in the explanation of apron damage to describe how the Flight Safety Foundation became involved in this area. For the past 10 years the Foundation has focused its efforts on four primary areas where the greatest loss of life, equipment, and resources have occurred. These four areas are controlled flight into terrain, approach and landing accidents, loss of aircraft control, and human error. The Foundation and the aviation industry have traditionally focused on safety-of-flight operations. We have utilized advanced training techniques in simulators and introduced CRM to cockpit, cabin, and maintenance operations, and this has brought about a level and stable safety rate in commercial aviation. We have also seen a maturing focus on safety in the maintenance arena. We now must shift the paradigm to address the emerging focus on ramp safety.

It is the contention of the Foundation that human error is in-

volved in almost every accident, and for this reason the Foundation has been a leading proponent of
a) the use of flight operational quality assurance and collection and interpretation of ground damage data,
b) the implementation and use of non-punitive reporting systems both in the air and on the ground,
c) the awareness and reduction of fatigue in the aviation industry, and
d) the improvement in safety on the apron.

Safety must be viewed by looking at all the parts of the aviation system. Just as in other industries, human error is prevalent throughout. We find that human error can enter the system through design of the aircraft, through regulatory involvement and oversight, through management intervention, through the ATC system, through the flight crew. And we find human error impacting the system on the apron, in the hangar, through airports design and operation, and through service providers. For these reasons, we have taken the decision to lead an international effort to reduce apron damage.

The Flight Safety Foundation began this effort with the formation of a working committee whose charter was to plan the best path for success. The actual study began with data collection as we strongly believe that everything the Foundation does should be data driven in order to optimize the resources expended. This data effort is currently under way and once sufficient data are obtained the data elements will be closely analyzed to determine as closely as possible those things that are negatively impacting apron safety. The data team is also working to develop the actual cost related to apron damage. This will address both direct and indirect costs.

While the data collection effort is ongoing, there are four other teams that are developing products designed to reduce or eliminate apron damage. These products will be used as interventions to stem the growing risk of apron damage and injury and to reverse the processes that are in place that allow or foster this dramatic loss. The FSF plan calls for implementation of the interventions on a limited basis to demonstrate the viability of the whole program. Once the limited implementation program is complete and any needed corrections have been applied, the program will be implemented on a global scale by utilizing regional breakouts to focus the program.

The first step for the Flight Safety Foundation was to create a working definition to add scope to the apron damage and human injury initiative and at the same time to establish a common point of reference. The working definition states: *"An incident that occurs on the airport movement area or in the hangar that results in either the loss of use of a piece of equipment (aircraft, vehicle, and/or facilities) for any period of time or a lost work day case that occurs when an individual is injured."*

The Foundation believes the primary cause of apron damage is human error, and this belief ties directly into our fourth primary area of emphasis, the reduction of accidents and incidents caused by human error. In 1993/1995 a study commissioned by the IATA Airside Safety Group into the causes and costs of apron damage concluded that the major cause of apron damage (92%) was "operator error." The survey concluded that the operator error included inadequate training, inadequate supervision, failure to follow standard procedures, pressure of work, inappropriate equipment, and inclement weather conditions.

We need to remember though that human error is quite normal.

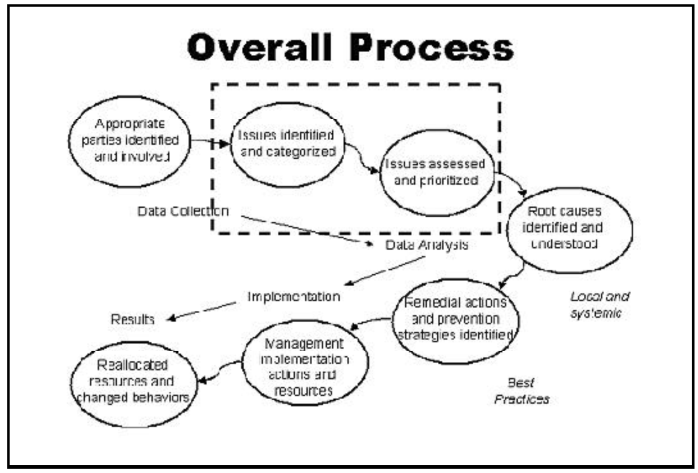

Figure 1

Figure 2

We all make mistakes and hopefully we learn from them. Someone once said that mistakes are the down side of having a brain. Mistakes are not only a result of our being human but there is benefit gained by learning from our errors. The fact that human errors are normal is not a reason to dismiss them as an unmanageable problem. Quite the contrary, if human error can be identified, causes determined, and interventions designed, we can implement the science of human factors and we can defeat the identified problems.

We must begin our assault on apron damage and human injury not only by obtaining data but by looking at such things as management oversight, training deficiencies, language difficulties, and fatigue as areas where we can begin this effort. By accepting the premise that human error is the primary cause of apron damage, it mandates that we specifically identify an error taxonomy that has identifiable and measurable parameters. Once we have accomplished this step and understand the problem we can design appropriate resolution strategies. This design will necessarily encompass error tolerance in procedure and equipment. Identification of the solution is not the ending point of this strategy. To truly combat apron damage and get the reduction that we are looking for, we need to modify behavior. This modification of behavior will occur in the implementation phase of the apron damage and human injury reduction effort (Figure 1).

As we began our research to identify possible solutions, logic dictated that we include as many organizations as possible that are stake holders. The following is a partial listing of stakeholders in the reduction or elimination losses on the apron:
- Airlines
- Cargo/package carriers
- Corporate operators
- Military
- Airport operators
- Insurers
- Fixed-base operators
- Ground handlers
- Fuel and oil suppliers
- Caterers
- Manufacturers
- Maintenance, repair, and overhaul facilities
- Airport designers
- International Civil Aviation Organization
- Airports Council International
- Flight Safety Foundation
- International Air Transport Association
- National Business Aviation Association
- Regulatory agencies

—Aviation authorities
—Occupational safety and health authorities
—Customs authorities
- Labor organizations
- Security organizations

Although the availability of data is limited, the Flight Safety Foundation has sufficient information from a variety of air carriers to estimate the magnitude of the problem from both the airline and the corporate aircraft industry perspective. We estimate that the loss exceeds US$4 billion on an annual basis for the air carriers alone. This figure is a combination of the direct costs and the associated indirect costs that typically run from 3 to 5 times the direct costs.

A quick example will provide some perspective as to the **direct costs** associated with apron damage to a Boeing 737.

This slide (Figure 2) does not depict the cost to the interior of the aircraft in the cargo compartments. Primarily damage to cargo compartments occurs to sidewall lining panels, ceiling panels, blow-out panels, and floor panels. These are typically caused by
- damaged sidewall and ceiling panels due to incorrectly assembled pallet load, or cargo operators leaning on sidewall panels to manually maneuver unit load devices (ULD).
- damage to floor panels from crowbars when used to manually maneuver ULDs.
- damaged or manually operated blow-out panels caused by strikes from ULDs or customs staff looking for illegal substances.
- damage to door seals from incorrectly assembled or misaligned pallets.

The **indirect costs** for an airline or an airport might include
- Lost direct revenue (ticket sales and cargo revenue)
- Aircraft diversions (replacements)
- Flight cancellations
- Passenger food and lodging
- Replacement labor and overtime
- Damage to public image
- Management and supervision time

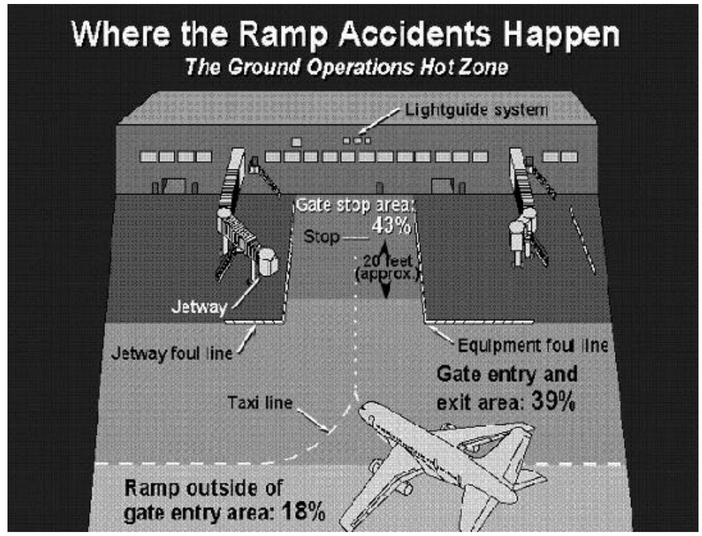

Figure 3

- Incident investigations
- Purchasing seats on another airline to accommodate passengers
- Pain and suffering for those injured and their families
- Adverse impact on operations

—Productivity and schedule efficiency
—Quality
—Costs
- Employee relations/overall company morale
- Regulatory agency reactions
- Total costs of workplace injuries
- Public perceptions

An actual incident of apron damage that involved a catering truck hitting an airplane showed that the direct costs were $17,000; however, the indirect cost of $230,000 for a grand total of $247,000. In another incident, a jetway operator hit an aircraft with the jet way. The airplane suffered $50,000 damage in direct costs and $600,000 in indirect costs.

The first argument put forward is that this loss is insured so the airlines are not loosing a significant dollar amount. The FSF recently reviewed data from one U.S.-based airline that indicated that in a 1-year period the airline had 274 reported cases of apron damage. When reviewing the insurance coverage it was determined that the deductible was $500,000 for an older-generation single-isle aircraft, $750,000 for a modern single-isle aircraft, and $1,000,000 for widebody aircraft. It was determined that the average event cost was $250,000. When this deductible of each incident was compared to reported apron damage cases, the result was that 273 of the reported cases were below the deductible limit. The only conclusion that one can come to is that the vast majority of apron damage is self-insured and, therefore, these cost of repairs come directly off the bottom line of the airline's balance sheet. This same airline's management indicated that it believes there are a number of unreported cases of apron damage.

To begin combating apron damage to aircraft, we need to determine where the loss is occurring. We currently have limited data that indicate both where the majority of the damage is occurring on the aircraft and also where on the movement area the damage is happening. These data were supplied by Boeing and suggest that the largest number of apron accidents occur in the gate stop area (Figure 3).

Figure 4

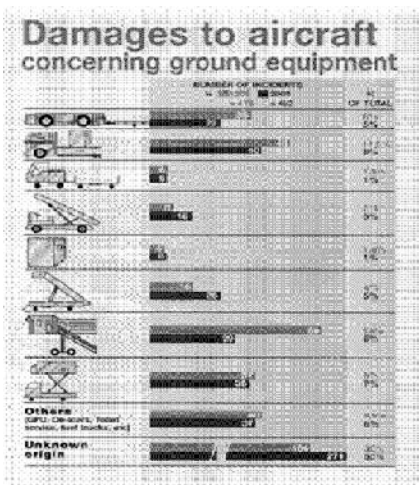

Figure 5

By reviewing Figure 4, we begin to see where the majority of damage is occurring relative to the airframe itself. We see that it is occurring at the primary locations of servicing on the fuselage, near the passenger doors, near the hold doors, and in the holds themselves. We have a basic understanding of what happened. We can see that more than 75% of the damage is in fuselage, passenger doors, holds doors, and holds. This gives us a good indication of where on the aircraft we need to focus.

If we were to look at the limited data available on ground equipment (Figure 5), we see that tugs, cargo positioning equipment, jetways, and food service vehicles seem to be the most common culprits. One item that stands out is that in the "Others" and "Unknown origin" categories, we have almost 2/3 of the damage. We as an industry must explore this area much more closely. This will be one of the tasks for the data collection working group that was chartered under the Flight Safety Foundation's new initiative to reduce damage and injury on the apron.

If we were to combine the information contained on these two charts we would see that there is a common link that can be challenged to reduce the overall cost of apron damage. Indal Technologies has developed an automated passenger bridge system that can dramatically reduce damage due to human error (Figure 6).

If this system were implemented globally, we could realize a 14% overall reduction in damage to air carrier airplanes. This system is adaptable to all existing and planned passenger bridges and requires only minimal adaptation to the aircraft. All one needs to do is place four small decals on the aircraft under the passenger loading doors and the Indal system does the rest automatically. This not only reduces the repair costs associated with passenger bridges but also allows for the repositioning of the passenger bridge operator to other duties on the airport.

This system uses two sensors that are located underneath the passenger bridge (Figure 7). Through the application of infrared technology, the system is able to make the bridge to the aircraft and not be affected by weather. There exists the possibility of saving the air carrier industry $560 million annually through this one piece of technology. If we added this type technology to ramp vehicles such as catering trucks, jetways, and cargo loaders we could then have the potential for saving upwards of $1.3 billion annually.

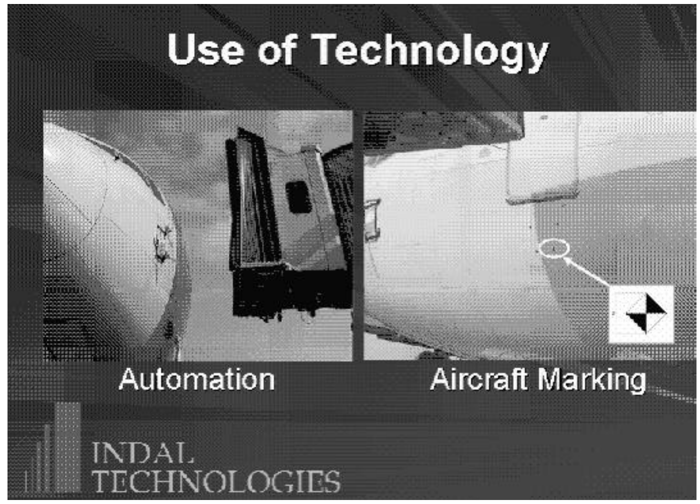

Figure 6

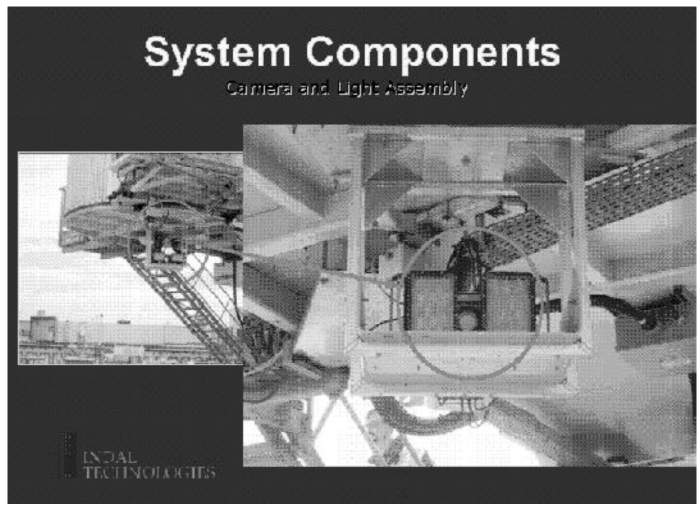

Figure 7

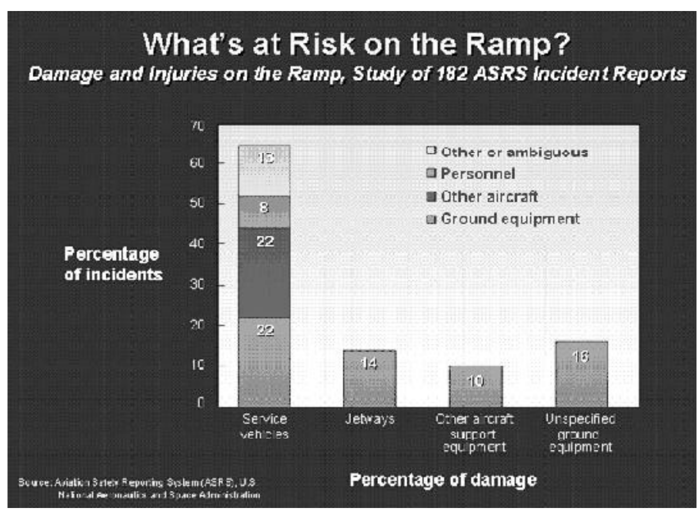

Figure 8

Another study conducted under the auspices of the Aviation

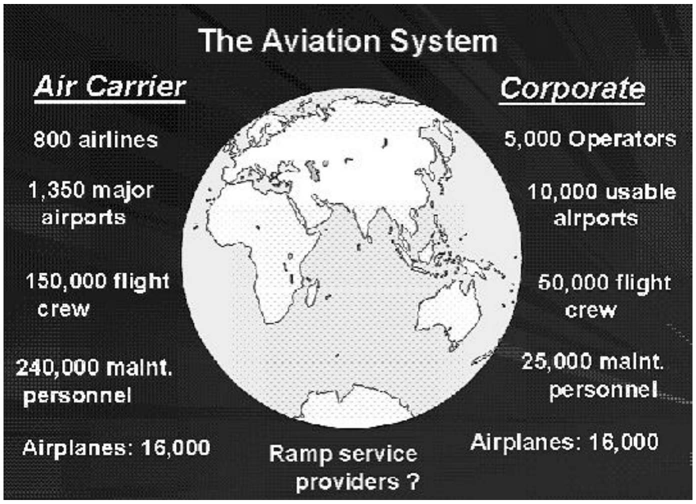

Figure 9

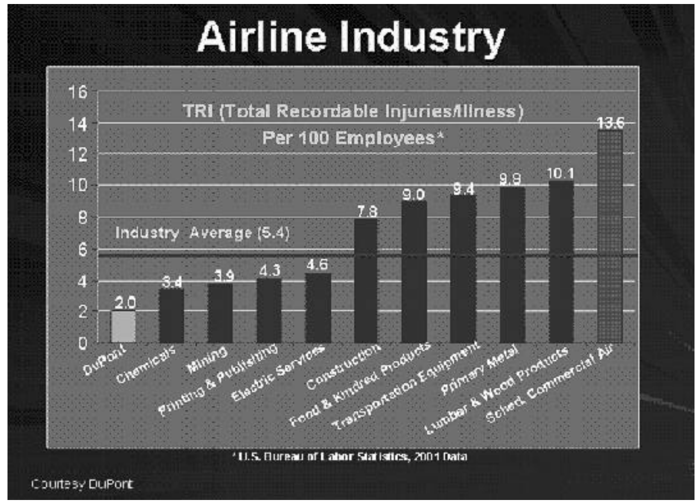

Figure 11

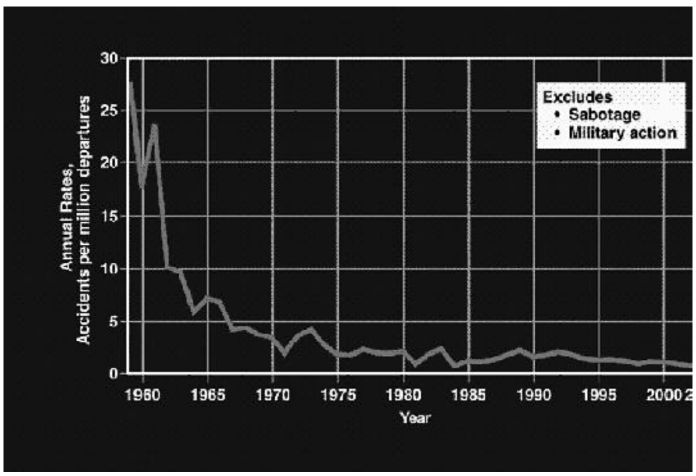

Figure 10

Safety Reporting System (ASRS) shows a different picture.

If we were to break out the corporate and business aircraft, we might see a slightly different picture that we would expect as these aircraft are normally serviced differently (Figure 8). It is routinely the case that the flight and cabin crew load baggage and meals into the airplane and that FBOs accomplish the ground handling. For corporate aircraft, we now believe the phase of apron operations where the highest percentage of damage incidents occurs is in the towing phase while the highest percentage of personal injury occurs during the loading of the aircraft. We see that in the ground-handling phase of the operation approximately 40% of the incidents occur to wingtips with a comparable number to the wing's trailing edge. It is postulated that these occur as the result of the aircraft being pushed into a congested hangar area without the use of ground guides or wing walkers. The other major category is damage to the leading edge of the wing. It has been postulated that the damage to the wingtips occurs because today's tug operators do not have the spatial recognition skills that their predecessors possessed.

How do we reduce apron damage? The process is obviously multifaceted. We must look to all stakeholders to manage the issue in their sphere of influence. When we look closely at the system the air carriers operate in, it gives a fairly good idea of the complexity of the global forces impacting them.

The picture for the corporate operator is slightly different (Figure 9). These aircraft have many more operators than the air carrier system, and they fly to many more airports. Their inclusion expands the number of airports that will be included in the solutions to the apron damage and personal injury initiative.

Some of the Foundation's solutions will be specific for each of the many stakeholders while some will cut diagonally across the aviation industry. For those that cut across the industry, there are basic principles that should be applied to all. The Flight Safety Foundation maintains that safety begins at the top and, therefore, it follows that apron safety begins at the top. The CEO, whether at the airport, airline, ground-handling company, or the corporate entity, sets company safety culture. He must walk the walk and talk the talk. It is a time-proven adage that the workers do well what the boss checks. If the CEO puts safety high on his corporate agenda and checks the results, then managers who set safety policy will conform to the CEOs lead. Finally, the management team must assume responsible for safety. If organizations have this basic structure in place, they are on the way to developing a strong safety culture within their organizations, which will greatly assist in reducing human error on the apron.

While the solutions will differ depending upon whether one is operating an airline, a corporate aircraft, an airport, or an air traffic control system, safety will fit into the production objectives. It will not be the prime objective as that will be to produce or sell at a profit but it must be openly recognized that apron safety supports the prime objective. It conserves resources and costs, prevents damage and injury, and reduces risk. Safety must be a core business value.

This chart (Figure 10) shows how we have driven hull losses down over the last half century. The accident rate has been stable at approximately one hull loss for every million departures for the past 25 plus years. We need to continue our efforts in this area, but at the same time we are calling for a paradigm shift. We need to look at the safety of the apron worker.

What about the actual line employees? Advocates have maintained for many years that aviation is the safest form of mass transportation and the statistics firmly support this. However, when we compare how employee injuries in the total aviation industry compare to that of other industries, we find a different picture. The following graph was developed by DuPont Safety Resources from U.S. Bureau of Labor Statistics and shows data for the United States.

These data (Figure 11) clearly show an industry average of 5.4

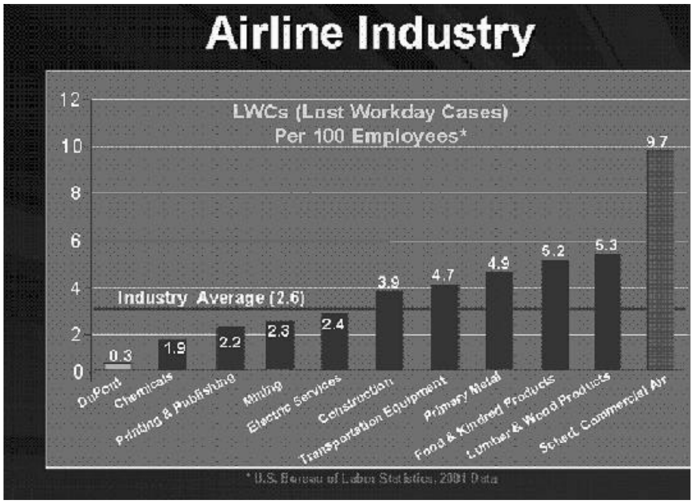

Figure 12

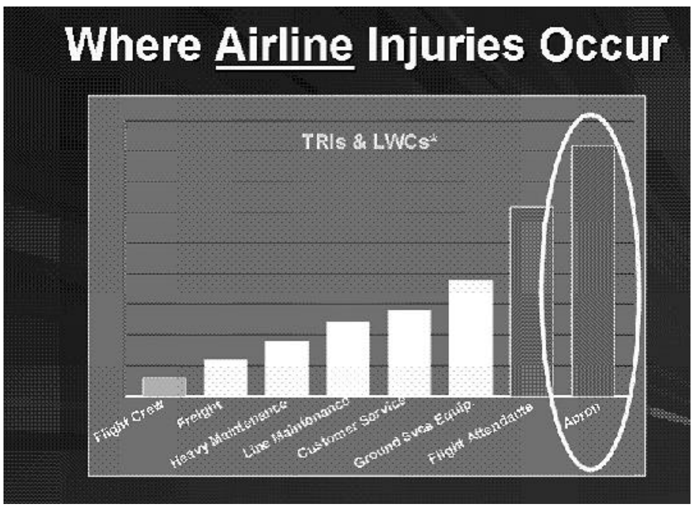

Figure 13

total recordable injuries (TRI) per 100 employees on an annual basis and that the rate for scheduled air carriers is 13.6. When we look at the DuPont average, we see that aviation experienced more than seven times more lost work days per 100 employees than DuPont on an annual basis. It is obvious to the Flight Safety Foundation that DuPont has developed a method of developing a safety culture that is worthy of emulation.

This graph (Figure 12) shows that in 2001 the aviation industry suffered 10 lost work days per 100 employees. This cost was significant in both terms of dollars and productivity. If this is somewhere near the average, it tells us we must move to change the situation. This is lost workday cases. As you can see again, our industry is not in good shape. You might also find it interesting to note that companies that are in what is perceived as higher danger industries actually have lower workplace injury rates because they have focused on improvements.

By combining the TRI and LWC, we get a more complete picture of where the risk is for the air carrier worker. You can see from this graph that the apron is the area where most injuries occur (Figure 13).

There will be both technological and human-centered approaches to the apron damage issue. Technology can not only assist us in the measurement of what is actually happening on the apron, but it can also assist us in numerous ways to eliminate certain categories of apron damage. One of the human-centered methods to help us obtain a clearer picture of what is happening on the apron is to develop and institute a confidential non-punitive reporting system. We cannot be certain that we are fixing the correct problem unless we know what is happening and obtain an insight into why it is occurring. Initiation of a non-punitive incident reporting system will be a major step in understanding the "why" as it relates to the incident's cause.

We must find a change agent, and that is what the Foundation's apron damage and human injury reduction initiative is about. This Foundation program began as a collaborative effort.

We have enlisted participants across the aviation industry who embrace the inclusion of work already accomplished by the International Air Transportation Association, the Regional Airline Association, the National Business Aviation Association, the U.S. Air Transportation Association, and the European Regions Airlines Association.

We have identified more than 100 initial issues more than are being addressed by volunteers who populate the five working groups. The working groups have been generally divided into

- Data collection and analysis,
- Education and training,
- Apron facilities, equipment, and operations,
- Management processes, and
- Industry awareness working team.

The data team members will work to define the metrics for the initiative and the objective targets. They will also be tasked to redefine the magnitude of the problem. They will conduct the basic data collection, analyses, and support the various working teams. In addition they will develop cost models that will include both direct and indirect costs.

The education and training team is working to understand and base line present-day industry practices regarding ground handling and recommend improvements to education and training.

The apron facilities, equipment, and operations working team will identify apron facilities, equipment ,and operational practices that improve safety. They will also assess and develop enhancements to design, installation, and operations that will reduce ground accidents.

We have asked the management processes team to identify management and leadership practices (culture) that impact safety. They are also tasked with assessing and developing enhancements to management practices designed to reduce ground accidents.

The final team is the industry awareness team, which is charged with keeping the industry aware of what is being developed. Specifically, this team will generate a multitiered and multimedia communications plan with long-term strategies and near-term tactics to communicate issues and to market results to stakeholders.

The entire process is expected to take approximately 3 years before we begin putting products and solutions in place. We are using the model that the Flight Safety Foundation used in its award-winning effort to reduce both controlled flight into terrain and approach and landing accidents. In addition, we will utilize the same management team and are very optimistic about the results.

It is our firm belief that equipment damage and human injury on the apron need not be a cost of doing business. ◆

The ATSB Ansett Class A Investigation

By R. Batt, L. Brown, S. Garniss, M. Watson, and J. Walsh, Australian Transport Safety Bureau
(Oral presentation by Richard Batt.—Editor)

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No photo available

Lawrie Brown *joined the ATSB in 1990 and is currently an investigation team leader. He has a 23-year background in general aviation as both professional pilot and LAME.*

No photo available

Suzanne Garniss *is a licensed aircraft maintenance engineer investigator with the ATSB. Prior to joining the ATSB in 2000, she worked as an airworthiness inspector with the Australian aviation regulator and as a licensed aircraft maintenance engineer in general aviation and for regional, domestic, and international airlines.*

No photo available

Mike Watson *is an operations (pilot) investigator with the ATSB, with experience in practical aviation and organizational issues. Prior to joining the ATSB in 1998, he worked as a pilot across Australia, had a truck business in Africa, and worked as a safety specialist for British Gas. He has an engineering background.*

No photo available

Julian Walsh *is a senior transport safety investigator with the ATSB. He is an air traffic services specialist and also has considerable experience in examining management and organizational issues. Prior to joining the ATSB, he was a senior RAAF officer who gained experience in a variety of command and staff appointments in operations support, training, flying safety, and personnel management*

If human error on the part of one or two individuals can go unchecked within an organization and result in a significant breakdown of the workings of the system, then the failure is a system error and not a human error.

Ansett Australia was a major Australian airline with a proud history and excellent safety record. However, in December 2000 and April 2001, a number of Ansett B-767 aircraft were withdrawn from service because there was uncertainty as to the continuing airworthiness status of the aircraft. While this did not constitute an accident or incident, the Australian Transport Safety Bureau (ATSB) considered that it indicated a potentially serious safety deficiency and commenced an investigation. The scope of the investigation was subsequently widened to include aspects related to the Australian Civil Aviation Safety Authority (CASA), the manufacturer Boeing, the U.S. Federal Aviation Administration, and aspects of the ICAO continuing airworthiness system. The ATSB report concluded that until the Ansett aircraft were withdrawn from service, there was little awareness of the safety deficiencies that existed within the operator and at various levels within the international continuing airworthiness system.

Ansett was the sixth airline worldwide, and the first airline outside North America, to operate the B-767. The introduction of that aircraft type into the Ansett fleet in 1983 was significant because the B-767 had been certified under the then new damage-tolerance design criteria. The Ansett B-767 aircraft accumulated a high number of flight cycles because they were mostly flown on comparatively short domestic sectors (Figure 1).

In December 2000 and in April 2001, a number of Ansett B-767 aircraft (Figure 1) were withdrawn from service because certain required fatigue inspections of the aircraft structure had not been carried out. That led to uncertainty that the continuing airworthiness of the aircraft could be assured. In December 2000, the concerns related to possible fatigue cracking in the body station 1809.5 bulkhead outer chord, in the rear fuselage of the aircraft. In April 2001, the concerns related to possible fatigue cracking of the wing front spar outboard pitch load fitting that connected the engine support structure to the wing. In both cases, undetected fatigue cracking had the potential to eventually lead to structural failure.

On Jan. 11, 2001, the ATSB commenced an investigation into the circumstances surrounding the withdrawal from service of the Ansett B-767 aircraft as the situation was regarded as indicative of a potential safety deficiency. On April 10, 2001, the ATSB investigation was extended to include an examination of the continuing airworthiness system for Australian Class A[1] aircraft such as the B-767.

Figure 1: Ansett B767 VH-RMG at Sydney Kingsford Smith Airport, June 1984.

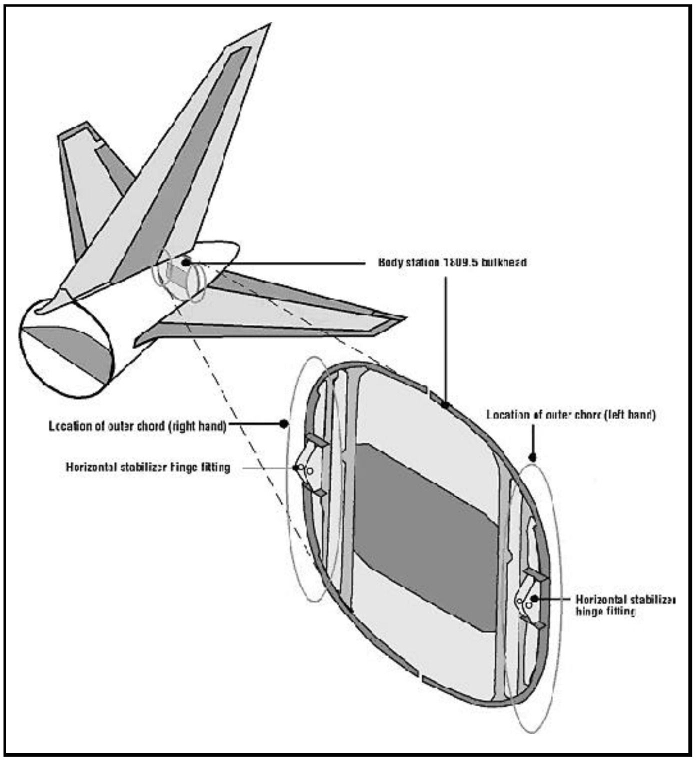

Figure 2: Location of B-767 body station 1809.5 bulkhead.

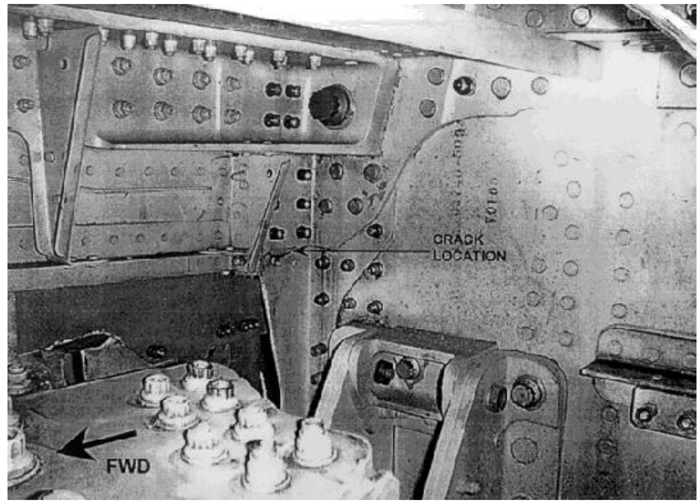

Figure 3: Fatigue crack in an Ansett B-767 body station 1809.5 bulkhead outer chord.

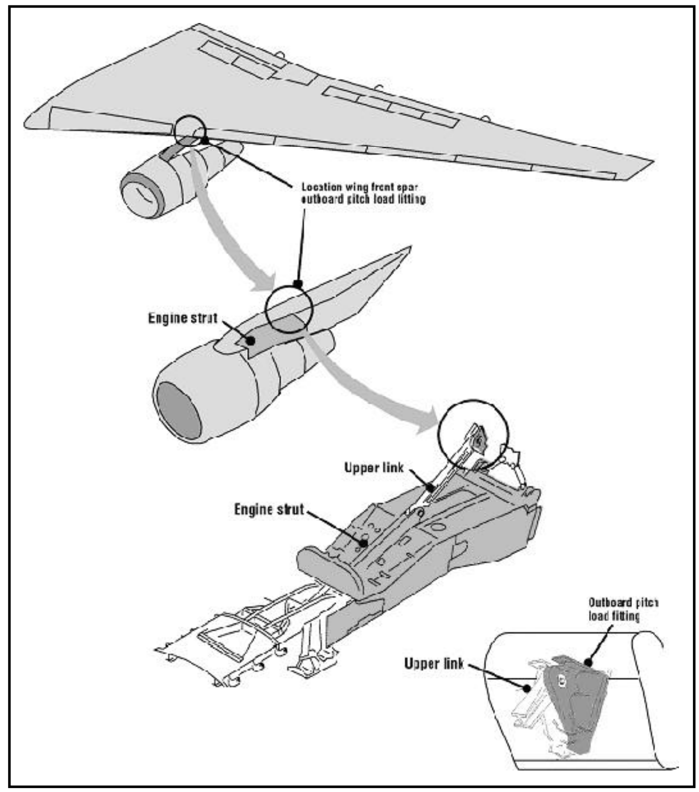

Figure 4. Location of B-767 wing front spar outboard pitch load fitting.

Damage-tolerance design and certification

The philosophy that underpins the design and maintenance of modern transport aircraft has evolved over time. The most recent approach to the control of fatigue and corrosion in aircraft structures is based on the concept of damage tolerance. The B-767 was the first U.S.-designed aircraft certified to damage-tolerance standards.

The damage-tolerance approach is based on the premise that while cracks due to fatigue and corrosion will develop in the aircraft structure, that process can be understood and controlled. Therefore, safety will not be compromised. The key to the effective control of the process is a comprehensive program of inspections of the aircraft structure. Those inspections fall into three broad categories:

- zonal inspection carried out on a routine basis,
- specific structural inspections developed from design-based criteria,
- airworthiness limitations structural inspections.

Airworthiness limitations structural inspections are developed after the aircraft type has entered service, largely to address fatigue or corrosion problem areas identified through in service experience or further testing and research. Because the airworthiness limitations structural inspections address concerns with a significant potential to affect the structural integrity of the aircraft, the inspections are considered mandatory.

Fatigue cracks in the B-767 body station 1809.5 bulkhead outer chord

In June 1997, Boeing introduced the airworthiness limitations structural inspections program for the B-767. The program was an essential part of the damage-tolerance requirements and was designed to detect fatigue cracking in susceptible areas that had been identified through testing and in-service experience. Ansett staff did not initially recognize that some airworthiness limitations structural inspections were required by 25,000 cycles and a period of almost 2.5 years elapsed before that error was identified. At the time that the inspection program was introduced, some Ansett B-767 aircraft had already flown more than 25,000 cycles. In June 2000, more 25,000 cycle inspections were introduced, including in the area of the body station 1809.5 bulkhead outer chord. Ansett did not initially act on this (Figures 2 and 3).

In December 2000, Ansett senior management became aware of the missed inspections, and the aircraft were withdrawn from service on Dec. 23, 2000.

At that time, both Ansett and CASA were of the belief that com-

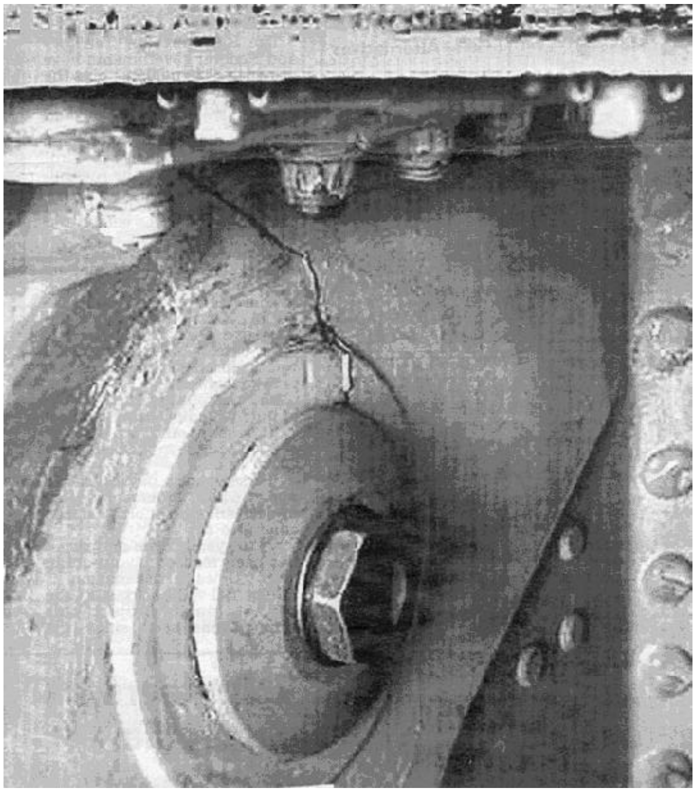

Figure 5: Fatigue crack in an Ansett B-767 wing front spar outboard pitch load fitting.

pliance with the missed inspections was mandatory. Subsequent legal advice indicated that the regulatory basis for mandating compliance with the airworthiness limitations structural inspections for Australian operators was unclear.

Fatigue cracks in the B-767 wing front spar outboard pitch load fitting

In March 2000, Boeing issued an alert service bulletin to detect and repair fatigue cracks in the wing front spar outboard pitch load fitting of the B-767 engine mounting strut. Boeing recommended that the work be carried out within 180 calendar days. A revision to the service bulletin was issued in November 2000. The wing front spar outboard pitch load fitting was part of the upper link load path between the engine and the wing. Cracks in the wing front spar pitch load fitting could have caused possible loss of the upper link load path and separation of the strut and engine from the wing.

In March 2001, Ansett became aware that it had not acted on either the original or the revised service bulletins. During the period from April 7-9, 2001, inspections revealed cracks in the pitch load fittings of three of the Ansett B-767 aircraft (Figure 4), and they were withdrawn from service. On April 9, 2001, CASA required that four more Ansett B-767 aircraft be withdrawn from service (Figure 5).

Deficiencies in the Ansett engineering and maintenance organization

The ATSB investigation found that there were systemic deficiencies within the Ansett engineering and maintenance organisation related to

- organizational structure and change management,

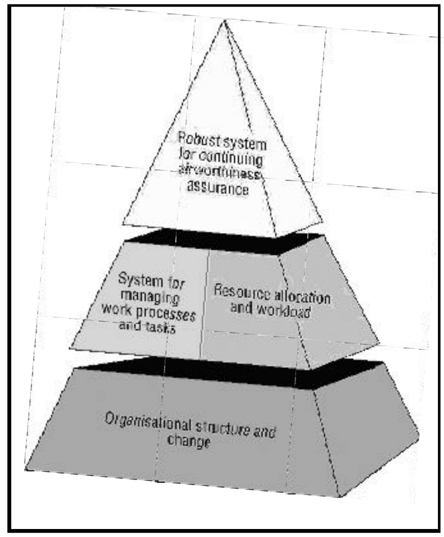

Figure 6. Factors affecting the Ansett system for continuing airworthiness assurance.

- systems for managing work processes and tasks,
- resource allocation and workload.

These factors did not act independently of each other but combined to greater effect, resulting in a loss of continuing airworthiness assurance.[2]

Ansett had undergone considerable change over a number of years. Many of the Ansett systems had developed at a time when the company faced a very different aviation environment. Over time, efficiency measures were introduced to improve productivity but the introduction of modern robust systems did not keep pace with the relative reduction in human resources and loss of corporate knowledge. In addition, risk management and implementation of change within the Ansett engineering and maintenance organization was flawed (Figure 6). Inadequate allowance was made for the extra demand on resources in some key areas during the change period.

The Ansett fleet was diverse and the point had been reached where some essential aircraft support programs were largely dependent on one or two people. Hence it was possible for an error or omission by a particular specialist to go undetected for a number of years.

Resource allocation and workload issues had been evident within some areas of the Ansett engineering and maintenance organisation for a considerable period of time. The investigation found that measures aimed at achieving greater productivity had been introduced throughout the organization without sufficient regard to the different circumstances and criticality of the different work areas. Insufficient consideration had been given to the possible consequences of resource constraints on the core activities of some safety critical areas of the organization.

Ansett staff had repeatedly expressed concern to senior Ansett engineering and maintenance management. Management suggested that work on some lower priority items could be halted in the short term. Putting non-urgent work on hold is at best a stopgap measure. The danger is that even non-urgent work must be done eventually, and in time will itself become urgent. People and robust systems are two of the prime defenses against error. Therefore, a combination of poor systems and inadequate resources has the potential to compromise safety.

A number of deficiencies within the Ansett engineering and maintenance organization identified in the Ansett Class A investigation were very similar to deficiencies that had previously been identified within the Ansett flight operations organization. The deficiencies within the flight operations organization came to light during the investigation of an accident that occurred in October 1994 in which an Ansett B-747 aircraft landed with the nose gear retracted and sustained substantial damage to the fuselage.[3] However, although Ansett initiated an ongoing safety review and improvement process throughout the company in response to the 1994 accident, similar deficiencies in management processes within the Ansett engineering and maintenance organization significantly contributed to the grounding of Ansett B-767 aircraft in December 2000 and April 2001.

The international continuing airworthiness system

The international continuing airworthiness system is essentially a complex communication system among all of the organizations responsible for the design, manufacture, regulation, operation, and maintenance of a transport aircraft type.

The operator is the focus of this communication system. They are both the initial source of much of the raw data that drives the system, as well as being the eventual recipient of the continuing airworthiness information that the system produces. The framework for these information flows between States, manufacturers/designers, and operators is outlined in ICAO Annex 6, *Operation of Aircraft*, and Annex 8, *Airworthiness of Aircraft*.

The activities that are necessary for continuing airworthiness are outlined in the ICAO *Airworthiness Manual* (Doc. 9760-AN/967, 2001) (Figure 7). Some of the main elements include

- aspects related to design criteria.
- the publication of information for the maintenance of the aircraft, and the implementation of that material by operators.
- the reporting and analysis of defect, accident and other maintenance and operational information, the transmission of recommended or mandatory action to operators, and subsequent action by the operator.
- accomplishment by the operator of all mandatory requirements including fatigue life limits and any necessary special tests or inspections.
- preparation of and compliance with airworthiness limitations structural inspections.[4]

The international continuing airworthiness system involves the activities of many different organizations. In many respects, the aircraft operator is the last link in an extended safety information chain in which each of the different organisations has its own unique perspective, objectives, and possibly conflicting priorities. That has the potential to affect the quality of the safety information that the operator ultimately receives.

The consistency and quality of the continuing airworthiness information that operators receive could be improved if all parties designed their practices to ensure that they worked toward clearly articulated end objectives for the entire international continuing airworthiness system, as well as any other domestic requirements.

The ATSB Ansett Class A investigation found that the responsibilities of the individual parties in the international continuing airworthiness system are not adequately defined to ensure that the entire system is not compromised by the action, or inaction, of one party.

The continuing airworthiness system should have inherent resilience to allow operators to be confident that the information continuing airworthiness they receive, and rely on, is correct, timely, and complete. Inherent resilience will allow the system to tolerate unexpected deviations that could result in predefined tolerances or limitations being exceeded.

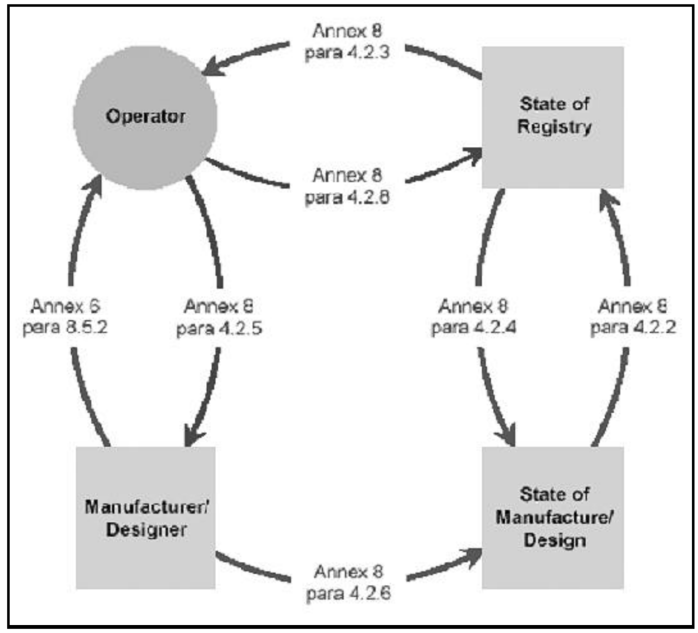

Figure 7. The ICAO framework for continuing airworthiness information flows.

The Australian Civil Aviation Safety Authority

The ATSB investigation found that based on the Ansett B-767 experience, the Australian system for continuing airworthiness of Class A aircraft was not as robust as it could have been, as evidenced by

- uncertainty about continuing airworthiness regulatory requirements,
- inadequate regulatory oversight of a major operator's continuing airworthiness activities,
- Australian major defect report information not being used to best effect.

No evidence was found to indicate that CASA had given formal consideration to monitoring the introduction of the B-767 airworthiness limitations structural inspection program by Ansett.

Prior to December 2000, there was apparently little or no awareness within CASA of the underlying systemic problems that had developed within the Ansett engineering and maintenance organization. The presence of organisational deficiencies remained undetected. In addition, there were delays in adapting regulatory oversight of Ansett in response to indications that Ansett was an organization facing increasing risk.

The decision by the then Civil Aviation Authority in the early 1990s to reduce its previous level of involvement in a number of safety-related areas did not adequately allow for possible longer-term adverse effects. This included reducing the work done by Authority specialist staff in reviewing manufacturer's service bulletins relevant to Australian Class A aircraft, and relying on operators' systems and on action by overseas regulators in some airworthiness matters.

CASA subsequently initiated a comprehensive review of its systems to monitor, assess, and act on service bulletins to ensure that those critical to safety could be readily identified and acted upon appropriately. Recommendations from that review were addressed in an associated implementation plan that detailed the nature and timing of the actions that CASA would take in response to the recommendations.

The U.S. Federal Aviation Administration

Delays by the U.S. Federal Aviation Administration contributed to a lack of awareness by Ansett and CASA of required B767 airworthiness limitations structural inspections. In August 1997, the FAA foreshadowed an airworthiness directive to mandate compliance with the June 1997 *Maintenance Planning Data Document* section 9 revision. However, the airworthiness directive was not issued until approximately 3.5 years later. This delay had the potential to result in poor safety outcomes.

Timely action by the FAA in issuing a relevant airworthiness directive had the potential to alert Ansett, CASA, and other operators to the process in train to mandate the B-767 airworthiness limitations structural inspection program, and of the timeframe specified for compliance with that program.

A breakdown in process within the FAA also resulted in a delay by the FAA in issuing an airworthiness directive in relation to the Boeing Alert service bulletin concerning the B-767 wing front spar outboard pitch load fittings. The initial service bulletin was issued by Boeing in March 2000, but the FAA did not issue an airworthiness directive in relation to the bulletin until April 2001.

There has been evidence of significant and endemic delays in the FAA rulemaking process over many years, and the events of December 2000 demonstrated the potential consequences of such delays. The ATSB Ansett Class A report recommended that it would be prudent for States of registry to consider the potential impact that delays in the FAA rulemaking process could have on the continuing airworthiness assurance of U.S.-designed and/or manufactured aircraft types on their register.

In response to the circumstances of the events of December 2000 and April 2001, the FAA has included further checks and balances designed to ensure that all service bulletins issued by U.S. manufacturers are properly reviewed and addressed. In addition, the FAA has established an "early warning system" to provide non-U.S. airworthiness authorities with information on pending occurrence investigations that may result in mandatory action by the FAA.

Lessons to be learned

The events depicted in the ATSB Ansett Class A report clearly demonstrate that a combination of inappropriate systems and inadequate resource allocation can lead to undesirable outcomes. This is because people and robust systems are two of the prime defenses against error in complex safety-critical systems, such as aviation. Both people and systems can detect and mitigate the effects of errors, from whatever source.

Consequently, all aspects of the air transport system must have effective mechanisms in place to detect and mitigate the effects of human error if it is to remain safe. If a failure by one or two individuals can result in a failure of the system as a whole, then the underlying problem is a deficient system, not human fallibility.

The situation that developed within the Ansett engineering and maintenance organization was the result of particular events and circumstances over an extended period of time. However, other environments could give rise to a similar situation, and, therefore, potentially lead to similar results. All operators should be aware of the potential for a combination of less than fully developed systems and stretched human resources to compromise continuing airworthiness assurance.

Even a relatively small air operator should not underestimate the complexity of ensuring the continuing airworthiness of its fleet. The international system is, by necessity, very complex. It is made up of a number of large organizations that have to work together to make another, larger, system work effectively.

In any complex system, subtle changes over time can lead to the development of situations that may result in unforeseen consequences. Without effective monitoring, the system may slowly deteriorate until it is no longer capable of performing the task for which it was originally intended. A gradual transformation may mask the effects of change until a combination of events leads to a rapid and severe readjustment. It is possible to see the situation that developed within Ansett in this light.

Ansett had undergone considerable change over a number of years. Many of the Ansett systems were developed at a time when the company faced a very different aviation environment. A number of significant changes had taken place since 1990. These changes included the ending of the two–airline policy in the domestic airline industry and the introduction of a "user pays" principle that required industry and users of the system to cover a significant part of the cost of the provision of air safety services.

Over time, efficiency measures were introduced to improve productivity within the Ansett organization. However, as Ansett emerged from the earlier protected environment, the equally necessary introduction of modern robust systems did not keep pace with the relative reduction in human resources. Therefore, a situation gradually developed in which the nature of the Ansett system fundamentally changed. That eventually had unforeseen, and undesired, consequences.

Until Ansett withdrew its aircraft from service, there was apparently little or no awareness within Ansett or CASA of the underlying systemic problems that had developed within the Ansett engineering and maintenance organization. The presence of organizational deficiencies remained undetected.

The question that naturally arises is, "How could this have happened?" The answer may in part lie simply in the need to be mindful.

The concept of "organizational mindfulness"[5] has been developed to help understand the successful operation of "high-reliability organizations." High-reliability organizations operate in an environment where it is not prudent to adopt a strategy of learning from mistakes. The essence of organizational mindfulness is the idea that no system can guarantee safety for once and for all. Rather, it is necessary for an organization to cultivate a state of continuous mindfulness, or unease, and always be alert to the possibility of system failure.[6]

The preoccupation of high-reliability organizations with possible failure means that they are willing to accept redundancy. They will deploy more people than is necessary in the normal course of events so that there are extra resources to deal with abnormal situations when they arise. This means that staff are not routinely placed in situations of overload that may adversely affect their performance.

While high-reliability organizations are preoccupied with failure, more conventional organizations focus on their successes. They use success to justify the elimination of what is seen as unnecessary effort and redundancy, and they interpret the absence of failure as evidence of the competence and skillfulness of their managers. This focus on success breeds confidence that all is well and leads to a tendency for management and staff to drift into complacency.

Australia has a long–standing reputation as a world leader in safe aviation operations. However, this investigation indicated that there were a number of deficiencies within the system for ensuring the continuing airworthiness of Class A aircraft in Australia. These deficiencies occurred within the operator concerned, Ansett, the regulatory body of the State of design, the FAA, and the Australian regulatory body, CASA.

That those safety deficiencies went undetected, both within the operator and within the regulators, for an extended period of time, raises the question as to whether Australia's historically good aviation safety record led to a degree of complacency within the aviation safety system.

The world aviation system has undergone considerable change in the last decade, and Australia has been no exception. Economic deregulation and changes in the commercial environment have been accompanied by equally major changes in the regulatory sphere, resulting in many improvements in safety and efficiency. Nevertheless, periodic review is needed to ensure that existing systems for maintaining air safety keep pace with the changing environment. ◆

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Boeing Human Factors products and services

http://www.boeing.com/commercial/ams/mss/brochures/humanfactors.html

FAA Human Factors in Aviation Maintenance and Inspection (HFAMI)

http://hfskyway.faa.gov/

Footnotes

1 Australian Class A aircraft refers to an aircraft with a certificate of airworthiness issued in the transport category, or one that is used for regular public transport operations.

2 Continuing airworthiness assurance refers to the confidence that there are robust systems in place to ensure that the continuing airworthiness status of the aircraft is known at all times.

3 BASI Investigation Report 1999403038 *Boeing 747-312 VH-INH, Sydney (Kingsford-Smith) Airport, NSW, Oct. 19, 1994*.

4 The ICAO *Airworthiness Manual* uses the term Supplemental Structural Inspection Programs. The Supplemental Structural Inspection Program is the term used to describe one possible means of compliance with the mandatory airworthiness limitations structural inspections.

5 Weick, K,E, and Sutcliffe, K.M. (2001). *Managing the Unexpected: Assuring High Performance in an Age of Complexity*. Jossey-Bass: San Francisco, U.S.A.

6 Similar safety concepts have been described as "chronic unease" (Reason, 1997) and "requisite imagination" (Westrum, 1993).

Juridical and Technical Aspects in The Investigation of Aviation Accidents And Incidents in Argentina And Latin America

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Foreword

It can be said that the technical and legal aspects of aircraft accidents and incidents are one of the most complex but less studied chapters of the contemporaneous air law. In fact, in all aviation accidents, the tension between the technical issues and legal regulations, as well as the discernment of liabilities, becomes dramatically evident since the objective of the investigation has a preventive purpose, meanwhile the civil or criminal procedures mainly lead to apportion of blame or liability.

This distinction is clearly made in Section 3.1 of Chapter 3 of Annex 13 of the 1944 Chicago Convention[1], through which is established that *"The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability."*

Although the technical and the juridical investigations, like Janus's faces, pull in opposite directions, they have a common border, upon which little is spoken in specialized forums and whose analysis will be the main object of this paper, since—often—the difference of purposes already mentioned generates an entropy whose vortex turns around the use by courts and judges of the information contained in the technical report of the investigation. Such a situation and its related weakening effect put in risk the effectiveness of both subsystems: the legal and the technical one.[2]

The Latin America scenario is an example of the situation described above. In Argentina—like in others Latin American countries—the Civil Aviation Code presents many asymmetries with regard to the international standards and practices recommended by ICAO, the most of which still have not been notified according to what is established in Article 38 of the 1944 Chicago Convention.[3] As ICAO practices represent both the minimum standards applicable to civil aviation and the last tendencies in the field, the updating of Argentinean and others Latin American Codes is crucial.[4] Such modernization has to adapt them to current aeronautical demands in order to harmonize the needs of justice with the proper technical investigation of accidents and incidents without risking flight safety.[5]

1. Annex 13 to the 1944 Chicago Convention on International Civil Aviation—origin and objectives

The preamble of the 1944 Chicago Convention, signed in Chicago on Dec. 7, 1944, clearly establishes that international civil aviation should be developed in a safe and orderly manner.

What is remarkable in this sentence is the fact that the word *safe* precedes the word *order*. Teleological speaking, and taking into account what is said by art. 31 of the 1969 Vienna Convention on the Law of Treaties[6], we think of such order of precedence is not casual but it seeks to highlight a goal itself. Consistently, when Article 44.a deals with the "objectives" of the organization, it also emphasizes the motto *"safe* and *orderly"* as the more important targets of the Convention.

Finally, Article 26 of Chapter IV on "Measures to Facilitate Air Navigation" sets down two principles: 1) every time an accident occurs it shall be investigated, and 2) the investigation shall be carried out by the country in which the accident took place. The rule was the source of Annex 13, entitled "Aircraft accident and incident Investigation."[7]

2. Necessity and purpose of the investigation of civil aviation accidents

Section 3.1 of Chapter 3 of Annex 13, entitled "Objective of the

Investigation," determines that *"The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability."*

The Argentinean Aeronautical Code, in force since 1967, alludes to the importance of carrying out aircraft accident inquiries not only in Title IX but also in its Preliminary Words (*Exposición de Motivos*).[8] The last one recognizes that the high degree of safety and efficiency in air carriage is—to a great extent—consequence of the scrutiny of the causes of the flight accidents. The first one regulates the issue through Articles 185 to 190 by establishing that *"Every aircraft accident will be investigated by the aeronautical authority to determine its causes and to establish the measures to avoid its repetition."* (Article 185)

Similar provisions can be found in the Brazilian Code of Aeronautics, which creates an aircraft accident investigation and prevention system that involves *"the manufacturing, maintenance, operation, and flight of aircraft, as well as the activities supporting civil aviation facilities in the Brazilian territory"* (Articles 86 and 87); the Aeronautical Code of Chile, whose Article 181 indicates that *"The investigation will be made with the purpose of determining the cause of the accident or incident, of adopting the necessary measures to avoid its repetition and...."*; the Civil Aeronautics Code of Guatemala, which empowers the civil aviation head office *"to investigate and coordinate from the administrative and technical point of view the aircraft accidents and incidents in Guatemala...* [in order] *to determine its causes and to establish the measures to prevent its repetition …."*; the Civil Aviation Act of Mexico, whose Article 81 sets down that the Secretariat of Communications and Transport *"will determine the probable cause of* [the accident]...."; the Civil Aeronautic Act of Peru, which regulates the topic in Title XV also recognizing that the objective of the investigation of the accident is *"to determine its causes and to establish the measures to avoid their reiteration"*; the Aeronautical Code of Uruguay, which reproduces almost the same formula; and the Civil Aviation Act of Venezuela, which highlights the goal of "[Approving] *norms applicable in the area of the State's security, and oriented to achieve the uniformity and equality of methods and procedures internationally accepted to improve the security, regularity, and efficiency of air navigation."* (Article 3.4)

3. Methodology of the inquiry

The Appendix of Annex 13 on the "Format of the Final Report" indicates the parts in which it is divided, and defines the titles of the Report following the logical methodological sequence of the technical investigation of the aircraft accident or incident. This task supposes an expert knowledge, training, and experience in multidisciplinary works that cannot be assumed without a quite solid professional preparation.

This training, knowledge, and preparation differs from those skills expected from a judge who resolves the case in light of the civil and criminal law.

4. Purpose and importance of recorders (FDR and CVR)

Both the flight data and the Cockpit voice recorders were specifically installed in aircraft as a technical aid for the investigation of accidents and incidents. In some cases, it would have been impossible or very difficult to determine the causes of accidents without counting on the information contained in these recorders.

Section 5.12 of the fifth chapter, which deals with "Investigation," recommends that—in principle—such information shouldn't be disclosed *"for purposes other than accident or incident investigation…."*

In Argentina, the Aeronautical Code neither mentions them nor legally protects the information, which may be due to the fact that— at the moment of the sanction of our Code (1967)—the incorporation of both recorders in air carriage was at the first stage. Similar blanks can be seen in other Latin American rules.

5. Asymmetries between the Argentine Aeronautical Code and other Latin American Acts with respect to Annex 13

i) Although there is a coincidence between the Argentine Aeronautical Code and Annex 13 on the purposes of the aircraft accident investigation, the Code says explicitly nothing about the importance of not civilly or criminally blaming anybody on the basis of the information gathered by technical investigators.[9] On the contrary, provisions of Decree 934/70 admit the use of the report to sanction people, at least from the administrative point of view.

The Code also lacks rules imposing the investigation of incidents or what should be done whether the State of occurrence decides not to investigate the accident or the investigation has been carried out superficially.

Once the aeronautical authority arrives at the place of the accident (namely, the Investigation Board of Civil Aviation Accidents—JIAAC in Spanish, depending on the Argentinean Air Force), Article 187 establishes that the removal or release of the aircraft, its parts, or remainders will be only possible with its previous consent. The first legal inference that can be obtained from this rule is that, in Argentina, the custody of the evidence in the case of a plane crash undoubtedly corresponds to the aeronautical authority. Nevertheless, judges usually take control of the FDR and CVR to utilize them as evidence to apportion blame or liability.

For instance, during the investigation of an accident of LAPA Air Company, happened on Aug. 31, 1999, at Jorge Newbery Airport, in the Buenos Aires, a criminal Judge ordered the seizure of flight data and cockpit voice recorders. After that, the judge gave them to the JIAAC with the unique mandate to send the records to the NTSB for their transcription and bring them back to the Judge. The information contained in the CVR was soon published by newspapers and reproduced on television, which affected the personal rights of the family and spouses of those who participated in the dialogues recorded on the CVR.

The definition of an aircraft accident given by the Argentinean Code does not coincide with Annex 13, Chapter 1, and when the Decree 934/70 alludes to the "operation of the aircraft," it does not give a cabal idea of the moment in which such operation starts. For this reason, Argentina has notified ICAO that in our country the concept of "accident" is broader than the ICAO's.

ii) Since 1986 Brazil has an Aeronautical Code approved by Act 7565. Its Article 94 indicates that *"The facilitation system of air transport, at hands of the Ministry of Aeronautics, aims to study the norms and practices recommended by the International Civil Aviation Organization—ICAO—and to propose to the respective organizations the more suitable measures to implement them in the country, guaranteeing the results and suggesting the necessary amendments for the improvement of the air services."*

Nevertheless, the set of articles related to administrative infractions also includes violations of *"rules, norms, or international* *clauses or acts"* (article 302.II.m). Such infractions will be weighed by an Aeronautical Judgment Board, whose creation is endorsed by the Ministry of Aeronautics by Article 322. The application of administrative sanctions neither prevents nor prejudices the infliction of civil sanctions by other authorities (Article 293), but if along with the administrative infliction a crime is detected, the aeronautical authority will immediately forward the file to the police or the judicial authority (Article 291.§ 1°). Notwithstanding all this, until now Brazil did not communicate any asymmetry between its national law and the international norms. Consequently, and taking in mind Articles 37 and 38 of the Chicago Convention, such silence must be interpreted at the international level in the sense that Brazil fulfils them perfectly. [10]

iii) Since 1990 the Republic of Chile has a new Aeronautical Code approved by Act 18916. Title XI—compounded by two articles—is devoted to the investigation of aircraft accidents and incidents. Article 181 establishes that *"The aeronautical authority shall carry out the administrative investigation of those aircraft accidents and incidents that take place on national territory..., without prejudice to faculties that correspond to the competent tribunals."*

Reading the first part of the article it seems to confirm the independence of the technical investigation—called here "administrative"—irrespective of that performed by Justice. However, the second part of the norm throws some doubts on this interpretation, because here it is indicated that *"The investigation will be made with the purpose of determining the cause of the accident or incident, of adopting the necessary measures to avoid its repetition and of blaming people for the infractions."*

iv) A new Civil Aviation Act was approved in Guatemala by Decree 93-2000. Its Article 5 specifies that *"for the activities foreseen in this Act, the government of Guatemala adopts the international norms of the International Civil Aviation Organization,"* and Article 117 determines that *"The investigation of aircraft accidents and incidents will be subjected to the norms and procedures established in international treaties ratified by Guatemala and its aim is the prevention of them."* Nevertheless, when the investigation of aircraft accidents and incidents is regulated in Title XIV, formed by articles 116 and 117, the first of which entitles the head office *"to investigate and coordinate from the administrative and technical point of view the aircraft accidents and incidents in Guatemala....."* [in order] *to determine its causes and to establish the measures to prevent its repetition, and if necessary sanctioning the infractors."* Accordingly, Article 129 of Title XV stipulates that *"If during the investigation of an accident or an infraction … the civil aviation head office discovers the commission of an infraction, illicit act, or crime, it will forward the pertinent documentation and other elements of evaluation to the competent authority."*

v) With the last amendment introduced in January 1998, the Mexican Civil Aviation Act regulates the topic addressed in this paper from articles 79 to 82 of Chapter XVI, entitled "Accidents and Search and Rescue Activities." The first remarkable note of this legislation is its nature of being of public interest (Article 1). In harmony with this feature, the international norms and treaties are beneath the national law (Article 4). The investigation shall be carried out by the Secretariat of Communications and Transport (Article 81) *"with hearing of the interested parties,"* adding that *"it will determine the probable cause of* [the accident] *and, if necessary, it will impose penalties…."* As with most of the already discussed Latin American legislation, this norm is in frank contradiction with what is stipulated in Annex 13. Nevertheless, Mexico is listed among the countries that ICAO has never received a notification detailing the asymmetries between its norms and the international ones.[11]

vi) Peru, Uruguay, and Venezuela are other examples of the inconsistencies between Latin American air laws and ICAO rules.

6. Proposals to update the investigation of accidents and incidents in the Argentinean Aeronautical Code

In order to be consistent with ICAO rules, the Argentinean Aeronautical Code should be updated in the following aspects:
1) the definition of accident and incident.
2) to make clear that the objective of the Investigation is not to apportion blames or responsibilities.
3) to protect the information and statements made by crew, cabin crew, witnesses, passengers, manufacturers, operators, or any other person, with the exclusive purpose of preventing futures accidents or incidents and of improving the flight safety.
4) in order to protect the flight recorders, prohibit their diffusion in any media. Apparently, Argentina—like other Latin American States—has forgotten that flight recorders are installed in aircraft with the object to facilitate the investigation of accidents and incidents, and consequently they don't have to be used for purposes other than the flight safety.
5) to eliminate any kind of sanctions as a result of the investigation.
6) to investigate not only accidents but also incidents.
7) to make obligatory the investigation of those accidents or incidents involving Argentinean aircraft to the extent they are not investigated in the State of occurrence.
8) to implement an obligatory system of notification of incidents.
9) to create a database on accidents and incidents.
10) to interchange the information on operational safety with other States.

7. Parts of the technical report that could be used

In order to avoid the action of justice preventing the action of the technical investigation, but also in order to avoid that an absolute confidentiality on the results of the technical investigation impairs the action of justice, certain parts of the technical report should be of free public access[12]—for instance, those that indicate which were the causes of the accident, and which are the recommendations to prevent similar occurrences.[13]

8. Privileged information: its definition and use

The Argentinean legal order lacks the idea of privileged information, a legal construction accepted by the U.S. legislation; therefore, the statements of witnesses made with preventive purposes before the Civil Aviation Accident Investigation Board are used in judicial processes to apportion blame or liability.

The goal of determining which data are privileged is to protect the information provided during the investigation of an accident or incident with the purpose of improving this task and of not impairing the future inquiries. For instance, 49 USCA § 1441(e) stipulates that *"No part of any report or reports of the National Transportation Safety Board relating to any accident or the investigation thereof, shall be admitted as evidence or used in any suit or action for damages growing out of any matter mentioned in such report or re-*

ports." Since it is privileged material, the judge is specially entitled to review the report privately to determine whether some of its elements or parts can be disclosed in the process.[14]

It is remarkable to recall here that the concept of privileged information has been incorporated by unanimity in the SICOFAA Aircraft Accidents Investigation Manual of the American Air Forces Cooperation System (SICOFAA, in Spanish).[15]. This precedent can be a starting point for the future legal trends and jurisprudence in Latin America.

9. Necessity of having harmonized legislation in the Latin American countries

Having analyzed the legislation of eight Latin American countries[16], two constant are observed: on one hand, a set of asymmetries between their provisions and the ICAO rules is not yet notified to the international organization. This behavior has to be seen as a failure to perform Articles 37 and 38 of the 1944 Chicago Convention. On the other hand, there is also a certain lack of homogeneity in domestic regulations of the investigation of civil aviation accidents. Both problems, together with the existence of some legal loopholes in the matter, lead us to propose the harmonization and integral treatment of the subject in all Latin American States as soon as possible.

10. Binding value of ICAO's annexes

As a result of the diplomatic conference held in Chicago between November and December of 1944 with the main objective of elaborating an agreement upon international civil aviation, a final act composed of five appendices was approved, the second of which contained the text of the 1944 Chicago Convention, and the fifth one a project of twelve Ordinances dealing with technical issues of international civil aviation.[17] The 12 Ordinances are mentioned in Article 54.l of Chicago Convention as *"international standards and recommended practices, for convenience designate them as Annexes to this Convention."*

Consequently, the most interesting question that prevails here is to discern whether those twelve Ordinances were included <u>as part of</u> the Chicago Treaty and, in such a case, which are their binding parts.[18] Finally, it is also relevant to inquire whether there is any legal difference between the first twelve Ordinances and the subsequent six technical annexes elaborated by the ICAO Council[19], like Annex 13 approved 7 years later.

In general, and according to the dominant opinion of contemporary authors, it could be held that they are the so-called norms of international regulation law. Taking care of the ontological differences, they resemble the decrees approved by public administration of any State with the intention of regulating the rights and obligations contained in the laws dictated or approved by the national parliament.

The previous considerations point out that the Annexes do not have the same legal nature of the Chicago Convention, but they have a binding nature derived from the above-mentioned Articles 37 and 38. Hence, their binding nature would be based on the *good faith* principle, which is unanimously considered by publicists as *ius cogens*, that is to say, as a peremptory norm that is part of the international "public order." Once the State communicates the asymmetry (and here it is necessary to emphasize that such a notification is a *pacta sunt servanda* obligation), ICAO immediately distributes the news to other members notifying that there is a country where the international recommended norm does not prevail or prevails with the communicated modifications. By communicating the asymmetry, such State can oppose its national rule toward other members. All this contributes, indeed, to good international faith. Therefore, in case of a breach, the derived legal consequences lack the severity of the case where the breach of a substantive legal norm could be detected. For that reason, the Chicago Convention does not indicate any specific sanction against the defaulting State. This omission debilitates both the effectiveness of Article 38 and the proclaimed target of reaching the highest possible degree of uniformity within the regulations in order to facilitate and improve the safety of air navigation (Article 37).[20]

11. Amendments to Annex 13 that make the protection of the information more effective

Although Chapter 3 of Annex 13 clearly establishes that the purpose of the investigation is not to apportion blame or liability, later in Chapter 5, entitled "Investigation," in Parr. 5.10 entitled "Coordination—Judicial Authorities," in Parr. 5.11 on "Informing Aviation Security Authorities," and in Parr. 5.12 on "Non-disclosure of Records," it is placed in the hands of justice the last decision to reveal them at a national and/or international level.

This ambiguity allows that certain information can be used for aims other than the prevention of future accidents or incidents, leaving the final and unquestionable decision to the criterion of justice, whose function is mainly devoted to apportion blame or liability.

In order to fulfil with the objectives of the investigation (Chapter 3), the following are our proposals of amendments so as to improve the above quoted paragraphs:

Parr. 5.10, as amended: (proposals are in bold, highlighting that Note 2 should be considered as a norm instead of a method.)
The State conducting the investigation shall recognize the need for coordination between the investigator-in-charge and the judicial authorities. Particular attention shall be given to evidence that requires prompt recording and analysis for the investigation to be successful, such as the examination and identification of victims and read-outs of flight **data and voice recorders (FDR and CVR)** recordings. **They shall be given without delay to the investigator-in-charge, since any unjustified or illegal retention would impede the investigation process and seriously affect flight safety. All this shall be done in order to avoid the security of other passengers, crew, and goods that may be directly affected.**

Possible conflicts between investigating and judicial authorities regarding the custody of flight **data and voice** recordings **(as well as another element related to the investigation of the causes of the accident) shall be** resolved by an official of the judicial authority carrying **them under temporary custody**, **in the understanding that the main custody corresponds to the authorities in charge of the investigation, unless a more important legal interest demonstrates to proceed otherwise.**

Note 1. (remains unchanged)

***Parr. 5.11, as amended*—Informing aviation security authorities** (proposals are in bold).
If, in the course of an investigation it becomes known, or it is suspected, that an act of unlawful interference was involved, **ac-**

cording to the definition given in the respective international treaties enforce, the investigator-in-charge shall immediately initiate action to ensure that the aviation security authorities of the State(s) concerned are so informed. **All the information and facts related to the unlawful interference shall be made available to the security authorities; the rest of the information shall be addressed according to the recommended in Parr. 5.12.**

***Parr. 5.12, as amended*—Non-disclosure of records** (proposals are in bold). The State conducting the investigation of an accident or incident, **wherever it occurs**, shall not make the following records available for purposes other than accident or incident investigation:
a) all statements taken from persons by the investigation authorities in the course of their investigation;
b) all communications between persons having been involved in the operation of the aircraft;
c) medical or private information regarding persons involved in the accident or incident;
d) cockpit voice recordings and transcripts from such recordings;
e) opinions expressed in the analysis of the information, including flight recorder information, **since the installation of flight data and voice recorders is exclusively for the investigation of accidents and incidents, or for other studies related to flight safety; and**
f) any privileged information obtained during the investigation.

5.12.1 These records shall be included in the final report or its appendices only when pertinent to the analysis of the accident or incident. Parts of the records not relevant to the analysis shall not be disclosed.

The appropriate authority for the administration of justice in the State that investigates the accident or incident shall be entitled to use the records mentioned in points a) **to f)** when determined, **based on founded reasons**, that their disclosure outweighs the adverse domestic and international impact such action may have on that or any future investigation.

12. The technical investigation of unlawful interference (opinion of an accident investigator)

Paragraph 5.11 of Annex 13, previously analyzed, establishes that in case of an evident or a suspected act of unlawful interference, the investigator-in-charge shall immediately initiate action to ensure that the aviation security authorities of the State(s) concerned are so informed.

But it is not clear which is the future relation of the investigator with the security authorities and which kind of protection shall be given to the records protected under parr. 5.12.

Also it should be considered that flight safety needs to take prompt action, and usually justice times do not take care of such necessity.

12.1 Proposal of amendments to Annex 17

Annex 17[21] defines security as *"a combination of measures and human and material resources intended to safeguard civil aviation against acts of unlawful interference,"* but there is no recommendation to the States to undertake an inquiry to prevent as soon as possible similar acts of interference.

Independently whether deaths or damage were caused by an accident or criminal attack, certainly aviation safety must be improved. Therefore, Annex 17 would have to be updated consistently with Annex 13 to carry out a technical investigation with the purpose of making safety recommendations to improve both safety and security with the object that future passengers, crew, and cargo fly safely.

ICAO should recommend that the State of occurrence shall undertake a technical investigation through which the task of justice, security, and investigation board are coordinated.

13. Conclusions

It is evident that justice is increasingly hampered the investigation of aircraft accidents and incidents.

This interference affects the readiness and quality of the technical investigation. We believe that, taking into account the strong pressures exerted by victims, insurances companies and the media—this problem will increase.

Although there are countries that have legislation consistent with Annex 13, other States do not have appropriate rules protecting the investigation from justice. Thus the risk of interference is real. This is worsened by the lack of a more-precise international legislation (ICAO's Annex 13).

Modern aviation is mainly international, and nobody is free from this problem, since the investigation of accidents is made on the basis of the particular legislation of the country of occurrence.

Particularly for the Latin American countries, inspired in different legal roots than other regions, there is not a strong safeguard for the use of the information gathered by investigators for other purposes.

Also the technical investigation—in coordination with the task of justice, security, and the investigation board—should be performed for the acts of unlawful interference (ICAO's Annex 17), since independently of how the accident happened or who carried out the act of unlawful interference, which is endangered is flight safety and the security of passengers, crew, cargo, and third parties on the surface.

Under this background, we think that ISASI has an important role to generate the appropriate improvements.

14. Recommendations

1) Annex 13 should be amended to improve the safeguard of records.
2) With the assistance of ISASI, Latin American countries should adapt their legislation to Annex 13.
3) ISASI may propose to ICAO the above detailed amendments. ◆

Footnotes

1 Annex 13 of the 1944 Chicago Convention on International Civil Aviation, on Aircraft Accident and Incident Investigation, ninth edition—July 2001
2 Capaldo, G.: *Investigation of Aircraft Accidents and Incidents in Latin America (Part I),* Zeitschrift für Luft-und Weltraumrecht, N° 3/2003, Köln, (pág. 332-354).
3 Ortiz, L.—Capaldo, G.: *Problems with the Use of Accident Technical Information by Justice in Argentina and Latin America,* in *Proceedings* of Boston Seminar of the International Society of Air Safety Investigators (ISASI 1999), Boston 1999 (pp. 55/56).
4 Ortiz, L.—Capaldo, G.: *Can Justice Use Technical and Personal Information Obtained Through Aircraft Accident Investigations? Journal of Air Law & Commerce*, Vol. 65—Issue 2, Spring 2000 (pp. 263/277).
5 Conclusions of the *"I Jornadas Nacionales para Jueces y Fiscales Federales sobre Aspectos Técnicos y Jurídicos de la Investigación de Accidentes de Aviación,"* Faculty of Law of the University of Buenos Aires, Sept. 7-8, 2000.
6 As a general rule of interpretation, Article 31 of the 1969 Vienna Conven-

tion determines that *"A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of* ***its object and purpose.****"*

7 The last amendment of Annex 13 was made in July 2001 (ninth edition) and entry into force three month later, in November 2001.

8 Código Aeronáutico de la República Argentina (Aeronautical Code, Argentina), Act 17285/67 as amended by Acts 19.620, 20.509/73 and 22.390.

9 Ortiz, L.: *Legislación Sobre investigación de Accidentes en la Argentina,* Seminario Sobre Investigación de Accidentes e Incidentes: dos Perspectivas Regionales. Santa Cruz de la Sierra, Bolivia, April 2-5, 2001.

10 Capaldo, G.: op. cit., see footnote 2.

11 Capaldo, G.: op. cit., see footnote 2.

12 Capaldo, G.: *El Derecho Aeronáutico en la Investigación de Accidentes Aéreos: Perspectivas Desde el Código Aeronáutico Argentino y su Probable Reforma,"* Comunicación Científica a la Sexta Ponencia sobre "Investigación de Accidentes Aéreos"—Instituto Iberoamericano de Derecho Aeronáutico, del Espacio y de la Aviación Comercial, Madrid Oct. 23-25, 2001.

13 Capaldo, G.: *Investigación de Accidentes e Incidentes Aéreos. Aspectos Técnicos, Jurídicos y Humanos,"* XXXI Jornadas Iberoamericanas de Derecho Aeronáutico y del Espacio y de la Aviación Comercial, Barcelona Oct. 22-25, 2002.

14 Matthewson, Charles: *It is a privilege,* Flying Safety, October 1994, and May 1995.

15 Ortiz, L.—Capaldo, G.: *Accidentes e Incidentes de Aviación. Algunos Aspectos Técnicos y Jurídicos,* Revista Aeroespacio—Nov/Dic 2000. See also footnotes 3 and 5.

16 Capaldo, G.: op. cit., see footnote 13.

17 Primavera, Joaquín: *Uma Questao Prévia: Vigoram os Anexos da ICAO na Ordem Jurídica Interna Portuguesa,* in Na Data do 50° Aniversário da Convencao de Chicago de 1944.

Abeyratne, R.I.R.: *The legal status of the Chicago Convention and its Annexes,* in *Air & Space Law*, Vol. XIX, N° 3, June 1994.

18 The difference between norm and recommended practice (or standard) was settled for the very first time in Resolution A1-31 of the ICAO's General Assembly.

19 Capaldo, G.: op. cit., see footnote 13.

20 Capaldo, G.: op. cit., see footnote 13.

21 Annex 17 to the Convention on International Civil Aviation—Security, seventh edition—April 2002.

The Protection of the Sources Of Safety Information

By James Burin, Flight Safety Foundation, U.S.A.

Jim Burin has 36 years of aviation experience and 28 years of experience in the aviation safety field. He is a graduate of Dartmouth College and has a master of science degree in systems analysis from the Naval Postgraduate School. His work in aviation safety includes controlled flight into terrain, human factors, safety program organization, accident investigation, operations, administration, education, and organizational and leadership influences on safety.He is a retired Navy captain, having commanded an attack squadron and a carrier air wing during his 30-year career. Prior to joining the Flight Safety Foundation, he was the director of the School of Aviation Safety in Monterey, Calif. As the director of technical programs his duties include organizing and overseeing safety committees and managing safety-related conferences and research. He has frequently spoken at safety conferences, seminars, and workshops around the world.

Aviation safety has an enviable and well-earned reputation for accident reduction and risk management. The way we reduce risk in aviation is a model for other organizations and disciplines. We use information from lessons learned and other sources, like FOQA, non-punitive reporting systems, LOSA, etc., to constantly improve our system. Without this information, aviation safety can not and will not improve. We use this information not to punish or place blame, but to prevent future accidents and reduce risk. However, there is a serious challenge to improving aviation safety today, and it does not deal with CFIT, runway incursions, or maintenance issues. This challenge was originally titled the "criminalization of safety," but the new title you see above more accurately reflects the goal of the Flight Safety Foundation's efforts. This effort involves complex factors that include types of legal systems, local cultures, traditions, and approaches to human error. What the Foundation is advocating is the need to develop an international framework that protects information obtained through all safety data-acquisition sources.

Now some may ask, Protection from what? Well, aviation professionals face punishment from several sources, like criminal proceedings, civil actions, or regulatory actions. Figure 1 is a partial listing of some safety events that have turned out to be judicial events also. Any punishment administered is based on factors such as the type of legal system in use, the local culture, and tradition. There are two basic legal systems in the world, Napoleonic (or Roman) law and common law. In Roman law, the judge decides what is truth and who is guilty. He is an active participant in the investigation. In common law, the judge just acts as a referee, and does not decide guilt or truth, and he is not involved in the investigation. Of course, there are variations and combinations of these two systems around the world.

There are also different approaches to human error. In the theoretical (or idealistic) approach, human beings are assumed

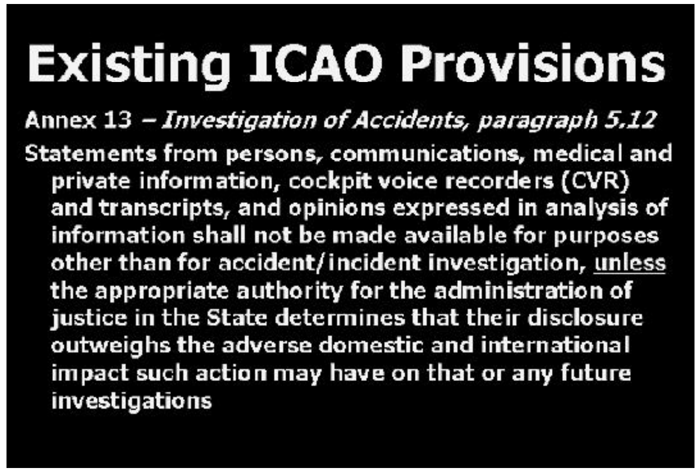


Figure 1

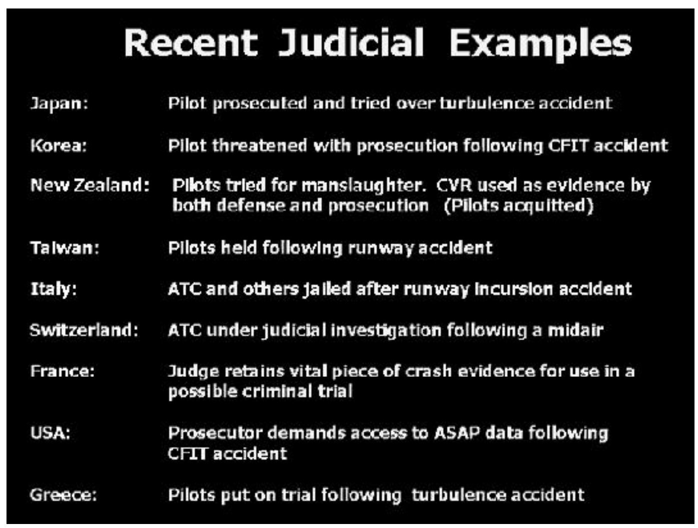


Figure 2

to be able to avoid all mistakes if they want, so an error is a lack of good will, and an accident is seen as the result of careless behavior and so it is a crime. In the practical (or realistic) approach to human error, human beings are seen as fallible, so to err is human and not necessarily careless behavior. In this approach, an accident is not a crime unless it involves gross negligence or willful misconduct. In safety, we separate errors and violations—the law does not. If a culture is blame centered, this will obviously discourage the flow of information concerning errors. Also, in some countries the culture may favor penalties for simple human error, so concealing one's own mistakes is in effect encouraged. Not a good way to improve any system.

Recent years have shown a trend toward the increased access to and utilization of accident and incident reports and other safety data as evidence in judicial proceedings. ICAO has several provisions that address this topic (see Figure 2). The cornerstone ICAO document is Annex 13, and the cornerstone provision is in paragraph 5.12 (see Figure 3). At first glance, this appears to be exactly what any safety professional would want to have in terms of protection. However, a closer look reveals that it may not provide as much protection as we might think, or want. After reading 5.12 closely, you can see that no State would ever have to file a difference to it. If you do not make the specified information available, you comply. If you do make the information available, you also comply. Not much protection there. In addition, 5.12 only addresses accident and serious incident records, such as CVRs, transcripts, and opinions. It does not address sources of safety information like FOQA, LOSA, non-punitive reporting systems, etc. A few countries—notably Australia, New Zealand, and Canada—have implemented 5.12 in its true spirit and indeed protect accident/incident records well. However, in a recent Eurocontrol survey, it was discovered that more than half of the countries surveyed did not even have the basic protections of Annex 13, 5.12 implemented into their national laws.

Some people feel that formal protection for safety information is not needed, and that common sense and some of the current "gentlemen's agreements" are sufficient to provide any protection required. However, it is not unusual to find that gentlemen are not always involved in these issues, and that common sense is not always so common in legal matters. However, the news isn't all bad—there are some success stories. In New Zealand, a long and bitter court battle resulted in a law being passed on the use (or more precisely the non-use) of the CVR in legal proceedings. Canada is about to pass an amendment to its national aeronautics act that requires that safety data reported on a voluntary basis be protected from disclosure and enforcement. In the United States, FAR Part 193 provides protection from FOIA for voluntarily submitted safety information. In 2003 the European Union passed a directive on occurrence reporting that greatly enhanced the protections provided. Finally, there is the Denmark case. This has become the poster child for this effort, as it is a real-world example of what can go wrong, and how formal protections can make it better. In 1996 Denmark developed a program requiring pilots, maintenance technicians, ATC controllers, and other aviation personnel to report specific flight occurrences. The program provided no guarantees of confidentiality. In 1997, because of freedom of information laws, Denmark was required to give access to these reports to the press. This action was not well received. The number of reports decreased by half in 1998, and a third again in 1999. The message was obvious, and a prime example of why we are involved in this effort. There was no protection, so the flow of vital safety information virtually stopped. In December 2000, a bill was proposed to the Danish parliament to make reporting of all matters of a flight-safety nature free of penalty and confidential. The bill passed in May 2001. In the first year after the passage of the new law, the number of reports doubled—and it continues to increase.

So the question is, What should be done to protect this vital safety information? At the request of Stuart Matthews, the president and CEO of Flight Safety Foundation, the Flight Safety Foundation's Icarus Committee addressed this issue and provided inputs back to Matthews. He reviewed these inputs and in January 2003 sent a letter to Dr. Assad Kotaite, the president of the ICAO Council, concerning protecting the sources of safety information to ensure the free flow of safety information. He offered the Foundation's assistance in drafting an assembly resolution to address the challenge. In February 2003, Dr. Kotaite responded positively to the letter and said an assembly resolution would provide the framework necessary and the timing was appropriate for the 2004 assembly. He said, "I believe the combined efforts and expertise of ICAO and the FSF offer the potential for a most successful outcome."

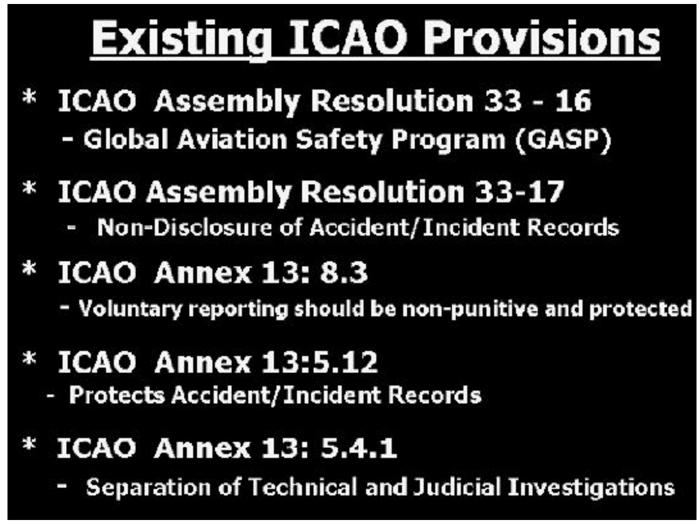


Figure 3

Since the exchange of letters in early 2003, the Foundation and ICAO have worked diligently to craft an assembly resolution that addresses this issue. The proposed resolution requires that ICAO develop legal guidance to assist States to enact national laws and regulations to protect information from safety data collection systems, while allowing for the proper administration of justice in the State. It also requires States to examine their existing legislation and adjust as necessary, or enact laws and regulations, to protect information from safety data-collection systems based on the legal tools developed by ICAO. In addition, the resolution requires that ICAO report to the next ordinary session of the assembly on this matter. The ICAO Council has endorsed the proposed resolution, and it was to go before the general assembly for approval in September 2004.

The public interest requires a balance between the protection of safety information and the availability of evidence in judicial actions. In addressing this challenge, the Flight Safety Foundation hopes to ensure protection of safety information sources, and thus maintain or increase the flow of safety information so vitally needed to constantly improve our already superb safety record. This will enable us to continue to strive toward the Foundation's goal of "making flying safer by reducing the risk of an accident." ◆

A300B4 Loss of All Hydraulics, Baghdad: A Remarkable Example Of Airmanship

By Yannick Malinge, Airbus Industrie, France

***Yannick Malinge** is vice-president of flight safety at Airbus. He has worked at Airbus since he became a graduated aeronautical engineer from the French National Civil Aviation School in 1986. He has been in charge of particular working groups with A330/ A340 launch customers (1987 to 1992); was deputy director of flight safety (1993 to 1997), which involved being in charge of various accident/major incident investigations; was director of technical support/coordination for flight test (1998-2002), which involved leading the technical support and coordination of flight tests during the flight test campaigns for the A319 corporate jet and the 340-500 and A340-600; and was director of product safety process (2002-2003), in charge of reviewing the Airbus internal safety process, in particular for the follow-up of in-service incidents.*

Introduction

On Nov. 22, 2003, an all-cargo A300, operated by DHL, registered OO-DLL, took off from Baghdad, bound for Bahrain. It was the A300B4, serial No. 94, manufactured on March 3, 1980. On board, the crew was made up of Eric, the pilot-in-command, also pilot flying; Steve, the first officer, also pilot non flying; and Mario, the flight engineer.

At the time of the event, the captain had accumulated a total of 3,300 flight hours, including 1,786 on type. The first officer had accumulated a total of 1,275 flight hours, including 199 on type, and the flight engineer had accumulated a total of 13,423 flight hours, including 1,709 on type.

They were prepared for a routine mission, transporting essentially mail to their intended destination from Baghdad to Bahrain.

At about 8,000 ft, a missile hit the left wing of the aircraft leading to the loss of all hydraulics systems.

With a remarkable airmanship and CRM, the crew managed to safely land the aircraft using only the engine thrust, which was the only remaining means to control the aircraft.

Three crew members, in a seemingly impossible situation, succeeded in recovering a measure of control and thus saving themselves and their aircraft. This extraordinary feat was achieved in spite of the extreme stress of the situation; they analyzed the problems and worked as a crew to manage the priorities.

1. Event description

The takeoff

The weather is clear, it is a short leg with a light load, the takeoff weight being only 100 tons, well below the MTOW of 165.9 tons.

Aligned on Runway 15 Left, the brakes are released and the thrust applied. The lightly loaded aircraft, in “slats only” configuration, is quickly airborne and slats are retracted at low altitude, and climb is established at 215 kts for maximum gradient.

The missile impact

At about 8,000 ft an explosion rocks the aircraft, followed in a few seconds by a succession of aural warnings. The flight engineer announces that the green and yellow hydraulic systems are lost, and 20 seconds later the blue system is also losing pressure.

The aircraft is now without conventional pilot input. Stick and rudder are ineffective. The flight control surfaces are deprived of their hydraulic power and are aligned with the airflow (zero hinge moment).

The configuration is frozen:

- Slats and flaps cannot be extended.
- Spoilers are no longer controlled.
- The position of the horizontal stabilizer cannot be adjusted. It is and will remain at the trim position for 215 kts with climb thrust.

Flying the aircraft without hydraulic power

Total loss of hydraulics is quickly identified. A state of emergency is declared by the PNF to ATC. The crew is advised that the left wing is on fire. The aircraft continues to climb and stabilizes with moderate left bank. A learning period begins during which the crew discovers how to control pitch by modulating thrust. Initially the thrust lever movements are large and essentially symmetrical, and the turn to the left thus continues,

Twenty-five long minutes after impact of the missile, the A300 lands on Runway 33L, without further damage.

Still without any direct means of directional control, the aircraft rapidly goes off the side of the runway. The throttles are now retarded and selected to full reverse. The sandy ground provides a significant extra braking force.

the aircraft performing a wide unsteady 360° turn.

The crew finds that they can effectively stop the climb by reducing thrust, but that this also causes the airspeed to increase. They must cope with this apparent paradox, due to the change in pitching moment that cannot be corrected by the jammed horizontal stabilizer.

The PF orders extension of the landing gear by the emergency gravity extension procedure, even though the speed already slightly exceeds 270 kts, the maximum allowed for landing gear extension. The gear comes down providing additional drag. This is the only means to bring the speed back toward 210 kts.

Now that the aircraft is controllable in pitch around level flight and at a speed compatible with landing, the PF learns to control the direction of flight.

The explosion of the missile has torn away a significant part of the left wing between the trailing edge and the web of the rear-spar, which is also the aft wall of the outboard fuel tank. Three thousand five hundred kg of fuel pour out and ignite rapidly.

There is a worsening dual asymmetry of shape and of weight between the left and the right wings, which is causing a continuous left turn. This must be corrected to enable a return to the airfield.

Asymmetric handling of the throttles can control bank. When the left engine alone is accelerated, the wings return to the horizontal, as when the right engine only is retarded. But it's not easy.

• The response to thrust change appears fast in pitch, but roll response is delayed since the roll results from the sideslip induced by the asymmetric thrust, and there is a lag before this takes effect.

• Since the left wing is damaged, the degree of asymmetric thrust must be found that is sufficient to compensate for the asymmetry of lift, and it must be maintained while the thrust is adjusted to control the slope. Easier to say than to do!

Approach

Finally, the PF learns this particular trick of performing such throttle gymnastics fairly quickly, and after several roll excursions slightly beyond 30°, confidence was gained. Now he can consider navigating back to the field, which he has lost sight of during these "training maneuvers."

The PNF takes on the navigation. A long final is needed, at least 20 nautical miles. After a second 360° turn to the left, followed by a straight outbound leg, the PF starts a right turn to come back toward Runway 33R, the longer of the two runways at Baghdad. The descent flightpath must now be established. That is not simple either: the descent angle selected by the average value of thrust is not easy to assess, since the whole process is subject to the phugoid oscillation. It is thus an average descent angle that must be judged, all the while maintaining the heading by asymmetric adjustment of the engines. This is not instinctive when the pitch is varying between 0° and 5° with a period of about 1 minute!

To complicate matters further, the turbulence associated with a wind of 20 kts from 290° (left crosswind component) tends to excite natural oscillations, and in addition GPWS warnings associated with the abnormal landing configuration sound repeatedly on short final.

The alignment is difficult: The PF adapts his objectives to the limited means of control available.

• Runway 33L seems closer to the actual track; they go for the left runway.

• Speed is high, OK to touch down at 220 kts considering the overall situation, in particular since it is determined by the crew that at such speed, they can control the aircraft.

The PF concentrates on the essential—keep the aircraft under control and reach the airfield where there are firemen services to fight the fire on the left wing.

The PNF assists with efficient and timely call outs and announces distances and altitudes. He recalls that the power must

The aircraft is finally stopped with the nose within the airport enclosure.

not be completely reduced; otherwise the symmetrical thrust would induce a turn to the left, particularly undesirable before ground contact.

The flight engineer monitors the fuel remaining in the damaged left wing. It is vital that both engines continue to run.

He stays, therefore, prepared to open the cross feed in case the left main (No. 1) tank empties, but not to soon because the fuel in the right wing would then be lost through the leak on the left side!

At 250 ft, the pitch attitude, still slowly oscillating, drops toward a negative value, which is most alarming so close to the ground. It is restored nose up by a large increase in thrust on both engines.

Toward 100 ft, the aircraft is tracking to the runway threshold, but with a heading 10° less than the orientation of the runway. The PF makes his final lateral control correction, reducing the right engine only. The aircraft banks to the right and the angle of convergence begins to diminish, but thanks to the high thrust maintained on the left engine, the aircraft does not dive toward the ground in the last few feet.

Landing

Twenty-five long minutes after impact of the missile, the A300 lands on Runway 33L, without further damage.

- At a positive pitch attitude (slightly above 2°),
- With a moderate sink rate (in any case less than the 10 ft/sec for which the landing gear is designed),
- And a bank angle of 10° to the right, and heading diverging about 8° to the left of the runway axis.

Still without any direct means of directional control, the aircraft rapidly goes off the side of the runway. The throttles are now retarded and selected to full reverse. The sandy ground provides a significant extra braking force.

Overall, the braking is very effective (approximately 0.5 g deceleration) and the aircraft, in spite of the high speed at touchdown, stops after a landing run of the order of 1 km.

The aircraft is finally stopped with the nose within the airport enclosure. It only remains to evacuate by the right escape slide.

2. Conclusion

This flight, which was concluded so fortunately, should be brought to the attention of the world community of pilots, just as was the flight of the DC-10 at Sioux City. It is a good lesson in flight safety that must not be forgotten.

Well done—Eric, Steve, Mario.

Lessons in terms of crew resource management

The crew, in a seemingly impossible situation, succeeded in recovering a measure of control and thus saving themselves and their aircraft. This extraordinary feat was achieved in spite of the extreme stress of the situation; they analyzed the problems and worked as a crew to manage the priorities.

Lessons in terms of training

Following the event, discussions and questions were raised regarding the need to train pilots to face similar situation. Airbus came to the following conclusions.

Each such situation is unique and cannot be trained for in advance. Therefore, training is not appropriate; however, the pilot community should know the basic principles. Crew will have to adapt, applying the following basic principles:

- Pitch is controlled by thrust.
- Speed must be accepted (provided vertical speed is controlled).
- Roll is controlled by differential thrust with considerable time response.
- DO NOT RETARD thrust at flare.

3. Congratulations

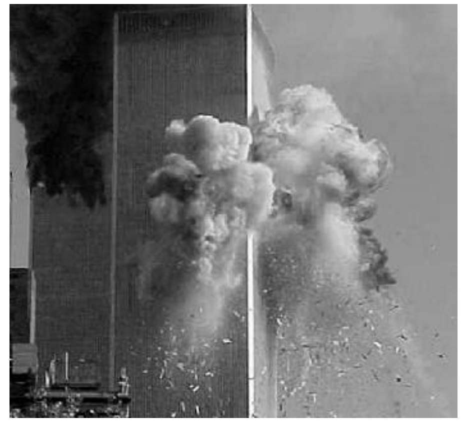
At a time when the finger is so often pointed at pilots, let us congratulate them for the extraordinary demonstration of the adaptability of humans to master such an improbable situation.

Well done—Eric, Steve, Mario. ◆

When an Aircraft Crash Is Not an Accident: Experiences of an Air Safety Investigator at Ground Zero

By Eric West, Federal Aviation Administration, U.S.A.





Eric West *is currently an air safety investigator with the Federal Aviation Administration in Washington, D.C., a position he has held for the last 5 years. Prior to this he was an aviation safety inspector with the FAA's Flight Standards District Office in Boston. His aviation experience began in the United States Navy when he was attached to several helicopter squadrons. After attending the University of Colorado, he continued his aviation pursuits by receiving his A&P license at Colorado Aero Tech. West has a pilot's license with an instrument rating and holds an inspection authorization. He has participated in several major accident investigations that include JFK Junior, EgyptAir, Singapore 006, Air China 129, China Air 611, and was the FAA representative in New York City during the 9/11 investigation.*

Good afternoon, ladies and gentlemen. It is an honor to be here with you today so I can share with you my experi ences concerning a very tragic event that happened to my country. First, I am going to tell you what happened on that day from my perspective. Second, I will share with you lessons I learned from that experience. Finally, I developed a checklist of items for your consideration if you are ever involved with investigating a terrorist-induced aviation disaster.

Tuesday morning, Sept. 11, 2001, just after 9:00 a.m., my calm and ordered world changed forever when I received a telephone call from my wife. She informed me that an aircraft just crashed into the World Trade Center in New York City and did I know anything about it? "No," I replied, "but let me check it out." A minute later, the accident investigation staff gathered around the TV. CNN showed a live shot of one of the World Trade Center towers with thick, black smoke pouring out of the upper stories.

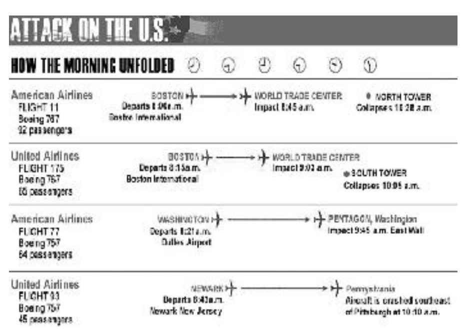
At 9:02 a.m., while still watching the news coverage, in a moment that I shall never forget, a large passenger jet aircraft came into view and made a sweeping turn towards the other World Trade Tower and aimed directly for it. I stepped back in horror as I watched the aircraft hit the other tower and disintegrate into a giant fireball.

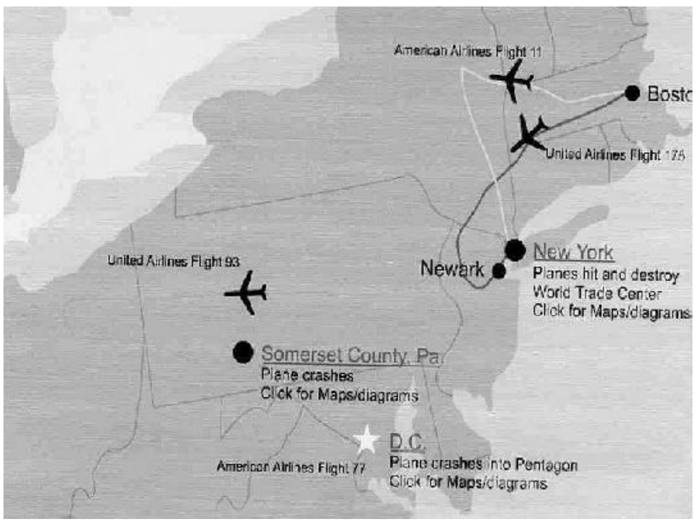
Frank Del Gandio and I ran up to the operations control center on the top floor. We watched and listened as emergency plans kicked in and, systematically, major airports began to close. Air traffic controllers from the New York area were the first to stop aircraft from taking off from JFK and La Guardia. The FAA's New England Region and Washington area soon followed. Nationwide, aircraft were directed by air traffic control to land at the nearest "suitable" airport. All aircraft responded to air traffic's request except United Flight 93, which was flying west over the state of Ohio.

At 9:45 a.m., we heard that American Airlines Flight 77 had hit the Pentagon just across the river from us.

This confirmed the fact that this was a large, coordinated terrorist attack involving at least three large air carrier aircraft. A fourth aircraft, United Flight 93, was being tracked by the Cleveland Air Traffic Control Center. Radar showed that the aircraft had TURNED AROUND over Ohio and was now headed southeast, on a bearing that pointed directly toward WASHINGTON, D.C.

Frank and I went back downstairs to our office conference room. We needed a window. From our 8th floor vantage point, we could see black smoke rising high in the sky from the direction of the Pentagon. Together, we searched the skies for Flight 93. At 10:10 a.m., we got the word that Flight 93 crashed in a wooded area outside of Shanksville,





Clockwise from top left: Pentagon hit; Shanksville crash site; New York City Ground Zero; flightpaths.

Pa. At the time, we did not know it, but the aircraft crashed because of the courageous actions of the passengers trying to take back control of the airplane. By sacrificing their lives, Washington, D.C., was saved from another terrorist attack.

In the midst of all this confusion and uncertainty, I tried to figure out where an air safety investigator would fit into this rather new and dangerous situation. Silently, I asked myself one important question.

DOES A CRIMINAL ACT INVOLVING COMMERCIAL AIRCRAFT ELIMINATE THE PARTICIPATION OF AIR SAFETY INVESTIGATORS IN THE INVESTIGATION?

My question was answered the next day, September 12, when the Federal Bureau of Investigation, the FBI, asked for FAA participation at all three locations. Air safety investigators from our office went to Pennsylvania, the Pentagon, and New York City. Since I was third on the "go list," I was instructed to go to New York City. In a matter of a few hours, I rented a car, went home to pack and said goodbye to my apprehensive wife and two children. Then I set off to the site of the largest disaster in America's history since Pearl Harbor—New York City—Ground Zero.

As you can imagine, security in and around New York City was extremely tight on the day I arrived. Nowhere was that more evident than lower Manhattan. I drove south along the Hudson River where police set up several barricades in order to keep the public from getting close to the world's largest crime scene. At each checkpoint, I showed my credentials and was allowed to pass. When I reached my destination, there were swarms of heavily armed FBI agents and Army National Guard soldiers guarding an old building.

Everyone had heavy-caliber weapons hanging off their shoulders and automatic pistols strapped to their legs. All I had on was a windbreaker with "FAA" in big yellow letters on the front and back and…NO gun. "What is the FAA?" asked an FBI agent as I got out of the car. "The Friendly Aviation Administration," I replied. My attempt at humor in a difficult time must have worked because the agent smiled and allowed me to proceed.

The FBI command center was in an old, rundown garage. At the top of the garage's ramp was an overhead garage door with a regular door cut into the middle of it. An armed agent guarded that door and checked my credentials. Upon entering, I was greeted by the smell of old oil and gasoline that was spiced with the musty smell of 450 people, who darted in an out of a maze of tables like frenzied electrons each attempting to find the path of least resistance. In the background was the steady hum of voices, talking on telephones. Each phone was attached to one of a hundred telephone wires hanging loosely from the ceiling. "Mr. West," I said to no one in particular, "welcome to your new home."

The garage space was expansive with large rectangular columns that supported the roof. In the center of the room, numerous tables were arranged in horizontal rows from left to right. Each table was task identified by a piece of poster board taped to the front. To the left of the center tables was a row of about 12 tables. They were perpendicular to the center tables and seated the supporting agencies. My table was in between the New York/New Jersey Port Authority Police and the United States Post Office Inspector General. Plastered on the right-side wall were life-sized posters of the 19 terrorists. It reminded me of the FBI's most-wanted bulletins that are on the wall at most post offices.

Now another question came to mind…

CAN AN AIR SAFETY INVESTIGATOR HELP LAW ENFORCEMENT AUTHORITIES IN THEIR QUEST TO DETERMINE WHAT HAPPENED?

FAA operations control center.

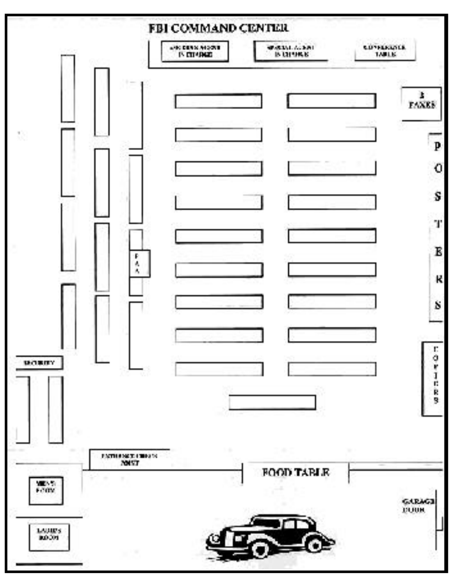
My table came with a black telephone and one in/out basket. I sat down with my notebook, pens, markers, and "go bag." First, I made a request log and a running telephone number contact directory. Second, I called the FAA operations control center. It was a very important source because:

1. It established links to anyone, anywhere.
2. It authenticated my identity, which allowed me quick access to information.
3. It arranged telecons.

For the first week, I could not access the Internet nor could I access the FAA via my laptop computer. This delayed my response time to the various agencies that needed my help. During this hectic week, I found that the FBI wanted hard copies of FAA documents and aircraft design specifications. To rely on the FBI's heavily taxed fax machines was impossible. So working through the FAA command center I got the local FAA district office to deliver the documentation directly to me. Now that I had established a link to any information I could possibly need, I asked myself one final question.

WHAT COULD THE FBI POSSIBLY WANT OR NEED FROM THE GUY WITH ONE PHONE AND A BASKET?

At first there were questions I could answer immediately, such as how a person obtained a pilot certificate. How flight-training facilities were monitored and how airport security was handled. The questions I could not answer right away turned into my requests for documentation. I remember providing information on several of the terrorists that had taken flight lessons in the U.S. Another need had such priority that the FBI dispatched one of their own aircraft to go and pick it up. My time was filled with a never-ending list of requests from the FBI that had to be tracked and logged into my notebook, and answered, one by one.



FBI command center.

During the aftermath of 9/11, everyone in New York City was very sensitive to any aircraft flying overhead. Once the airspace in New York was opened to commercial traffic again, I was asked to prevent airplanes from flying over large gatherings of people during special events. One of these events was the first baseball game to be played in New York City since 9/11. Another was the memorial to the victims of that tragic day. I contacted air traffic control and initiated temporary flight restrictions over such places as Shea Stadium, Yankee Stadium, the Statue of Liberty, and Ground Zero.

Ground Zero

My first visit to Ground Zero was a 3-mile ride from the garage in a New York State Police car. The purpose was to educate the workers at Ground Zero. By educate, I mean an NTSB investigator and I delivered a brand-new cockpit voice recorder (CVR) and flight data recorder (FDR) so the workers had a better chance of identifying them in the debris. Two blocks from the site, we transferred to a golf cart to get closer. A lieutenant with the Brooklyn New York Fire Department drove the cart. He told us his station lost seven men when the south tower collapsed. That moment is forever burned into my memory.

NOTHING in my lifetime prepared me for the sight and smell of Ground Zero. The pictures I am going to show are two-dimensional. What are missing in these slides are the smell, the gray dust, and smoke, mixed with the grit on your teeth as your eyes record the results of wanton destruction. It overpowers one's senses, making words meaningless. Before entering Ground Zero, I "suited up" in a hard hat, respirator, and work boots.

The entrance to the main wreckage site was located between two small parts of the Trade Centers that remained standing.

As I entered the site between the remnants of the two towers, I noticed what appeared to be a bagel store.

I took this picture to remind me that when this attack occurred, people were busy with normal everyday activities. The World Trade Center was now a wasteland, accented by the very distinctive outside steel facades sticking out of the rubble.

White smoke and steam billowed out of the many hills of scrap

Entering Ground Zero

and debris as if they were miniature volcanoes on the surface of another world.

The millions of tons of building wreckage generated so much pressure that infrared scanners recorded temperatures as high as 1,800 degrees Fahrenheit inside the debris field.

Buildings surrounding the Trade Center monoliths took their share of damage. The pressure wave that was created as the towers collapsed under their own weight blew out hundreds of surrounding office windows in an instant.

Dozens of bordering structures would be officially condemned and rendered structurally unsound, never to be used again. During the cleanup operation, hundreds of pieces from both aircraft were found on the rooftops of buildings as far as 5 blocks away.

One day, I was summoned to an FBI tent near Ground Zero and shown a piece of evidence. It was a U.S. pilot's certificate that was found in the rubble, yet it was in perfect condition. As the agent handed it to me, I immediately recognized the Department of Transportation symbol in the upper left-hand corner. I was holding the certificate that belonged to one of the airline pilots. I couldn't help thinking how on Earth this fragile piece of paper managed to withstand such an explosion and why almost 3,000 innocent people had died. Again I was hit with another dose of reality, but this time I almost broke down.

Toward the end of September, the FBI decided to change command center locations. We moved to the FBI Federal Building about 3 blocks from Ground Zero. The workload had lightened and the investigation was running smoothly until Monday, Nov. 12, 2001. At 9:30 in the morning, an FBI agent tapped me on the shoulder and pointed to a television monitor. Breaking news on a local channel announced that American Airlines Flight 587 out of JFK airport crashed just after take off.

Then I was told that the FBI special agent in charge wanted me at the accident site immediately. I was ushered outside where two squad cars were waiting and was directed to get into the NYPD squad car. Inside the car were two NYPD detectives. After quick introductions, the detective behind the wheel secured my seatbelt, flipped on the siren, and shoved the car into gear.

Beginning in lower Manhattan, the detective cut across street centerlines and weaved in and out of stalled traffic as drivers heeded the wail of the siren and flashing lights. We crossed the Brooklyn Bridge at 75 miles per hour with the FBI car right behind. From Brooklyn, it is a short distance into the heart of Queens. In less than 25 minutes, we drove 20 miles through New York City traffic to within 2 blocks of the crash site.

Once again I was going to an aircraft crash site surrounded by law enforcement and criminal investigators. Great speculation as to the cause of the crash was prevalent that morning. Another American airplane was down in New York; it was a federal holiday and only 2 months and a day since 9/11. Everyone gathered on a street corner about 2 blocks from the crash site. Behind us stood an ordinary, single-family brick house. Two by two, 20 agents and I snaked our way toward the front door. I thought I was in a movie when the head agent rang the doorbell, held up his badge, and commandeered a little old lady's house.

Once everyone was inside the house, the lead FBI agent raised his hand and called for silence. You could hear a pin drop it was so quiet. The agent pointed over at the dining room table that was empty except for a lone, black telephone. In a clear, loud, and authoritative voice he told the room full of agents, "THAT IS THE FAA PHONE." The FBI directed me, in no uncertain terms, to find out what I could. This was no time for guesswork; I had to get something concrete.

Remembering the events of 9/11 and the takeover of the cockpits by the terrorists, my gut told me to contact the JFK air traffic control tower. I acted quickly and explained to the tower chief where I was and who I was with and that I needed details of what he knew. He replied, "No abnormal communications between the aircraft and the tower." Apparently, that sole piece of information was enough for the FBI. We left the little brick house and walked to another building a short distance away.

Thick black smoke and ferocious flames continued to rise from the crash site off to our left. We entered a Catholic elementary school that was filled to the brim with police and emergency personnel. I was ordered by the FBI to remain outside a classroom until called. Soon I heard a loud voice shout out, "FAA!" I entered the room and came face-to-face and shook hands with the mayor of New York City, Rudolph Giuliani. The FBI asked me to explain to the mayor exactly what I was told by the JFK tower chief.

"NO ABNORMAL COMMUNICATIONS BETWEEN THE TOWER AND THE AIRCRAFT."

The mayor looked over at the lead FBI agent and asked for his advice. His answer was short and to the point. "Let's keep this investigation with the NTSB." The decision was made and Mayor Giuliani went public with the information; a "normal" accident investigation began.

After that, I went to the crash site. There must have been a thousand rescue workers in and around the residential area battling widespread fires where the aircraft came down.

I received information that both engines had separated from the aircraft so I went to find them. The left engine fell in front of a gas station.

It must have come straight down because it did not hit the station or the gas pumps. The right engine landed next to someone's house and destroyed a boat and garage.

The NTSB and FAA Go Teams arrived later that day, and after briefing the FAA IIC, I returned back to the FBI command center.

Now for some lessons learned. First, nothing is more important than preparation, so it is suggested that you

- Be prepared for ANYTHING because if it can happen it will happen.
- Make sure there exists an agreement between the accident investigation agencies and the criminal investigation agency.
- Keep a log of everything that you have done, who you called, phone numbers, etc.
- I found that it worked well to have one person as the point of contact at the FBI command center.
- Keep your boss informed of what you are doing and what you need. Give a briefing to the home office at least once a day.
- Have a security clearance of SECRET or higher from your government because you will be exposed to very sensitive information.
- Don't pretend to know everything. No one does. So call on the experts within your organization for assistance.
- Remain in the loop when information passes between your organization and other outside agencies.
- Let people do their jobs. Do not pressure experts in your organization by constantly calling them and urging them to move faster.

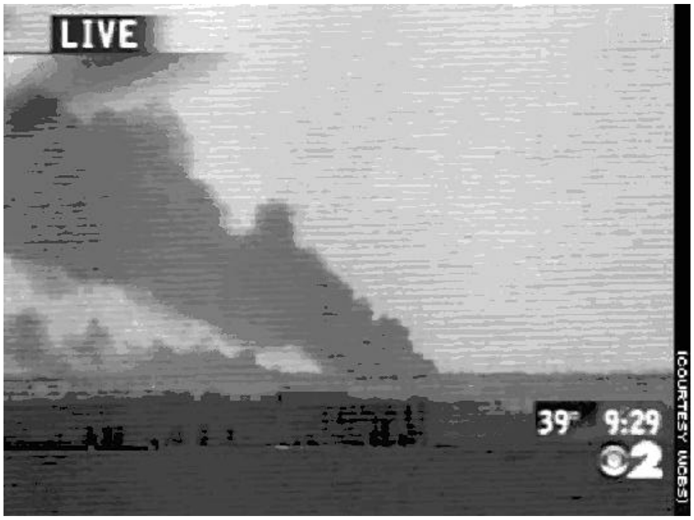
Crash Site of American Airlines Flight 587

- Have dark T-shirts made with your agency's name in yellow so you can be easily identified by anyone who needs you.
- These investigations last a long time, so be prepared to set up a relief schedule.
- Make sure the credit limit on your business credit card is set high enough for an extended stay.
- Throw preconceived notions out the window about where you are going and what the people are like. We all hear tales about how tourists complain about the people from New York City. Nothing was further from the truth. New Yorkers are great people.
- Keep a separate phone line or cell phone available for your family.

Copies of my investigator checklist are available for you after my presentation. Comments are welcome. Contact me through my e-mail address that will appear at the bottom of the checklist.

I am going to end my presentation by reading to you a short passage taken from the *New Yorker* magazine.

On Sept. 15, 2001, at Denver International Airport, the pilot of United Airlines Flight 564 said the following just before departure. "First I want to thank you for being brave enough to fly today. The doors are now closed, and we have no help from the outside for any problems that might occur inside this plane. As you could tell when you checked in, the government has made some changes to increase security in the airports. They have not, however, made any rules about what happens after those doors close. Until they do that, we have made our own rules and I want to share them with you. Here is our plan and our rules. If someone or several people stand up and say they are hijacking this plane, I want you all to stand up together. Then take whatever you have available to you and throw it at them. Throw it at their faces and heads so they will have to raise their hands to protect themselves. The very best protections you have against knives are the pillows and blankets. Who-



ever is close to these people should then try to get a blanket over their heads. Then they won't be able to see. Once that is done, get them down and keep them down and keep them there. Do not let them up. I will then land the plane at the closest place, and we will take care of them. After all, there are usually only a few of them and we are 200 plus strong. We will not allow them to take over this plane. I find it interesting that the U.S. Constitution begins with the words "We the people." That's who we are, the people, and we will not be defeated."[1]

AND WE WILL NEVER FORGET!

Thank you. ◆

ADDENDUM: INVESTIGATOR CHECKLIST

Now I would like to offer my investigator checklist in addition to the standard go bag for your review and evaluation.

Setting up

1. Credentials—make them as valid and bona fide as possible.
2. Business cards—have as much information on them as possible.
3. Notebook with your agency contact points, phone numbers, and other agencies contact points, including the military. This is the backup to your computer.
4. Develop a request log to document your answers to the who, what, when, where, why, and how questions.
5. Employ a turnover log (if there is a need to man the station for more than 12 hours).
6. Have an ample supply of office supplies such as pens, paper, highlighters, markers, file and expandable folders, fax cover sheets, and graph paper.
7. You must have access to a fax machine and copier.

Personal vehicle

1. Drive a rental or government car with no fewer than four doors, and four-wheel drive.
2. Obtain, as soon as possible, an official permit from the agency in charge of the investigation that gives you access to sensitive areas.
3. Obtain a magnetic logo for your car door that has your agency or company name and symbol. Note: Keep magnets away from your computer.
4. Use "official vehicles" as much as possible.

Communications equipment

1. Digital camera with extra batteries.
2. Laptop computer with extra batteries, room and car charging units, Internet capability, and a CD burner.
3. Non-sensitive communications can be done over the Internet.
4. For sensitive information, you will need an encrypted program.
5. Computer must have picture downloading capability.
6. Administrative rights for different printers.
7. Cell phone with charger and extra batteries.
8. Small, portable printer with lots of paper and print cartridges.
9. Extension cord with multiple outlets for plugs.
10. Pager—for those times you are in a meeting and all cell phones are turned off.

Personal needs

1. A month's supply of aspirin and other medication.
2. Scissors.
3. First-aid kit.
4. Enough money to last a month and a roll of coins for vending machines.
5. Arrange for hotel accommodations for a long-term stay.
6. Obtain local maps.
7. Bottled water and snacks to keep you going for 3 days.
8. Your own personal respirator and extra filters.
9. Maintain personal hygiene, including washing one's hands and face before eating just like your mother taught you to do. If not, have a bottle of Imodium AD handy.

E-mail address: eric.west@faa.gov

Endnotes

[1]The *New Yorker* magazine, Oct. 15, 2001, Page 53.

The Size of the Aircraft Doesn't Matter

By Lorenda Ward, National Transportation Safety Board, U.S.A.

Lorenda Ward *is an investigator-in-charge (IIC) for the National Transportation Safety Board. She was part of the NTSB team that supported the FBI at both the Pentagon and the World Trade Center after the Sept. 11,2001, terrorist attacks. She was the IIC for Air Midwest Flight 5481 and the U.S. accredited representative to numerous foreign accident and incident investigations. Before coming to the Safety Board, she worked for the U.S. Navy as an aerospace engineer on the EA-6B and F-14 programs. She has both a bachelor's and master's degree in aerospace engineering from Auburn University and holds a private pilot's license.*

Abstract

There is much to learn from an accident investigation, no matter how large or small the accident aircraft may be. The U.S. National Transportation Safety Board recently investigated the crash of a Raytheon Beechcraft 1900D in Charlotte, N.C., that resulted in 22 safety recommendations to the Federal Aviation Administration (FAA). The recommendations mainly focused on maintenance and weight-and-balance issues and the oversight of those issues. The NTSB's investigations into two Beech Super King Air accidents are additional examples of small-aircraft investigations having a large impact on safety. A Beech Super King Air carrying the Oklahoma State University basketball team crashed on Jan. 27, 2001, near Strasburg, Colorado, in IFR conditions. The NTSB made an unprecedented recommendation to the National Collegiate Athletic Association, the National Association of Intercollegiate Athletics, and the American Council on Education to improve collegiate air travel policies and procedures. The other Beech Super King Air accident occurred in Front Royal, Va., on Oct. 26, 1993, while the aircraft was on an FAA repositioning flight. Seven of the eight recommendations to the FAA dealt with the structure of the FAA flight program. The Safety Board recommended that the FAA model its flight program after a civilian Federal Aviation Regulation (FAR) Part 135 operation. This paper will discuss the recommendations that resulted from these three accident investigations and some lessons learned by investigators during the investigations.

"Investigate, Communicate, and Educate"

In keeping with this year's theme for the conference, this paper will cover three accident investigations that the Safety Board conducted involving small aircraft. The intent is to communicate to you the value that can be gained from small investigations, i.e., safety recommendations, and to educate you on the lessons learned by our investigators during these investigations.

Charlotte investigation

The Beech 1900D accident occurred on Jan. 8, 2003, in Charlotte, N.C. The author of this paper was the investigator-in-charge (IIC) and followed the accident investigation from beginning to end. The final report was issued just a little more than a year after the accident. The accident occurred just shortly after takeoff, killing the two crew members and 19 passengers on board. The aircraft was destroyed by the ground impact and post-crash fire. Because this accident occurred just after takeoff, we naturally started looking at the flight control systems and how the aircraft was loaded. The first question was, "Did the crew members calculate the weight and balance correctly?" We found that they did. Given the weight-and-balance procedures that were in place at the time, the crew members actions were proper. However, we also found that the use of average passenger and baggage weights (as opposed to actual weights) resulted in a computed weight that differed greatly from the actual weight. In other words, if the weight and balance calculation had been based on the true weight of the passengers and baggage, it would have been apparent to the pilots that the flight was well outside the center of gravity (cg) envelope and over maximum takeoff gross weight. The important issue here is that the flight crew was erroneously led to believe that their cg was further forward than it actually was. This resulted in the flight taking off in a significantly tail-heavy condition.

The Beech 1900D accident occurred on Jan. 8, 2003, in Charlotte, N.C.

While one group of investigators was looking into the weight-and-balance issues, the systems group was examining the flight control systems. In the airplane wreckage, the pitch control (or elevator) turnbuckles were found at an unusual setting. The maintenance records revealed that maintenance was performed on the accident aircraft's elevator system a few days earlier. In fact, the turnbuckles had been adjusted during that time. Interviews with maintenance personnel revealed that during the maintenance, a mechanic, who was receiving on-the-job training (OJT) at the time found that the elevator cable tension was low and that he adjusted the cable tension using the elevator rigging procedure in the maintenance manual. But, with the approval of his OJT instructor, he **selectively** skipped some of the other steps in the rigging procedure. The result was that the newly rigged elevator now had limited travel in the airplane-nose-down direction. The combination of the limited elevator travel and the aft cg resulted in the airplane losing pitch control, which was what the Safety Board determined to be the probable cause of the accident.

As you can see, we had two major issues to contend with: the use of incorrect average weights and the maintenance training program for mechanics. Almost all of the recommendations issued to the FAA dealt with these issues. A few of the recommendations will be highlighted. A full listing of the safety recommendations appears in the final report (Aircraft Accident Report NTSB/AAR-04/01), which is posted on the Safety Board's website at http://www.ntsb.gov.

Weight-and-balance recommendations

The use of assumed average passenger and baggage weights (in place of actual weights) for weight-and-balance calculations has long been an industry practice for carriers operating aircraft with more than nine passenger seats. However, using average weights has potential problems. The assumed average weights may not be an accurate representation of the general population, and the actual passengers weights on a given flight may not represent the statistical norm of the general population. For example, a survey conducted after the accident found that the actual average weight of American adults was roughly 20 pounds higher than the average weights being used in many operators' average weight programs. Accordingly, the use of average weights carries a risk of being outside the weight-and-balance envelope, which was the case with the accident in Charlotte.

It is important to note that baggage weights are extremely important for small aircraft, such as the Beech 1900D, that have only one cargo hold or bin. This is because unlike a large aircraft within which you can move the baggage from one cargo hold to another to change the cg, in smaller aircraft there is only one cargo hold.

Clearly, if average passenger weights are not valid then the use of average weights does more harm than good. The Safety Board recommended that the FAA identify situations where actual weights were required versus average weights and recommended that it examine technology for using actual weights versus average weights. The Safety Board also recommended that the FAA require air carriers to periodically survey passenger and baggage weights, to retain the data from their survey, and to develop cg safety margins to account for variances in average weights of passengers and baggage.

Maintenance program recommendations

As a result of its findings regarding the maintenance of the accident aircraft's elevator cables, the Safety Board recommended that aircraft manufacturers establish appropriate procedures for a complete functional check of critical flight systems after maintenance work has been done on that system and that air carriers incorporate those checks in their maintenance procedures. This may sound like a common-sense item, but, to our surprise, it wasn't being done, nor was it required. The Board also looked at how maintenance training was being accomplished, especially OJT, and recommended that maintenance training programs be approved by the FAA, just as the training programs for pilots and flight attendants are. Many of the other maintenance-related recommendations focused on the need for improved maintenance oversight by both the operators and the FAA.

Lessons learned from the Charlotte investigation

An investigation safety lesson was learned the hard way when a systems investigator slipped and injured his back while working around the wreckage. The investigator was wearing the protective footwear covers (yellow booties) that are included with the PPE kit. These covers are required to be worn in areas where bloodborne pathogens may be present. The investigator slipped because the footwear covers do not have good traction on slippery surfaces. They also have a tendency to get caught on objects or become torn from contact with sharp edges. After this incident, our OSHA representative researched other footwear options that would meet our bloodborne pathogen program requirements <u>and</u> not add to the safety hazards presented by the work environment. The OSHA experts have offered several possible replacement boot types, but we still haven't found a suitable boot. The problem is, of course, finding a cost-effective boot that has good traction, that can meet the decontamination standards, and that stand up to our rugged work environment. Many investigators have complained over the years about these boot covers, but it took someone getting hurt to cause us to examine alternatives.

Strasburg investigation

Another example of a less-complex investigation that led to important increases in air safety concerned the loss of a Beech Super King Air on Jan. 27, 2001, near Strasburg, Colo. This accident investigation was closely followed by the American public because the aircraft was carrying members of the Oklahoma State University (OSU) basketball team. Unfortunately, all 10 people on the airplane were killed.

The immediate cause of the accident was reasonably straightforward. The aircraft lost a.c. electrical power and, thus, primary flight instrumentation during a climb through instrument meteorological conditions. This probably occurred because of a failed electrical relay or inverter. The Safety Board determined that although standby flight instruments should have been available, the pilots became spatially disoriented and lost control of the airplane.

During the investigation, ancillary research revealed that Oklahoma State University did not provide any significant oversight of this flight, or any other school-sponsored flight carrying students to events away from the university. Furthermore, the Board determined that this may have been true at many other colleges and universities around the nation. To its credit though, with the encouragement of the Safety Board, OSU formulated a comprehensive travel management system that now promotes safe university-sponsored travel and provides the necessary oversight to ensure that transportation services are carried out in accordance

The Beech Super King Air accident occurred on Jan. 27, 2001, near Strasburg, Colo.

with the provisions of the revised policy. For example, in addition to the oversight provided by the university's athletic director, athletic staff, and coaches, OSU now retains an aviation consultant with expertise in operations, safety and certification of aircraft.

Recommendation

The Safety Board thought that OSU's new safety-oriented travel policies were developed well enough to make a formal recommendation to encourage the National Collegiate Athletic Association, the National Association of Intercollegiate Athletics, and the American Council on Education to follow OSU's lead in these matters. Again, although this accident involved a small airplane, the results of the investigation and proactive participation by Oklahoma State University will undoubtedly save lives in the future.

Lessons learned while on scene

This is one of the Board's first on-scene investigations where a new on-scene hazard "risk analysis" form was filled out before actually launching and every day while working on the wreckage. The IIC uses this form as a planning tool to make everyone more aware of the hazardous conditions that the investigators are working under. On the form, a numerical value is assigned to a variety of working conditions (weather, lighting, terrain, and the like). If the total value exceeds a certain number, then a mitigation plan has to be put in place. In this case, an identified risk was the very cold weather at the accident site. The IIC chose to combat the cold conditions by having several vehicles lined up along the debris field with the engines running and the heaters on. These vehicles acted as warming stations for the investigators and were heavily utilized.

Front Royal investigation

Another Beech Super King Air accident also illustrates the fact that the size of an accident often has little to do with the actual safety benefits of good recommendations. This accident involved an aircraft operated by the FAA that crashed into mountainous terrain during a repositioning flight near Front Royal, Va., in 1993. The Board determined that the probable cause of the accident was the failure of the pilot to stay in visual meteorological conditions (VMC) while in mountainous terrain.

An important aspect of this rather straightforward case concerned discoveries during the investigation of the shortcomings within the entire, quite fragmented FAA flight program. For instance, Board investigators found that although each FAA flying unit had a check airman, training captain, and safety officer slots, these positions were always considered extra duties, and decisions made by these pilots were often overridden by people not directly associated with the FAA flying program. In addition, due to scheduling biases, an unusual supervisory structure, and a lack of available flying time, FAA first officers were that in name only. They were rarely allowed to actually fly and land the airplanes and, for the most part, only served as radio operators on FAA flights.

Recommendations

Seven of the eight recommendations to the FAA that resulted from this investigation had to do with the structure of the FAA flight program, rather than the actions of the flight crew that crashed the airplane. In short, the Board recommended that the FAA flight program model itself after a civilian FAR Part 135 operation, with all the checks and balances, inspection requirements, and aircraft and pilot certifications standards that a small airline would be subject to. The FAA took these recommendations very seriously, and its flight program today is much safer than it was in 1993.

Lesson learned

The accident occurred in daylight conditions, but when one investigator, who lived close to the accident site, arrived on scene, it was dark. The wreckage was in a mountainous area, and the terrain was rugged; but this investigator, anxious to do his job, began searching for the wreckage. When the IIC learned of this, he immediately told the investigator to stop his search effort to prevent him from possibly injuring himself. The following day the wreckage was located by aerial search. The lesson learned here is obvious. Any type of search effort, or any work on aircraft wreckage at all for that matter, is usually not advisable unless such actions can be done under very controlled, safe conditions.

In conclusion, there is much to be gained from small-aircraft accident investigations. As you can see from the three accidents discussed here, more than two dozen recommendations were issued that undoubtedly have saved lives, and quite a few valuable lessons on how to investigate safely were learned. ◆

Investigation of Fatal Double Engine Flame-out to Shorts SD 360 Turboprop

New Approach to Powerplant Investigation and an Unusual Cause Determined.

By Peter Coombs, Air Accident Investigation Branch, U.K.

***Peter Coombs** joined the U.K. AAIB in 1972 and has performed more than 200 field investigations to civil and military fixed- and rotary-wing aircraft and a comparable number of other technical investigations. As a student apprentice with the British Aircraft Corporation from 1966, he gained experience of manufacture, development, and testing of aircraft and missiles, including BAC 1-11, VC10, and Bristol Britannia airliners, before becoming a design engineer on the Concorde SST. Awarded a master of science degree in aircraft design at the College of Aeronautics, Cranfield, in 1971, he flies single- and multi-engine aircraft and is an active flying instructor.*

Accident background

In the early evening of Feb. 27, 2001, a Shorts SD 360 twin turboprop aircraft took off from Edinburgh, Scotland. Although normally serving as a passenger airliner, on this occasion it was carrying only two flight crew and a cargo of mail. Just over a minute after take off, a distress call was received stating that both engines had failed. The machine descended rapidly and ditched in shallow but exposed and extremely choppy waters of a local sea inlet, the Firth of Fourth. It sustained considerable damage at the water impact and soon became partly submerged. Neither crewmember survived.

Investigation of the accident required salvage of the aircraft from the very exposed waters, where it was lying between low- and high-tide positions, followed by detailed examination of its systems and powerplants, development of a robust theory as to the cause of the obscure double power loss, and the preparation and implementation of experiments to support the theory.

The wreck site was such that the aircraft could only be accessed on one occasion on foot (Figure 1) before the changing tidal cycle dictated that at the lowest tides the aircraft still remained partly submerged (Figure 2). This situation was to continue until approximately a week had passed. The recovery task was further hampered by the extent to which the aircraft became buried in the sand with succeeding tides (Figure 3).

Eventually, however, the wreckage was salvaged (Figure 4) and detailed examination began. In the meantime, both the DFDR and the CVR were recovered, decontaminated, and replayed successfully.

My past experience of multiple power loss has led me to expect that one engine may lose power for a variety of reasons, while a second engine generally does so after a time interval, usually following crew actions intended to secure the first engine but incorrectly applied. The only other double power losses I can recall investigating have been

Figure 1: General view of main section of wreckage at low tide, on the morning after the accident.

Figure 2: View of partly submerged wreckage at subsequent low tide.

Figure 3: View of almost submerged wreckage at high tide.

Figure 4: Salvage ships in position during lifting 6 days after accident.

(1) an occasion on which both engines were selected to nearly empty main tanks on departure, following accidental fuel uplift into auxiliary tanks, unobserved by the crew.
(2) an occasion when an Eastern Bloc certificated aircraft, equipped with an automatic engine safety/shut down system, suffered an electrical fault which energized fuel shutoff valves on both engines, driving them to the closed position shortly after takeoff.

Fuel exhaustion, severe engine intake icing, and volcanic ash contamination are, of course, also well-known multiple power loss causes.

The simple two-tank fuel system layout of the SD 360 did not favor the possibility of a system handling error. The possibility of a repetition of the second failure scenario described above was effectively precluded by the purely mechanical operation of both HP and LP fuel valves and the ergonomic difficulty of operating both left- and right-hand controls of either simultaneously. The large fuel uplift apparently carried out at Edinburgh, together with fuel remaining on arrival, virtually precluded the possibility of complete fuel exhaustion so soon after departure, and the aircraft was not flying in icing conditions at the time of the power loss. Finally, as I am sure you know, there are no volcanoes within 5,000 miles upwind of Edinburgh.

It was, therefore, with great surprise that I learned from our recorder specialists that both engine torque values dropped from climb power to zero precipitately and within milliseconds of one another. This occurred at about 1,800 feet, within 8 seconds of the captain requesting the first officer to select the anti-ice systems and almost exactly 5 seconds after the sound of two switch selections, which were immediately followed by the electrical sound of two motors operating.

Relevant features of the aircraft

The aircraft type is powered by two PT 6A series reverse-flow turboprop engines. Each engine is orientated with its compressor at the rear. There are a number of reversals of air and combustion gas flow directions within each powerplant (a total of 720 degrees direction change of flow axis between the external intake and the aft facing exhausts). As shown in Figure 5, air is supplied to the engines via a forward-facing intake behind and below each propeller, while exhaust gases leave via a pair of curved pipes at the front of each engine, arranged to direct the gases backward. The air, having entered each external intake, passes below the whole length of the relevant engine, before turning through a right angle and travelling vertically upward into airtight plenum chambers. From these, it is drawn into each engine compressor through a cylindrical mesh guard (Figure 5). An external view of a nacelle on the salvaged wreck, showing the intake and one exhaust stack, is shown at Figure 6 (page 102).

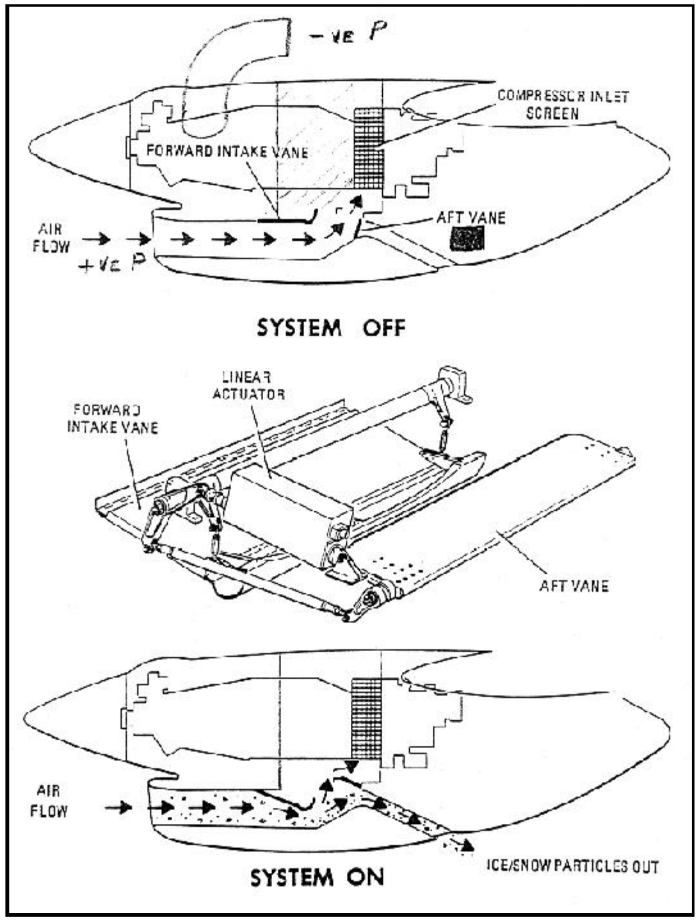


Figure 5: Schematics of nacelle with inertia separator vanes in normal (or OFF) position, above, and deployed (or ON) position, below. Plenum chamber volume is shaded in upper section. Vane drive mechanism is shown in middle diagram.

In icing conditions, the crew may select so-called anti-icing vanes to the ON position (Figure 5). Under these circumstances, a ramp (or forward vane) is lowered from the top surface of each air intake path, reducing the available cross-section for the airflow and causing it to both accelerate and change direction through a bigger angle than would be the case without the vanes deployed. This centrifuges solids and liquids to the outer radius of the curved airflow path. At the same time, a bypass door (or aft vane) opens in each airflow, causing that part of the flow cross-section containing the solids and liquids to be ejected overboard rather than to enter the plenum chambers to risk forming a frozen obstruction on the mesh guard covering the inlet to the relevant engine.

Initial tests

Tests carried out on an example of the linear actuator type, which drives the inertia separators (Figure 5), confirmed that the frequency of the electrical "noise" produced was identical to that of the acoustic noise present on the CVR initiating 5 seconds before engine torque was recorded as lost by the DFDR. It, therefore, became clear that staggered operation of the selector switches of

Figure 6: Left engine nacelle with external intake and one exhaust stack visible after wreckage recovery.

each inertia separator took place 5 seconds before a similarly staggered sudden loss of all power on both engines occurred. There was thus little doubt that deployment of each inertia separator had lead to the consequent power loss of the corresponding engine. This left the question of how this entirely normal system operation could have had such a dramatic and abnormal effect on both engines.

Relevant weather

Early in the investigation it became clear that the aircraft had arrived at Edinburgh at midnight, approximately 17 hours before the accident and had been refueled with the intention of departing within 2 hours. Snow began to fall as the aircraft arrived, however, and became so severe that deicing services and runway snow clearance activities became overwhelmed. No movements took place through the remainder of that night, and snow continued to fall until 0800 the next morning. Services only recovered early in the afternoon.

Through the night, moderate snow (the meteorological term) was accompanied by wind gusting up to 40 knots from a NNE direction. The aircraft was also parked on a heading of approximately NNE. The temperature was between zero and +1°C. As the day began, the wind moderated but continued to gust up to 17 knots on the same heading while the temperature slowly rose to 2 °C by midday.

Sequence of events prior to departure

A new crew arrived in the early afternoon and observed that the aircraft was now free of visible contamination apart from an area of the windscreen. Following a preflight check, the aircraft was started but it was found that a generator would not come on line. The aircraft was shut down and assistance summoned.

A ground engineer carried out trouble shooting and a simple rectification. This required both engines to be briefly run by the crew while electrical loads were applied. These included operation of all anti-icing systems, i.e., windscreens, propellers, air intakes, and inertia separators, before the engines were again shut down. Once the problem was rectified, normal predeparture actions took place and the engines were restarted. During taxiing, the normal checks were carried out. These included a check of the auto-feather. When a propeller is feathered on this type, the corresponding inertia separator is automatically powered to the anti-ice position to further reduce drag.

The accident flight

With inertia separators now reset to the normal position, take off and initial climb took place followed by torque and RPM reduction to climb settings. Only shortly after further reselection of the inertia separators to the anti-ice position, in preparation for entering a sub-zero cloud layer, did the fatal double power loss occur.

Investigation process

Since the most unusual event during the period of idleness at Edinburgh was the weather of the night, I decided to find out what effect the snowfall had on the air intake systems. A special rig was, therefore, built, consisting of a controllable extractor fan mounted on a tapered transition tube incorporating pressure tapping points. The tube was bolted in the place of one exhaust stack of an engine in a borrowed SD 360 aircraft. The other exhaust on that engine was sealed off. The pressure tapings were connected to a digital pitot-static test set.

A downstream pressure drop was created by the fan, having similar magnitude to the pressure difference between the intake face and exit pipe pressures (Figure 5) calculated for the known average headwind speed recorded during the night's snow storm. The speed of the airflow created in the extractor tube was measured by means of the digital test set and the corresponding speed in the intake system calculated. Despite the complex flow path through the total powerplant and the effect of at least seven stages of fixed and a similar number of stages of rotating blades in each engine, the velocity through the system was found to be a high percentage of the local wind speed.

An engine intake system and engine cowling panels, salvaged from the wrecked aircraft, were then assembled into a mock-up of a nacelle incorporating a dummy engine, complete with the intake mesh. Sealed plenum chamber bulkheads were manufactured from Plexiglas and fitted in representative positions within the cowlings. An electric extractor fan was mounted within the dummy engine and an adjustable shutoff valve was fitted at the forward end. Figure 7 shows the front of the arrangement before the adjustable shutoff valve was fitted. The fan was run and the valve adjusted to create airflow velocities in the mock intake system of similar values to those measured and calculated earlier in the intake of the borrowed aircraft.

Simulated snow flakes, comprised of finely cut fragments of expanded polystyrene, were released near the external intake, and their progress through the trunking and into the plenum chamber was observed via the Plexiglas rear bulkhead. It was found that the flakes readily rose up to and over the top of the dummy engine.

It was, therefore, clear that during the night, the wind, despite the complex flow path involved, created a powerful airflow into the external forward-facing intakes, through the intake trunking, upward via the plenum chambers, through the engine inlet mesh filters and through the engines. This airflow had sufficient speed to lift snowflakes up into the area of the plenum chambers, passing around and over the engines. Numerous pipes, tubes wiring looms, and skin stiffeners within the plenum chambers would have ensured that snow was readily deposited on these obstructions and the chamber volumes easily filled with snow. Figure 8 shows a plenum chamber interior volume with the upper cowling removed. The condition of many parked aircraft noted in the morning after the snowfall ceased attested to the large volume of snow that must have passed into the intake and thus remained in the plenum chambers.

Effect of ambient conditions

Although the ambient temperature rose above freezing during the following morning, the large heat sink of the snow filled plenum chambers, allied with the latent heat of melting ice and the small margin of ambient temperature above freezing level would have severely limited the volume of trapped snow that melted. In contrast, the outside surfaces of the aircraft heated more rapidly, due to exposure to sunlight and ultimately required no deicing. Examination, by a crew, of the high-mounted aircraft intakes from the ground or indeed from a closer position would not, for geometric reasons, enable the interior of the plenum chambers to be seen.

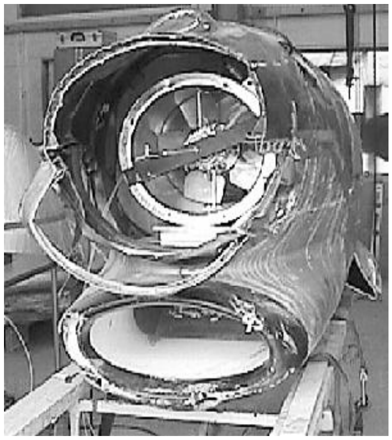


Figure 7: Assembled nacelle mock-up, utilizing panels salvaged from wrecked aircraft, incorporating cylinder forming dummy engine. Extractor fan can be seen. Adjustable valve has yet to be fitted to threaded shaft in front of fan. Transparent Plexiglas bulkheads are fitted in place of metal bulkheads at front and rear of plenum chamber (not visible).

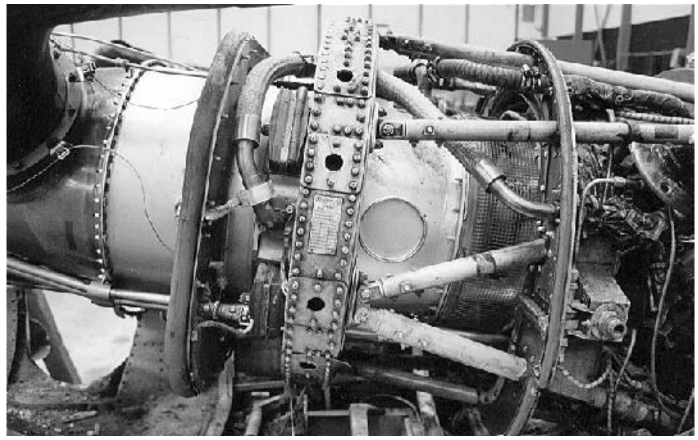


Figure 8: View of interior of plenum chamber with cowlings removed. Enclosed volume is between orange-colored seals. Exhaust stack visible at top left.

Effect of subsequent engine operation

Engine starting would rapidly raise the temperature of the engine carcasses, causing the deposited snow to turn to slush and fall from the plenum chambers into the region of the inertia separators. Although some melt material may have been ingested, the bulk of the tightly packed slushy substance would have arrived at and remained in the area of the vanes. Since air was being drawn through a narrowing cross-section created by the wet slush deposit, and the deployed inertia separators, a condition analogous with the throat of a carburetor would occur in which a temperature drop would be created. A drop of only approximately 2 degrees C would lead to gradual refreezing and solidification of the surface of the slush. Operation of the inertia separators would cause the bypass doors to move the solidifying ice volume forward. Once the separators were returned to the normal position, however, the solidified masses would be free to slide backward towards the bypass doors, under the influence of the airflow. After engine shutdown, the wind would continue to drive air at just above freezing temperature over the refrozen slush, limiting the effect of the hot engines on the ice and rapidly cooling the engines by both internal and external flow.

The engines were soon restarted, creating a renewed cooling effect, presumably returning the slush to a fully frozen state. Again, inertia separators were operated automatically during auto-feather checks, presumably driving refrozen slush forward. Once the separators were returned to the off position, the ice was again free to slide back toward the bypass doors.

As was stated earlier, there is compelling evidence that the anti-ice vanes were selected ON seconds before the fatal power loss. This action normally causes a 50% area reduction or blocking of the free flow of air to the engines at the position of each first vane and a similar 50% blocking at the more down downstream position of the bypass door (Figure 5, page 101). Data supplied by the engine manufacturer showed that an 87% reduction of cross-sectional area of the intake duct, under the torque, RPM, and ambient air conditions recorded and derived at the time of the power loss, would cause engine surge and flame-out. A similar degree of blocking occurring at the low power settings and, hence, much lower mass-flow rates present during operation of the intake vanes on the ground, however, would not have this effect.

Thus a mechanism can be visualized in which weather conditions introduced large volumes of snow into the intake systems where it remained undetected and in a largely solid state. Operation of engines and vanes took place in a sequence that resulted in a large volume of refrozen slush finally lodging in the region of the inertia separators where it added to the blocking effect created by deployment of the latter. With the final volume of slush reducing each inlet duct cross-section by approximately 40%, the effect of its presence and that of the deployment of the vanes would have been sufficient to cause both engines to surge and flame out. The DFDR shows that the HP spools of both engines decelerated almost immediately to below their self-sustaining speed. This effect, coupled with the absence of continuous or auto ignition, ensured that flame-out was total and the engines did not relight.

Summary

Although many other possible causes have been suggested for this power loss, none was found to be as likely as the process described above, given the known conditions and sequence of events. As with most accidents involving icing, the direct evidence was lost and in this case the contamination conditions within the intake systems could not be physically confirmed. Nonetheless, a process of reasonable deduction, based on all the available evidence and the test results, leads us to conclude that the sequence described above was the cause of the power loss. ◆

Field Investigation of the Accident Involving an Ilyushin IL-76 Transport Aircraft in East Timor

By S. A. Barter[1], L. Molent[1], P. Robertson[2], S. Thompson[3], G. Fox[3], and G. Kimmins[3], Defense Science and Technology Organization, Australian Transport Safety Bureau, and Directorate of Flying Safety, ADF, Australia

(Oral presentation by Simon Barter.—Editor)

Simon Barter *graduated from RMIT with qualifications in metallurgical science, Surface finishing and corrosion control. While at DSTO, he has been involved with the metallurgical investigation of aircraft structures and components from many different aircraft types. His involvement in the investigation of numerous aircraft accidents has been the highlight of this work, having completed the Cranfield Aviation Safety Center Aircraft Accident Investigation course. He now works in the structural integrity area undertaking research into fatigue and fracture in high-strength alloys and aircraft accident investigation techniques, and is a member of the DSTO Aircraft Accident Investigation Committee.*

No photo available

Lorris Molent *graduated from the RMIT with a bachelor of engineering (aeronautical) degree. While at DSTO, he has worked in the fields of aircraft structural integrity, structural mechanics, structural and fatigue testing, advanced bonded repair, aircraft vulnerability, and aircraft accident investigation. He has more than 100 publications in these technical areas and is a qualified aircraft accident investigator. He has been attached to both the Australian Civil Aviation Department and the U.S. Navy (NAVAIR) in Washington, D.C., as an airworthiness engineer. Molent currently the leads the combat aircraft structural integrity activities in DSTO, and managers F/A-18 structural integrity as well as the FT46 International Follow-On Structural Test Project's (IFOSTP) full-scale F/A-18 aft fuselage fatigue test.*

No photo available

Phil Robertson *is a senior transport safety investigator with the Australian Transport Safety Bureau. He led the Australian investigation team during the onsite investigation of the IL-76 accident at Baucau, Timor-Leste, and was responsible for compiling the accident report. He holds an air transport pilot (Aeroplane) license, and has command type ratings on B-727 and B-737 transport-category aircraft. Before joining the ATSB, he worked in the regulatory environment in the Middle East as a flight operations inspector, where his duties included responsibility for investigating accidents and incidents involving State-registered aircraft. Before that, he worked as an airline pilot in Australia.*

No photo available

Squadron Leader Thompson *joined the Australian Defense Force in 1979. Following initial employment as a clearance diver, he graduated as a pilot in 1985. He has flown fixed- and rotary-wing aircraft with the Navy, Army, and Air Force, including the CT4, Macchi, Squirrel, Wessex, Bell 206, HS748, and Seahawk. In 2000 Squadron Leader Thompson completed aircraft accident investigator training with the United States Air Force. Employed for 4 years at the Directorate of Flying Safety as an air safety investigator, his primary area of responsibility was defense transport aircraft. During his tour as an investigator, he participated in four major investigations and conducted several safety reviews of squadrons including detached units in the Middle East.*

No photo available

Squadron Leader Fox *joined the Australian Defense Force in 1987. He studied for 3 years at the Australian Defense Force Academy and attained a bachelor of science degree in political studies. He completed RAAF pilot course in 1991 and has had operational tours flying Falcon 900, Boeing 737-BBJ, P-3C Orions, and instructed ab-initio pilots on the PC-9. In August 2000 Squadron Leader Fox completed the United States Navy aviation safety officer's course and commenced a 3½ year post at the Directorate of Flying Safety as an air safety investigator. He has participated in a number of accident and incident investigations.*

No photo available

Squadron Leader Geoff Kimmins *joined the Royal Australian Air Force in 1977 as a technician trainee. On graduation he worked on Macchi, Caribou, and Iroquois aircraft. He was a part of the Tactical Air Support Force and took part in numerous tactical field exercises. In the mid 80s, a desk job beckoned at RAAF Logistics Command. Following commissioning as an engineering officer in 1990, he served variously at a tactical support unit, 84WG with Air Lift Group and Headquarters Air Command. He was able to complete the full maintenance circle on the Caribou aircraft as the senior engineering officer at 38 Squadron. He was trained as an air safety investigator in 2002 and has spent more than 2 years and numerous investigations at the Defense Flying Safety Directorate.*

Abstract

On Jan. 31, 2003, at 0621 UTC (1521 local time), an Ilyushin 76TD, registered RDPL-34141, impacted the ground near Caicido village during an approach to Runway 14 at Cakung Airport, Baucau, Timor-Leste. The aircraft was destroyed and the wreckage lay about 2 km to the northwest of the airport. The Lao PDR-operated aircraft departed Macau International Airport, Macau, and was on an international non-scheduled cargo flight to Baucau. Air traffic services were not available at Baucau at the time of the occurrence, and none of the six on board the aircraft,

which was carrying about 31 tons of telecommunications equipment, survived.

The East Timor government requested assistance from Australia. Members from the Australian Transport Safety Bureau (ATSB) and the Directorate of Flying Safety (DFS) responded. At the request of DFS, two DSTO officers also assisted the team. This small team consisting of less then 10 persons at any time undertook a detailed investigation of a large transport accident in difficult circumstances, involving interaction with several nations, to produce a successful outcome. This was achieved by the use of technological field tools, having significant on-site engineering and materials expertise, and using international cooperation in the analysis of data collected. This paper will outline the on-site engineering and materials wreckage evaluation, wreckage mapping, flight reconstruction, difficulties in investigating third-world registered charter operations, and will discuss some of the issues that arose during the early part of the investigation.

1. Introduction

On Jan. 31, 2003, an Ilyushin 76TD aircraft impacted the ground during an approach to land on Runway 14 at Cakung Airport, Baucau, Timor-Leste (East Timor).

Within a few hours of the occurrence, the government of East Timor requested Australia to provide assistance with the accident investigation. Australia agreed to assist, and assigned the Australian Transport Safety Bureau (ATSB) to conduct the investigation for and on behalf of Timor-Leste, and in accordance with the SARPS of Annex 13 to the Chicago Convention[1].

This paper will outline the on-site engineering and materials wreckage evaluation, wreckage mapping, flight reconstruction, difficulties in investigating third-world registered charter operations, and will discuss some of the issues that arose during the early part of the investigation. Further details can be found at references[2,3].

1.1 History of flight

On Jan. 31, 2003, at 0621 UTC (1521 local time), an Ilyushin 76TD, registered RDPL34141, impacted terrain near Caicido village during an approach to land on Runway 14 at Cakung Airport, Baucau, Timor-Leste. The impact site was about 1 nm (2 km) to the northwest of the aerodrome. The accident site is depicted in Figure 1.

The Lao PDR-registered aircraft departed Macau International Airport, Macau 5 hours 29 minutes earlier, at 0052 UTC, and was on an international non-scheduled cargo flight to Baucau. There were two pilots, one flight engineer, one navigator, and two loadmasters on board, and the aircraft was carrying a cargo of about 31 tons of telecommunications equipment.

The aircraft departed Macau about 9 hours behind schedule because of noise restrictions on the departure of Stage II aircraft from Macau. The crew rested in a hotel during the stopover in Macau, while the two loadmasters remained on board the aircraft to supervise the loading of the cargo.

Witnesses at Cakung Airport, Baucau at the time of the occurrence estimated the cloud base to be about 1,000 ft (305 m) above ground level (AGL), and visibility to be about 1,500 m (0.8 nm).

The lowest safe altitude (LSALT) for the last route segment of the flight between Ambon and Baucau was 4,500 ft (1,372 m) AMSL. Instrument approach and landing procedures were available for Runways 14 and 32 at Baucau, using the Baucau non-

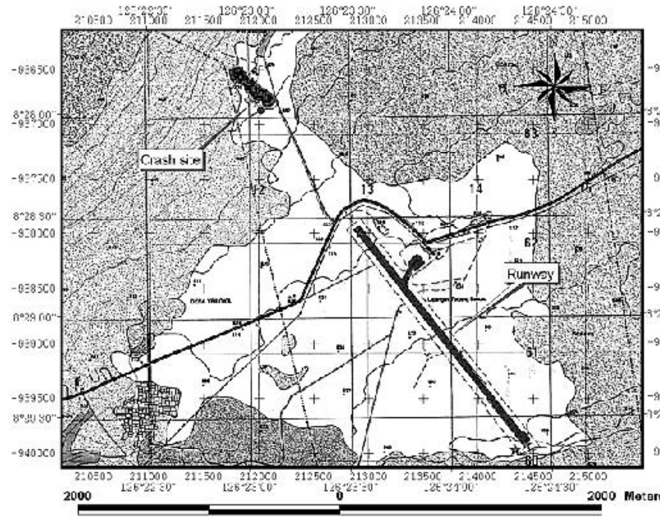


Figure 1. Map of Cakung Airport runway in relation to crash site laid over a local area topographical map.

directional beacon (NDB). The aircraft was fitted with equipment to allow the crew to conduct an NDB approach. The approved approach plates for those procedures were available on request from the Civil Aviation Division (CAD), Timor-Leste. Approach plates for the Runway 14 and 32 Baucau NDB procedures were also published by Jeppesen Sanderson, Inc. (Jeppesen) and the Royal Australian Air Force (RAAF). Each version of the Runway 14 NDB procedure depicted the inbound track of the procedure as being 146 degrees magnetic, and the minimum descent altitude for landing on Runway 14 as 2,260 ft (698 m) AMSL. That was equivalent to a height of 531 ft (162 m) AGL. The threshold elevation for Runway 14 was annotated on each version of the charts as 1,729 ft (527 m) AMSL.

The Jeppesen aerodrome chart depicted the threshold of Runway 14 as being about 0.9 nm (1,700 m) southeast of the NDB. The Jeppesen Runway 14 and 32 NDB approach plates also depicted the runway in that position, relative to the NDB. During the investigation, the actual threshold of Runway 14 was found to be about 1.35 nm (2,500 m) northwest of where it was depicted on those charts. The runway heading for Runway 14 at Baucau was depicted as 135 degrees magnetic on the aerodrome chart issued by CAD. It was also depicted as 135 degrees magnetic on the Jeppesen aerodrome chart. Following the accident, the runway was surveyed and the actual runway heading was determined to be 139 degrees magnetic.

Air traffic services (ATS) were not provided to the occurrence aircraft at Baucau. A notice to airmen (NOTAM) valid at the time of the occurrence advised that ATS was only available for aircraft conducting United Nations troop rotations at Baucau. At 0540UTC, the ATS staff at Baucau received advice from ATS in Brisbane, Australia, that the aircraft's revised arrival time was 0610UTC. At 0553UTC, the crew contacted Baucau ATS. The controller at Baucau advised the crew that ATS was not available, and that landing would be at their discretion, which they acknowledged.

According to the cockpit voice recorder (CVR), the crew set the aircraft altimeter sub-scales to 714 mm of mercury (Hg) as the aircraft was descending through 2,400 m (7,784 ft) on approach to Baucau. That altimeter sub-scale setting was equivalent to 952.8 hectopascals (hPa). The crew positioned the aircraft to overfly Runway 14, and after observing the runway below them, they flew the aircraft on a heading of 135 degrees magnetic before climbing to a height of 500 m (1,640 ft) AGL and positioning on a left downwind leg for Runway 14. The crew was unable to visually sight the runway during the downwind leg, but discussed passing 4 to 5 km (2.1 nm to2.7 nm) laterally abeam Runway ".135." The crew then positioned the aircraft for an approach to Runway 14, using the onboard navigation equipment. However, the aircraft overflew the runway before the crew expected it, and a landing could not be achieved from this approach. The crew again climbed the aircraft to 500 m (1,640 ft) AGL, and with reference to the onboard navigation equipment, they repositioned the aircraft for another approach to Runway 14. When the aircraft was on final approach, the crew descended the aircraft. According to the CVR, at about 2 km (1 nm) from the aerodrome, the crew realized that the aircraft was too low on the approach. The FDR data revealed that the aircraft pitch attitude was then increased; however, the thrust lever angles remained unchanged. Three seconds later, the aircraft impacted the ground.

Witnesses at the aerodrome reported seeing (and photographing) the aircraft overfly the aerodrome twice before its impact with the ground. Witnesses also reported that

- the aircraft landing gear was not extended as it overflew the aerodrome on the first occasion.
- the aircraft landing gear was extended during the second approach (Figure 2), but the aircraft appeared too high to be able to land, and discontinued the landing approach.
- the weather at the time was overcast with a low cloud base.
- a few minutes after the aircraft's second overflight, they heard an explosion to the northwest of the aerodrome shortly after 1520 local time and saw flames and smoke in that vicinity.
- three residents from Caicido village each observed the aircraft suddenly emerge from low cloud close to the ground just before its impact with trees. One of the residents was standing near the trees at the time. Another of the residents was blown to the ground by jet blast from the aircraft as it flew by just before the impact.

The weather conditions at the accident site were described as low misty cloud with light rain, with a visibility from 200 to 300 m. At 0740 UTC, several fires were reported to have still been burning within the wreckage, one of which was described as being a "major fire that was flaming bright white."

1.2 Inquires/damage to aircraft/ property/fire/survival aspects

Impact forces and the post-impact fire destroyed the aircraft, and all six persons on board were killed. The accident was deemed unsurvivable. The investigation was unable to determine the individual total levels of experience on the IL-76 TD aircraft type for the pilot-in-command, copilot, flight engineer ,or flight navigator. An IL-76 TD type rating was entered in each of those flight crewmember's Russian flight crew licenses, and all had held those type ratings for at least 10 years.

During the impact sequence, the right wingtip of the aircraft struck a partially constructed house to the left of the centerline of the wreckage trail, about 190 m from the first impact point. The house, which was occupied at the time by its owner, was severely damaged. The owner of the house was physically uninjured by the impact. Crops near the wreckage trail were also damaged from a combination of turbine fuel, which sprayed from the aircraft fuel tanks as they ruptured during the impact sequence, and from the post-impact fire.

Figure 2. The aircraft as observed during the second overflight at Baucau Airport at about 06:00:20 UTC, note the extended nose landing gear.

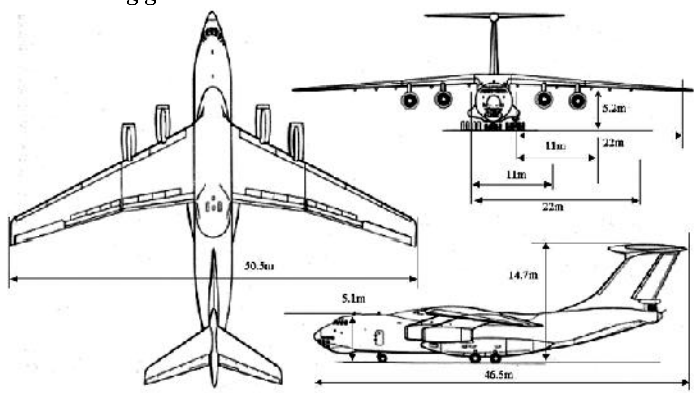


Figure 3. An overview of the IL-76 aircraft.

Figure 4. An IL-76 aircraft (one of two operated by Euro Asia Aviation—EAA). Courtesy EAA.

2. Investigatory response

Shortly after the occurrence of the accident and the request for aid to Australia from the Timor-Leste government, a team of Australian investigators was assembled and dispatched to Baucau. The accident investigation team (AIT) consisted of members from the Australian Transport Safety Bureau (ATSB) and the Directorate of Flying Safety (DFS). At the request of DFS two Defense Science and Technology Organization (DSTO) officers were seconded to assist the team by supplying scientific investigatory support on-site including mapping the wreckage site and the wreckage distribution, and conducting an assessment of the mechanical condition of the aircraft prior to impact and to assess the nature of the post-impact breakup.

The Australian AIT arrived to commence the investigation on Feb. 2, 2003. The United Nations Mission In Support of East Timor (UNMISET) provided logistical support and the Baucau airport managers (PAE) provided a secure room for the team to operate from. The Australian AIT compromised one ATSB officer, P. Robertson, two operations investigators, and one engineering investigator from DFS and two structural and materials scientists/investigators from DSTO. To this team a liaison officer from UNMISET was attached and gave invaluable support to the investigation team in the form of supplies of water, arranging accommodation and medical aid, and numerous other administration tasks.

The Timor-Leste Department of Civil Aviation also supplied one officer as investigatory support; however, his experience in aircraft accident investigation was limited.

It was agreed that the head of the AIT would be the secretary of the Timor-Leste Department of Civil Aviation and the Australian team would report through this channel. Robertson was appointed by the State as the accredited representative while the remaining team members were to be advisors to the accredited representative in accordance with ICAO Annex 13, Sections 5.23 and 5.2.4[1]. Several days later, members from the civilian aviation organization from the aircraft's country of registration (Laos) arrived, as did the Russian operators and owners of the aircraft. As specified by ICAO Annex 13, the Laotians officially joined the AIT whilst the Russians were provided controlled access to the incident site. The Laotians and Russians aided in the understanding of the organizational aspects of the preflight registration of the aircraft, crew, and the maintenance and ownership records of the aircraft, which were found to be complex since the aircraft had been owned and leased by several entities during its life.

The place of the occurrence was at Cakung Airport, Baucau. Although Baucau is the second largest city in Timor-Leste, its facilities compared to even small towns in developed counties were very limited. The infrastructure that is often relied on to aid an investigation of large transport accident was not available, and the field investigators had to be largely self-reliant.

The Australian AIT was a relevantly small team for the investigation of such an accident in difficult conditions involving several countries, with very limited local support and an aircraft foreign to the investigators experience. This case became a test of international collaboration in accident investigation and the leveraging of investigatory techniques by the use of robust advanced technology in field investigation.

2.1 Aircraft information and description

Upon arrival in Baucau, the AIT had very little information regarding the IL-76 aircraft. What information that was available consisted of aircraft dimensional drawings and a photo of the sister aircraft to the one involved in the accident (Figure 3 and Figure 4). A further source of data were resources found on the Internet that gave some information of the aircraft type, and details of this and other accidents as reported in the media. Among many, some of the websites where such information is available for a wide range of aircraft are http://www.airdisaster.com and http://aviation-safety.net/database for accident information, http://www.airliners.net/search/photo for photos, and http://www.aeronautics.ru/archive/vvs/il76-01.htm for IL-76-specific information. Subsequently further detailed information became available from the owners and State of registry as well papers found in the wreckage, and from the inspection of, and discussions with, the pilots of another Ilyushin passenger transport that arrived at Cakung Airport for UN troop rotations during the investigation.

2.2 Aircraft ownership/registration/operators

With the increasing use of charter aircraft registered in third-world counties to transport cargo and passengers, combined with the large number of ex-Soviet Union aircraft and aircrew on the market, extraordinarily complex ownership and responsibility arrangements have developed that make the task of investigating accidents backgrounds for aircraft maintenance, flight crew compliance, and who should join in the investigation difficult. This accident gives some insight into the complexities that may arise.

During the course of the investigation it was found that the aircraft was manufactured as an IL-76 MD variant in 1986, and was originally operated in the Ukraine. It was converted to an IL-76 TD variant in 2001. The aircraft's owners, who were based at Sharjah in the United Arab Emirates (UAE), purchased the aircraft in July 2001 from a Ukraine-based air cargo operator. The owners registered the aircraft in the Islamic Republic of Iran, which issued the aircraft with certificates of airworthiness and registration, and in September 2001, it was leased to an Iranian company operating from Teheran.

The lease with the Iranian operator continued until December 2001. The owners then leased the aircraft to another Iranian operator that also operated from Teheran. The new lease expired in October 2002, after which the aircraft was relocated to the UAE and the Iranian registration was cancelled.

On Nov. 1, 2002, the UAE owners leased the aircraft to a Lao PDR-based company for 1 year. Under the terms of the lease, the lessor was required to provide the flight crew and the loadmasters. The lease specified that the pilot-in-command was fully responsible for the flight safety of the aircraft. The lease also specified that the flight crew was required to comply with the legislation of the Lao PDR, and that the lease agreement was subject to the approval of the Lao PDR Department of Civil Aviation (DCA). The lessor was required to provide the flight crew with all required flight documentation, including a complete set of Jeppesen enroute navigation charts. The lease specified that the lessee would not be entitled to sublease the aircraft to a third party without the prior written consent of the lessor.

On Nov. 9, 2002, the Lao DCA issued air operator certificate (AOC) to the lessee. The AOC included information that the Lao-based company had met operator certification requirements specified in the civil airworthiness requirements of the Lao DCA, and was authorized to conduct commercial air transport operations.

On Nov. 18, 2002, the Lao PDR-based company entered into an arrangement to sublease the aircraft to another company based in Cambodia. Under the terms of the proposed sublease, which was signed by both parties, the lessor would provide the aircraft flight crew to the lessee. The proposed sublease specified that the aircraft was to remain registered by the Lao PDR, and that supervision over the flight, technical, and commercial operation was the lessor's "competent authority." The proposed sublease also specified that the lessee was to act as the lessor's agent for the provision of necessary waybills and cargo documentation in accordance with the laws of the countries to, through, or over which the aircraft was to be flown. The lessee was also required to supervise the provision of that documentation through its representatives.

On Dec. 30, 2002, the Lao DCA issued a letter of clarification concerning the original lease agreement, dated Nov. 1, 2002, and the proposed sublease, dated Nov. 18, 2002. The Lao DCA concluded the letter with the statement that the Cambodian-based operator was an operator of the aircraft owned by the Sharjah, UAE-based company.

On Jan. 20, 2003, the Cambodian-based company executed a cargo transportation agreement with a Singapore-based company for the flight from Macau to Baucau on Jan. 30, 2003 to carry cargo. The Cambodian-based company was listed on the agreement as the "carrier," and the Singapore-based company was listed as the "client." The cargo manifest, however, listed the Lao-based company against the aircraft type and registration details.

On January 28, a request was sent to the UN in Timor-Leste for landing permission for the aircraft's intended arrival at Baucau on January 30. CAD approved the request for landing permission. Also on that date the Singapore-based company contacted a freight-forwarding company in Dili and requested that the freight-forwarder arrange for payment of landing fees and the provision of ATS at Baucau for the occurrence flight. The freight-forwarder contacted UN Air Operations and was given a quote for the provision of administration and security, rescue and firefighting services, and ATS. UN Air Operations subsequently reported that freight-forwarder indicated that the only service needed at Baucau would be help with unloading the cargo. The freight-forwarder subsequently reported that it made no payments for the services needed, because "we never received an invoice from the UN." UNMISET subsequently reported that no one associated with the operator ever advised UNMISET of a request or a need for the provision of ATS for the aircraft at Baucau.

On February 7, the general director of the Lao-based company reported that the request for landing permission, dated Jan. 28, 2003, and sent under the letterhead of his company, had been sent without his authorization. On the March 20, the chairman of the Cambodian-based company advised that although both parties had signed the proposed sublease document, the Lao-based company had not received consent from the aircraft owners in the UAE to enter into the sublease. The chairman advised that under the circumstances, the inferred sublease had not taken effect, and the Cambodian-based company had, therefore, acted as an intermediary between the Singapore-based company and the Lao-based company for the occurrence flight. On July 21, 2003, the Cambodian-based company advised the AIT in writing that the formalities for the proposed sublease had not been finalized at the time of the occurrence.

The site investigators recovered the aircraft's technical log from the aircraft wreckage that indicated that the aircraft underwent an "A" check at Sharjah, UAE, at 2,312 airframe hours with no major problems reported.

3. Wreckage examination and analysis

The small investigation team along with the remoteness of the accident site from modern support facilities and the investigators home base meant that the investigation team had to be in part self-reliant. The data collected from the site had to be sufficient and of a quality high enough to allow a robust analysis of the accident to be made, since revisiting the site would be very difficult if not impossible once the investigators had returned to Australia. This is not dissimilar to most aircraft accident sites (if not for the same reasons) since weather conditions can obliterate witness marks, cleaning up the wreckage is usually a priority of local authorities, or disturbance of the wreckage by unauthorized people or animals makes site evidence perishable.

To aid in the collection of as much data as possible in the shortest time, the team relied heavily on digital image capture and review of these images on site (there were no film development labs in Baucau, which would have allowed conventional film to be developed and reviewed). On-site scientific support was available in the form of the two DSTO scientists—one an aircraft structures specialist, the other a materials specialist, who collectively have expertise in mapping, failure analysis, materials toxicology, structural collapse, and accident site investigation. The main data collection aids were several high-resolution digital cameras (redundancy is important), a differentially corrected mapping grade GPS unit[3,5], laser range finder with built-in inclinometer and digital compass, and a light-weight laptop with mapping, image manipulation, word processing, and other software to document and review witness interviews, catalogue and store documentation (including photographs) collected, and back up this data to CD-Rs.

3.1 Data collection

The GPS is a satellite-based system operated by the United States Department of Defense. GPS provides an all-weather, worldwide, 24-hour service, which can be used for calculating positions and time. To make this system available to unlimited users, a passive ranging method called pseudoranging is used. The satellites are active (transmit) and the user's units are passive (receive). The satellite transmissions enable computation of the user's position and velocity "relative" to a spheroid datum (model of the earth's surface). Positioning accuracy is attainable from 1 cm to 100 m, depending on the type of receiver used, antenna dynamics, number and position of the satellites in view, mode of operation, and the processing (error correction) techniques employed by the user.

GPS, as a military system, was initially intentionally degraded (selective availability—SA) from achieving the highest positioning accuracy for a system relying on the GPS satellite data alone. The growing demand for civil use of this highly capable system has led to the SA degradation of the signal being turned off. Nevertheless, the high use of the system by the civil community has resulted in other data and functions being added by the civil community to create a system that gives high RELATIVE (to a spheroid datum) positioning accuracy.

The GPS gives users their position in all areas of the world. However, real-world ABSOLUTE positioning is extremely complex.

The spheroid datum used by the GPS system is the world geodetic datum or system (WGS). The positions given by a GPS unit are referenced to this model of the earth's surface, rather than the actual surface of the earth. The earth is in fact a very complex shape that is not easily modeled. The WGS uses the center of the earth's mass as its origin (geocentric) and three axes (Cartesian coordinate system) from that origin to define alignment. The WGS datum was established by using observations from satellites orbiting the earth over a long time and is, therefore, quite accurate. The version promulgated in 1984 and, therefore, known as WGS-84 is the datum used by GPS receivers.

The GPS system used for the accident mapping allows a user-defined library of features, which are usually referred to as fea-

Item classification (pre-site)	Feature type	User-defined attribute collected	Actual feature name used (site)
Generic point	Point	Photo No., Note	Generic point
Generic line	Line	Photo No., Note	Generic line
Generic area	Area	Photo No., Note	Generic area
Fence	Line	Photo No., Note	Fence
Road	Line	Photo No., Note	Road
Right-hand wing wing	Area	Photo No., Note	Right-hand
Left-hand wing	Area	Photo No., Note	Left-hand wing
Wing Parts	Point	Photo No., Note	Wing parts
Horizontal stabilizer	Point	Photo No., Note	H-stab
Vertical stabilizer	Point	Photo No., Note	V-stab
Engine	Area	Photo No., Note	Engine
Engine parts	Point	Photo No., Note	Engine parts
Fuselage parts	Area	Photo No., Note	Fuselage area
Fuselage parts	Point	Photo No., Note	Fuselage
Main landing gear	Point	Photo No., Note	MLG
Nose landing gear	Point	Photo No., Note	NLG
Ground marks	Line	Photo No., Note	Ground marks
Ground marks	Point	Photo No., Note	Ground marks
Instruments	Point	Photo No., Note	Instruments
Actuators	Point	Photo No., Note	Actuators
Tower	Point		Tower

Note: The software produces a separate attribute name for each attribute taken.

Table 1. Data dictionary used for the investigation of the IL-76 accident at Baucau.

tures or themes to be loading into the hand-held data logger. The details to be collected in the field (position, notes, etc.), about each logged item are called attributes. A "pen based" ruggedized data logger is connected to the GPS/communications receiver, and is capable of logging many positions along with simple notes and other details about the item being logged, such as the identifiers of any digital pictures that are taken at the time.

The library loaded into the data logger is known as the data dictionary. Typically, the data dictionary will include all the feature categories that are to be located and mapped. These are separated into point, line, or area features. General features (not belonging to any of the other categories) with point, line, or area shapes are automatically included in the data dictionary to cover features not included in the rest of the dictionary. These are listed as point generic, line generic, and area generic respectively.

Data dictionaries should be tailored to particular accidents, as the decisions made when choosing the features for inclusion in the dictionary will affect the display and flexibility of the maps produced. While the data can be manipulated after the event, a good dictionary will save a lot of time in data manipulation during analysis. Since this accident was in many ways unique (large Russian four-engine transport at a site that was remote from Australia) alterations to the data dictionary were carried out from time to time during data collection to aid in the presentation of items mapped. Maps were produced and reviewed at the end of each session in the field to assess the progress of the data collection and to aid in the assessment of the developing scenarios.

The software used to control the data logger and to generate the data dictionaries will also display the data as simple maps in real time on the data logger display. To further manipulate the data and to join other data to the GPS and notes collected in the field, a more powerful software GIS (geographical information system) package is used. This package was used during the site examination at the end of each session. All of the maps presented in this paper have been produced with that GIS package.

A data dictionary for this accident was prepared using the data logger software after an initial inspection of the accident site. It was subsequently modified during field use. The dictionary had the features listed in Table 1. During data collection, the data are stored with a number of attributes for each position mapped. These included GPS position, time, and date; height; position shape (point, line, or area); feature name; data file; number of fixes taken for this data point; standard deviation between fixes taken for a data point; and other user defined attributes.

3.2 Site examination preparation

Prior to examination of the wreckage, appropriate preparation measures had to be taken because of the difficult conditions expected at the site. The team took sufficient personal protective equipment to carry out the site examination, water had to be sourced from the UN, French ration packs were supplied by the UN, and equipment to be used at the site had to be tested and set up for the site work. In particular, reliance on the differentially corrected GPS unit meant that a correction service for the area had to be obtained and the correction accuracy tested. This was assessed by mapping items around the airfield such as the tower and local roads, etc., and checking their positions each day. Previous experience with mapping aircraft accident sites had found that even if the maps do not add greatly to the outcome of the investigation, the process concentrates the investigators on the detail of the wreckage and forces close scrutiny of items that may become important in the post-site investigation analysis, and as such mapping by this method has been found to be an invaluable aid in several accident investigations.

GPS correction was supplied by OmniSTAR, which supplies world-wide coverage from 60º north to 60º south using fixed-base stations in various positions situated around the world, and supplying the correction signals via satellite communications. The GPS unit used had an inbuilt receiver designed to receive these correction signals and calculate the corrected position on the fly (differentially corrected GPS: DGPS). This service normally supplied a sub-meter accuracy ideal for the mapping of aircraft wreckage.

3.3 Site examination

he Timor-Leste police with the aid of UN police were maintaining site security, and this proved mostly effective, although the police on site spent a notable amount of time "kicking tin."

On arriving at the wreckage site, the following tasks were initiated by the engineering team:

- Inspect site, and site security, establish site safety concerns, clear or make safe any hazards identified.
- Form an e xamination strategy based on the initial inspection.
- Develop a data dictionary for the site mapping so that initial analysis can be achieved.
- Map reference items such as fences, road, etc.
- Commence detailed site examination and mapping while looking for aircraft extremities, all engines, control surface configuration, instruments, FDR, and CVR, etc.

From the initial examination, it was concluded that the wreckage path (130° magnetic) was approximately aligned with the heading of Runway 14 (Figure 5, page 110) (i.e., the aircraft had approached from this direction).

In general, two people were involved with the mapping process (see Figure 6). Integral to the process was the logging of items (point, line, or area), cataloguing them appropriately (e.g., left-hand wing skin, lying inverted), digitally photographing the items, and referencing the data logged with the appropriate photograph number.

During the wreckage mapping, apart from the moving map produced in the data logger, more complete interim maps were produced and updated on a laptop PC in the AIT office. Viewing these maps gave the investigating team the confidence to proceed with other tasks, and to make changes to the mapping requirements as required, therefore, making far greater use of the available time and resources. Sufficient data were collected over 4 days of mapping in weather that varied from clear skies to tropical downpours.

Several problems were encountered during the mapping of the IL-76 wreckage, mostly related to variation in the accuracy of the unit. The location of the site was very remote from the nearest correction stations (Darwin: about 660 km away and Denpasar: about 700 km away) with the result that in the event that storms built up during the day at Baucau the error increased, sometimes in an erratic manner. This was most notable when locations previously mapped were "displaced" by several meters the next day when compared to the positions previously logged and presented on the moving map of the data logger. This was always associated with large thunderstorms over large quadrants of the sky. To alleviate this, offset corrections were entered while logging new items where nearby previously logged items were available so that local relative accuracy could be maintained. This could be carried out since on the first day of mapping the weather was clear and a large number of key items scattered widely over the accident site had been mapped, and the displacements between these key items and the items subsequently being mapped were relatively short, and the offset did not drift very quickly. Upgrading the DGPS receiver to a dual frequency unit or a unit that also uses the Russian GPS satellite array to improve accuracy could reduce weather-related problems such as this. Alternately a second unit could have been set up locally at a fixed known point and its signal could have been used to calculate the local corrections required to correct the roving units readings. Such systems are commercially available and give excellent relative accuracy and allow operation without remote correction signals being required.

On the second day of mapping the correction signal, while correctly acquired initially, could not be maintained for more than a few minutes. This was found to be the result of the correction supplier erroneously turning off the activation for the receiver. The signal was restored for the next mapping session while those items logged without correction were manually corrected using offsets to the key items.

Battery problems were encountered that resulted in the correction signal being lost. It was eventually found that of the six 12V lead acid camcorder batteries taken to Baucau, two would not hold a charge and caused unpredictable DGPS operation. Generally with the increasing use of battery-powered technology as an aid to investigators in the field, considerable attention needs to be given to reliable lightweight and high-power-density batteries and reliable fast chargers. Purpose-manufactured lithium-ion batteries have now replaced most of the batteries used during this investigation.

Figure 5. Looking at the accident site toward Runway 14.

Figure 6. Team members mapping piece of engine diffuser.

Figure 7. The FRD and CVRs as found in the wreckage. Note that these were "wire" recorders.

3.4 Flight recorders

The FDR and CVRs were recovered on the first day of on-site examination. The aircraft was fitted with one FDR, two CVRs, and a quick access recorder (QAR). The FDR and CVRs were recovered from the rear fuselage section in the wreckage. The QAR was recovered from the cockpit wreckage area. The impact forces extensively damaged the QAR, and no flight data could be recovered from it.

The casings of the FDR and CVR storage units were sooted from the post-impact fire, but revealed no evidence of heat or structural damage since the recorders had been found in a relatively undamaged section of the tail of the aircraft (Figure 7). Examination of the recorded data revealed that the FDR had operated normally until impact. The parameters recorded by the FDR included lateral acceleration, vertical acceleration ("g"), rudder position, elevator position, magnetic heading, roll, stabilizer position in degrees, pitch angle in degrees, angle of attack in degrees, barometric altitude in meters, with reference to a standard sea level pressure datum of 760 mm Hg (1,013.2 hPa), radio altitude in meters, GPWS activation, indicated airspeed in km/hour, thrust lever angles for each engine, N2 for each engine, EGT for each engine, wing slat extension, landing gear activation, autopilot pitch engagement, autopilot roll engagement.

On advice from the Australian accredited representative, CAD forwarded the FDR and CVRs to the Russian Interstate Aviation Committee, Air Transport Accident Investigation Commission (CIS) (IAC) for readout and analysis.

The wire-recording medium in one of the CVRs was dislodged from the recorder spools in that unit and provided no useful data. The other cockpit voice recorder provided good quality audio information for the descent and approaches to Baucau. This recorder was a single-channel recorder, and combined all onboard audio channels into one recorded channel. It operated in an automatic "autostart" mode, and the recording media only moved and recorded acoustical and time data if the flight crew operated the intercom or the radio transmitter keys. The system incorporated a disengaging delay of about 15 seconds between when the intercom or the radio transmitter keys were released and when the recording media stopped. The aircraft was not fitted with a "hot mic" system that would provide acoustical data to the CVR. Additionally, the CVR was not equipped with a cockpit area microphone (CAM). Both hot mic and CAM systems provide a CVR with the capacity to capture flightcrew communications and acoustical signals relating to the operation of the aircraft. Those signals improve the ability to analyze the activities of a flight crew and the operation of the aircraft in the period leading up to an occurrence. Both hot mic and CAM are most effective when the CVR is continuously recording acoustical data. Without a CAM, the CVR on the occurrence aircraft was not able to record the flightdeck aural environment as required under the standard described in 2.1.1.b) of Attachment B to Annex 6 Part I to the Chicago Convention.

Readout of recorded flight crew conversations was obtained for the final 40 minutes of the flight. The CVR transcript was prepared by the IAC and was a translation from the Russian language to the English language. From the CVR, it was evident that the pilot-in-command was the handling pilot for the flight. The IAC reported that because the time intervals between the flightcrew conversations recorded on the CVR during the second landing approach were less than 10 seconds, any audible warnings generated by the radio altimeter system and the GPWS would have been recorded on the CVR. However, none were evident.

The recorded flight data provided by the CIS IAC were also used as one of the inputs into a generic flight visualization program (graphic replay software: GRS) developed by DSTO (Figure 8). Other inputs were wind direction and strength, a topographical map as a render on the ground surface, the wreckage mapping information, and the positions of the runway as depicted by the on-site mapping and in the Jeppesen approach plate.

The evaluated pressure altitude varied slightly from the "smoothed" true pressure altitude derived from the variable recorded barometric altitude data. The impact point was 495 m (1,625 ft) above the 760 mm Hg (1,013.2 hPa) datum. The evaluated pressure altitude at impact was 609 m (1,998 ft), indicating a discrepancy of 114 m (374 ft) between the recorded barometric data and the evaluated pressure data.

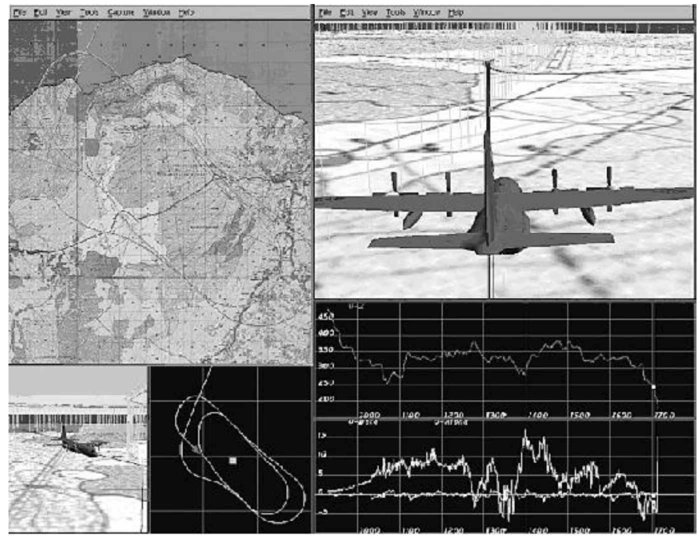


Figure 8. Graphical replay image of last moments of flight.

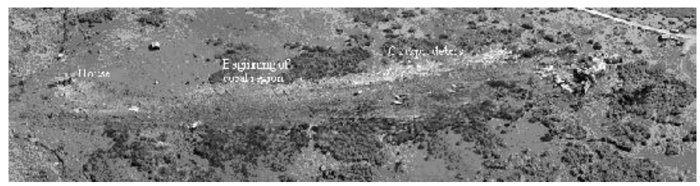


Figure 9. Looking down on the second half of the wreckage trail from the house (at the left of this figure) to the final resting place of the main wreckage (to the right of the picture).

3.5 Wreckage

The wreckage trail was aligned on a track of about 130 degrees magnetic. The aircraft began to break up immediately after impact. It also slewed about 5 degrees to the left during the break-up sequence, as is evident in Figure 9. Despite the destruction of the aircraft during the break-up sequence, all extremities of the airframe were located. The four engine cores were also located. They were relatively intact, and each revealed damage consistent with engine rotation while delivering power.

The post-occurrence examination of airframe and engine parts revealed no evidence of inflight breakup or mechanical failure. There was also no evidence of any pre-impact explosion or fire. All meltage within the wreckage displayed evidence of a vertical flow in relation to the ground, which suggested that the individual metallic structures were in a static state when they were exposed to the heat source that resulted in the melting process. While there was evidence of sooting and ash on the wreckage, there was no evidence of slipstream effect to indicate that fire had occurred before impact.

The engine cores and accessories were mostly intact; however each engine fan assembly had separated from its respective engine, and fan blades were spread throughout the accident site suggesting that the engines were operating at the time of the impact.

The post-occurrence technical examination of the engine fan blades found in the wreckage did not display any evidence of a birdstrike or blending repairs. It was not possible to determine whether the engines had sustained any foreign object damage before impact because of the significant damage resulting during from the impact sequence. The FDR EGT and N2 plots revealed no apparent aircraft engine anomalies during the descent into Baucau or during the approach sequences.

The slat and flap assemblies that had remained attached to primary wing structure were in the extended position. The flap tracks were lubricated and displayed no evidence of significant wear. The screw jack and actuator positions were consistent with the wing high lift devices having been extended at the time of impact. No slat or flap abnormalities could be found, which would have suggested a problem during the approach sequences.

All landing gear assemblies were found in the extended position, and no landing gear abnormalities were evident during the approach sequences.

4. Wreckage map

The data collected in the field with the DGPS mapping system were presented in a number of different formats to show particular wreckage patterns as part of the analysis of the aircraft breakup. The team also used the equipment to map the runway and other features of interest (see Figure 1, page 105). After 5 days, about 900 items of wreckage were mapped covering the airfield and the main wreckage site (Figure 10). These maps were highly flexible allowing separation of specific types of wreckage as shown in Figure 11, which shows the relative location of engine parts compared to the main wreckage.

A comparison between the position of the runway and the reference point as shown on the WPEC Jeppesen Baucau chart (Aug. 30, 2002) was made, and it was found that when measured with the DGPS (WGS84) the runway was displaced from the position presented in the chart. Figure 12 depicts the extent of this displacement, which occurred in latitude, longitude, and (also) height. Included in this Figure is the RAAF plate for comparison. The difference in height, between the charts and the DGPS, can probably be explained since it appears that the WGS84 model is incorrect at Baucau by about 140 feet (i.e., the shore was found to be shown as about 140 feet on the WGS84 datum of the DGPS) so that the elevations quoted on the chart are about correct when measured above sea level and incorrect if assumed to be WGS84 compliant. The airport reference point (ARP) could not be found in the position noted in the chart, although a survey marker was found near the southern end of the runway, which was thought could be the ARP.

Many (approximately 300) of the items plotted at the crash site were categorized and photographed. Within the first few days, coupled with the examination of physical witness marks, the maps allowed a plausible incident scenario to be developed. A brief summary of the impact and wreckage analysis follows.

4.1 Summary of the impact and aircraft breakup

The aircraft's impact and disintegration is thought to have followed the following sequence based on the evidence gathered during the wreckage and site examination and mapping:

One landing gear bogie contacted the slightly rising ground before a clump of trees leaving the distinct witness scar found in the ground. This scar was on a heading of approximately 130^0 magnetic. Measurements of the ground witness marks clearly indicated that a main landing gear bogie produced them. The impressions in the ground suggested that the attitude of the aircraft was slightly nose up. This is supported by the absence of any other marking suggesting that another bogie had contacted the ground. This is also supported by the wheel marks ending some distance before the trees; it is possible that the aircraft had

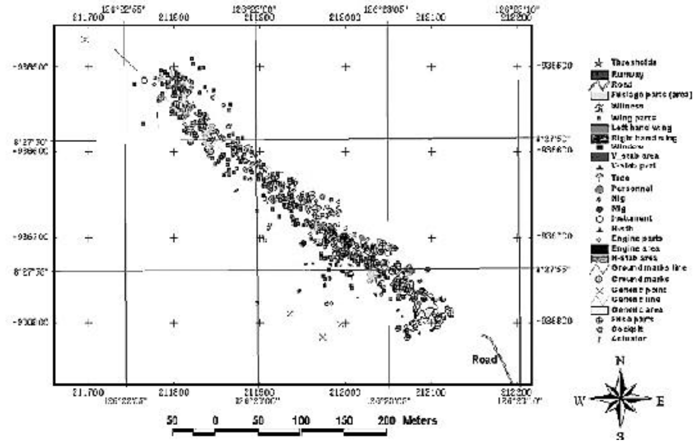


Figure 10. General map of the wreckage distribution.

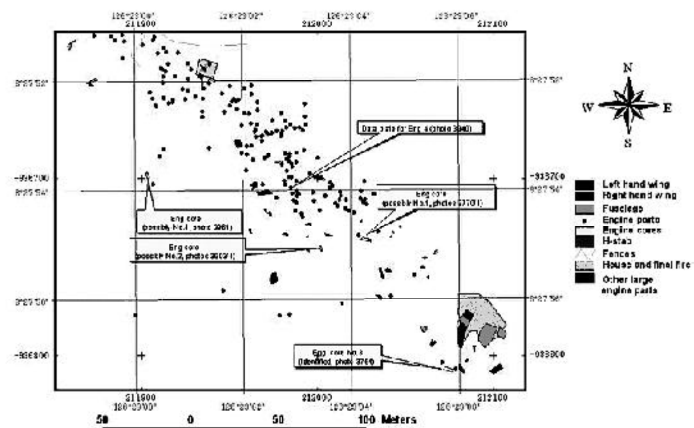


Figure 11. Map concentrating on large wing and all engine pieces. Note only engine Number 3 was positively identified from its serial plate. The identity of the other engines was estimated from their relative positions on the wing and their relative damage post accident. Engine numbering— left to right.

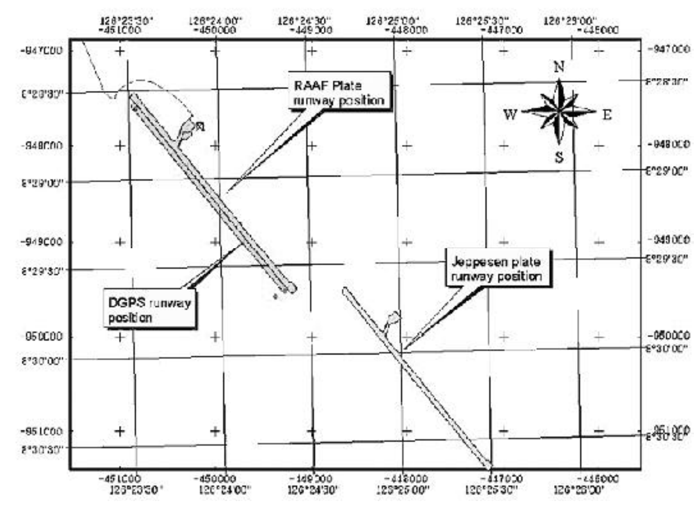


Figure 12. Map of runway (green) as measured by the DGPS unit, and the runway's approximate position as indicated on the RAAF (blue) approach chart and the Jeppesen Baucau chart (red). The red dots are the DGPS-measured runway thresholds and suspected ARP.

begun to climb prior to the left wing contacting the trees. The dry stonewall running across the imaginary continuation of the wheel track also had only one impact region (four indentations consistent with the four wheels of a main landing gear bogie could clearly be seen in the top of the wall) consistent with an undercarriage bogie, but slightly to the right of the initial wheel track. This suggested that the aircraft was about 1 m above the ground when its left wing impacted the trees.

The slope of the cuts through the trees was between about 1.5^{0} and about 4^{0} upward and away from the track. Given that the aircraft has a reported down wing dihedral of 3^{0} (under flight loads this angle is expected to decrease), this suggests that the aircraft had its left wing slightly up at tree impact. The distance from the centerline of the wheel marks to the furthest damaged tree trunk was about 22 m, while another tree, undamaged, was about 27 m from this track. Since the distance from the centerline of the left and right bogies to the left wingtip is 22.4 m and 28.2 m, respectively (see Figure 3, page 106), it is likely that the left-hand (rear, since the nose was up) bogie had produced the witness mark on the ground (given that the aircraft had not drifted laterally).

Assuming that the left-hand bogie had contacted the ground, then the distance between it and the trees to the left, when it became abreast of the trees on an imaginary continuation of the wheel marks (1 1m), referred to as T1, indicates that the left wing had struck the tree just outboard of the starboard outboard engine pylon (Figure 13). The most distant damaged tree, T3, would thus have struck approximately 1 m from the wingtip. This was consistent with a piece of the outboard aileron, being found directly under the trees and with pieces of an engine fan being found from these trees forward along the wreckage path.

Given that the left-hand bogie had contacted the ground first, then it must be speculated that the pilot (or copilot) upon seeing the trees initiated a bank to the right (and probably a simultaneous pull up), thus causing the slightly upward left-hand wing to leave the observed impact damage to the trees. The attitude deduced from the observations would have had to be attained in the 41 m between the bogie leaving the ground and the aircraft impacting the trees[1]. The bank to the right would also suggest that the wall was impacted by the right-hand bogie (thus positioning the impact approximately 2 m from the initial bogie track, to the right of this track).

The height above the ground in the tree cuts was approximately 7 m. Given that the wheel impacts to the fence were about 1 m above the ground, then this distance is consistent with the left wing having caused the tree damage.

The wing impact damage caused its internal fuel to be sprayed forward. The fuel chemical damage caused the foliage in the vicinity to be "browned."

The impact damage to the left wing (including the loss of the high lift devices, i.e., flaps and slats, and possibly severe damage to the wing box resulting in the wing outboard of the outer engine beginning to bend upward) would have reduced its lift producing capability, and with the right-hand wing producing lift, the aircraft would have proceeded to roll to the left. Since the trees were substantial (about 0.5 m diameter in the impact regions) then a sudden violent yaw toward the left would also have occurred. During this roll and yaw, it is considered likely that the aft-most fuselage section partially separated from the main body of the aircraft. The roll would also have resulted in the forward fuselage contacting

Figure 13. Overview of initial impact site.

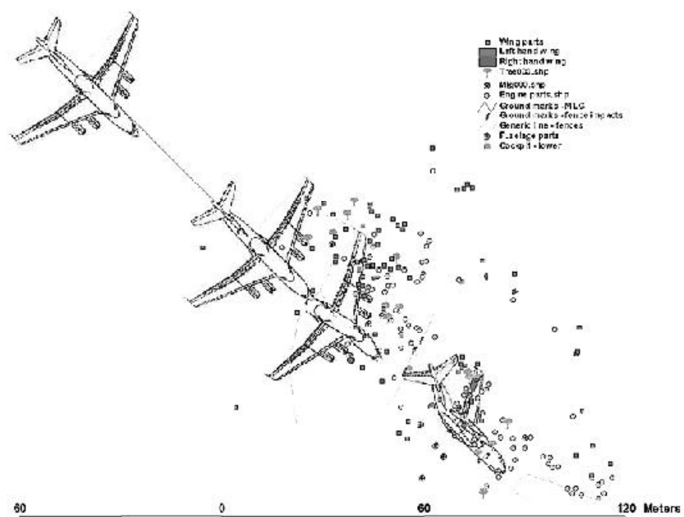


Figure 14. A scaled IL-76 drawing placed on a map of the initial impact area to show the possible positions of the aircraft during this part of the impact sequence. The yellow dot is the lower cockpit wiper blade. It is possible that impact with the nearby fence is responsible for the position in which it was found.

either the ground, vegetation, and/or one of the stone walls (a nearby stone wall had been extensively damaged by impact) momentarily as evidenced by pieces of lower cockpit window and wiper blade not far down track from the impact trees. The roll would also have caused the damaged left-hand wing to contact the ground as witnessed by a piece of wingtip skin found forward of the impacted trees. It is suggested that this may have caused the wing to fold up (just outboard of the outboard engine) had it not already started to do so, losing several ribs in the process. At this point the aircraft is effectively rolling about the "folded" left-hand wing. The yaw also swung the final debris trail slightly to the left of the initial ground mark direction.

By the time that the right wingtip hit the house on the left side of the debris trail, the wing (and most of the aircraft) was inverted (the several large pieces found were all inverted) and had yawed somewhat from its original heading. A standby attitude indicator recovered in this vicinity supports this proposition. With the aircraft still yawing, the left wing tip (red) light contacted the ground close by (23 m laterally). This is consistent with the outer left wing section having folded over the inner section as described above, thus positioning the red light approximately 23 m from the green light. Forward and to the right of this region, significant pieces of the left-hand outer wing were found. In Figure 14 (page 113) a scaled IL-76 image has been placed on a map of the 'initial tree impact to house area' to show the possible positions of the aircraft during this part of the impact sequence.

Just after the house impact the aircraft crossed a large area of serrated-like coral ridges that were perpendicular to the path of the aircraft (consisting of extremely hard limestone) and could be likened to an enormous "cheese grater," Figure 15. As the inverted forward fuselage and cockpit contacted the ground heavily here, it probably separated from the remaining fuselage due to failure of the regions initially damaged during the tree impacts and ground contact that occurred earlier. As this section traversed this area, it was shredded into relative small fragments leaving most of the cockpit items to the left of the centerline of the track.

During the travel through this section, the damaged wing with its fuel leaking is now yawed roughly parallel to the wreckage path, thus restricting the fire damage to the center of the wreckage trail. This yawing motion and fire trail is evident from Figure 9 (page 111).

The remaining wing sections and center-to-rear fuselage continued the yawing motion until coming to rest generally facing toward the initial impact point. The wings were inverted at this point and had yawed through 180° or more. Most of the cargo was thrown forward and to the left of this region (Figure 16). The remaining right-hand wing section was notably longer than the left, consistent with the left-hand wing damage described earlier. Three of the four main landing gear bogies located in this region and were relatively undamaged, also suggesting that the aircraft traveled to its final resting place inverted.

The aft section containing the horizontal T-tail must have separated from the remaining fuselage before coming to rest. This was evident since only the leading edge of the vertical tail had impact markings (scraping marks). Had it been together with the rest of the fuselage in its normal position, when the aircraft became inverted far greater damage would have occurred.

Since the aircraft wings spent much of the ground travel inverted, and the fan sections of the engines had absorbed most of the impact damage noted to each of the engines, it is considered that the engines had sufficient time to spool down from their landing thrust power level, accounting for the relative low level of damage to their cores.

5. Discussion

The investigation[2] determined that the flight crew's compliance with procedures was not at a level to ensure the safe operation of the aircraft. Before the flight crew commenced the descent into Baucau, the pilot-in-command briefed them that he would conduct a non-precision instrument approach at Baucau, with reference to the Baucau NDB.

The flight instruments fitted in the occurrence aircraft provided readings of height, speed, and distance in metric units. The pilot-in-command's briefing included information on the relevant heights for the missed approach procedure expressed in feet, and not in their metric equivalents. None of the other crewmembers commented on that fact. The CVR data revealed that the pilot-in-command did not refer to the source of data that he used for the briefing on the intended NDB approach at

Figure 15. Wreckage scattered throughout the region of "coral outcrop" looking east.

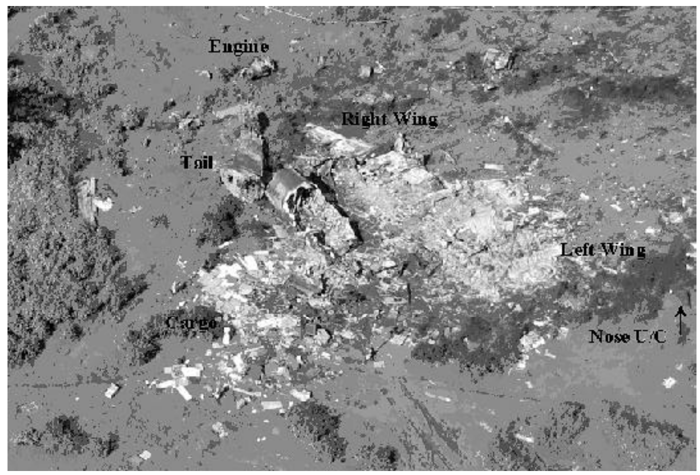


Figure 16. Looking down at wing and tail sections.

Baucau. The pilot-in-command's arrival briefing also contained no information or discussion on the

- planned altimeter subscale settings for the descent to Baucau.
- applicable minimum sector altitude (MSA) within 10 nm (18 km) of the Baucau NDB; the MSA was 9,300 ft (2,834 m) above mean sea level (AMSL).
- commencement altitude for the Runway 14 NDB approach at Baucau, which was 5,500 ft (1,676 m) AMSL.
- lowest safe altitude (LSALT) for the last route sector into Baucau, which was 4,500 ft (1,372 m) AMSL.
- applicable minimum descent altitude (height) (MDA(H)) for the approach.
- expected weather at Baucau.
- Baucau NOTAMs.

The CVR data revealed that none of the other crewmembers commented on the omission of this critical information. As a result, the arrival briefing was not effective.

Controlled airspace was established at Baucau, but ATS at Baucau was only available for UN aircraft on UN troop rotation days. The NOTAMs for Baucau included that information. The occurrence aircraft was not engaged in UN troop rotation operations, and no troop rotations took place during the aircraft's approach to Baucau. When the aircraft was about 300 km from Baucau, the pilot-in-command instructed the copilot to call Baucau ATS. Over the next 23 minutes, the copilot called Baucau Tower 25 times, but received no response to those calls. The flight navigator then called Baucau Tower. A controller, who was present at Baucau aerodrome at the time, but not on operational duty, advised the flight crew that ATS was not available and that landing would be at the discretion of the flight crew. The flight navigator acknowledged the controller's advice, but did not seek information from the controller about the prevailing weather at the aerodrome. That was a missed opportunity for the flight crew to obtain updated information on the weather at Baucau. Had the flight crew sought and received that information, it may have provided them with an improved situational awareness of the prevailing weather. During the descent in Timor-Leste airspace, none of the flight crew monitored the Timor common high frequency of 123.45 MHz while the aircraft was above 10,000 ft (3,048 m). They also did not monitor the Timor common low frequency of 127.1 MHz while the aircraft was below 10,000 ft, or broadcast their intentions and traffic information on that frequency. Therefore, the flight crew had no assurance that there was no conflicting traffic. The flight crew's disregard of the requirement for traffic information broadcasts within Timor-Leste airspace increased the potential risk of an inflight collision. The pilot-in-command diverted the aircraft from the published inbound track to the Baucau NDB, and descended the aircraft below the published 10 NM MSA. He continued descending the aircraft through the commencement altitude for the published non-precision instrument approach for Runway 14, and through the LSALT. None of the other crewmembers commented that the pilot-in-command had breached those relevant safety heights. The Baucau NOTAMs included information that instrument approach charts for Baucau were available from the CAD of the Ministry of Transport, Communication, and Public Works, Timor-Leste. However, the investigation determined that the flight crew used Jeppesen instrument and approach charts and not the CAD-issued charts. As the aircraft approached Baucau, the flight crew decided to conduct an over-flight of the aerodrome before making a landing approach, and during the over-flight, the flight crew realized that the runway was not where they expected it to be. The investigation determined that the flight crew did not conduct the over-flight of the aerodrome, or either of the landing approaches, with reference to the Baucau NDB. The flight crew used selected data from their instrument approach charts for Baucau to formulate a user-defined non-precision approach using the onboard GPS. That user-defined procedure was a non-approved procedure. It deviated from normal practice, bypassed all the safety criteria and risk treatments built into the design of the published precision approach procedures, and increased the risk of a controlled flight into terrain (CFIT) accident. The flight navigator provided the pilot-in-command with distance to run and lateral offset distance from the runway centerline during the over-flight and the first landing approach. The flight navigator's reference to distance and lateral offset during those maneuvers corresponded to the position of the aircraft in relation to the threshold of Runway 14 as depicted on the Jeppesen charts. The navigation data provided by the flight navigator was, therefore, accurate in terms of where he expected the threshold of Runway 14 to be, based on the Jeppesen charts. However, erroneous data on the Jeppesen charts meant that it was inaccurate in terms of where the threshold of Runway 14 was actually located. The flight crew's inappropriate reliance on that data therefore increased the risk of a CFIT event.

Had the flight crew followed the non-precision Runway 14 NDB approach procedure as published on either the CAD or Jeppesen charts, and not descended below the relevant MDA(H) until visual flight was ensured, the position of the runway, as depicted on the Jeppesen charts, would have been irrelevant. Although the runway would not have appeared where the flight crew expected it to be at the MDA(H), in visual meteorological conditions (VMC) a safe approach could have been conducted to the actual threshold of Runway 14. Alternatively, if a visual approach could not be made from the relevant MDA(H), a safe missed approach could have been conducted by following the published missed approach procedures. During the over-flight and the subsequent (first) landing approach, the flight crew realized that the runway was not where they expected it to be as it was depicted on the Jeppesen charts. The pilot-in-command discontinued the landing approach, and the flight navigator stated that he would apply a 4 km correction to position the aircraft for a second landing approach to where he thought the runway was located. By applying the 4 km correction, the flight navigator was providing the pilot-in-command with inaccurate data, and resulted in the aircraft being repositioned toward a point about 1.65 km (0.88 nm) northwest of the actual position of the threshold of Runway 14. That incorrect data substantially increased the hazards of the user-defined approach procedure, and the risk of a CFIT event at that stage of the flight increased to a high degree. The flight crew did not appear to identify the hazards associated with the intended improvised approach procedure and were, therefore, not in a position to manage the associated risks.

As the aircraft turned on to the final approach heading during the second landing approach, the flight navigator stated that the aircraft was high on the approach profile, based on his assumption of the location of the threshold of Runway 14. The pilot-in-command increased the rate of descent of the aircraft to about 18 m/sec (3,543 fpm), and stated "increased." None of the other crewmembers commented on the high rate of descent, or drew the pilot-in-command's attention to the fact that the approach was unstabilized at that point. The risk of a CFIT event is diminished by a stabilized approach, and the high descent rate in close proximity to terrain at that stage of the flight increased the risk of a CFIT event to the point where impact with terrain was almost certain. The CVR data provided no evidence that the flight crew was monitoring the increasing risk and evaluating whether to discontinue the approach to treat that risk. The flight engineer misinterpreted the pilot-in-command's statement "increased" to be an instruction for him to increase the engine thrust, and he advanced the thrust levers. It took about 2 seconds for the pilot-in-command to realize that engine thrust had been increased, and he reacted by calling, "No, I increased vertical speed" and reduced the engine thrust. The flight engineer's action in increasing engine thrust was a significant distraction to the pilot-in-command at that stage of the flight, and probably diverted his attention from the primary task of flying the aircraft to restoring the thrust to the proper setting.

At about the same time, the aircraft descended through 162 m, which was the published MDH for a straight-in landing on the Runway 14 NDB approach. Neither the pilot-in-command nor the copilot appeared to notice that the aircraft had descended through the MDH, and it is probable that both were distracted by the flight engineer's erroneous action. The risk of a CFIT event is diminished if an approach is flown no lower than the published

MDA(H) of an instrument approach procedure until visual flight can be ensured and maintained. At that stage of the flight, descent below the MDH in instrument meteorological conditions (IMC) at a high rate of descent meant that the risk of a CFIT event had increased to an unacceptably high level and could not be treated. Impact with terrain was almost certain from that point onward.

The high rate of descent continued unchecked until slightly less than 2 seconds before impact. It is probable that the pilot-in-command and the copilot were each unaware of the high rate of descent, because neither was monitoring the flight instruments while they were looking ahead of the aircraft and trying to establish visual contact with the ground. Just before impact the copilot urgently expressed concern that impact with terrain seemed certain. In response the pilot-in-command applied back elevator to increase the aircraft pitch attitude, without simultaneously increasing the engine thrust. Consequently, the pilot-in-command's attempt to avoid impact with terrain was unsuccessful because of the inertia of the aircraft and its close proximity to terrain.

The aircraft's impact with terrain was a direct consequence of the pilot-in-command descending the aircraft below the published minimum descent height for the Runway 14 non-precision instrument approach procedure in an unstabilized manner. Furthermore, it was also as a result of poor planning by the flight crew and less-than-effective crew coordination. During that landing approach, the actions of the flight crew steadily increased the risk of a CFIT to an extreme level, yet they seemed unaware that the likelihood of impact with terrain was almost certain until shortly before it occurred.

Research conducted by an aviation industry task force, under the patronage of the ICAO, has credited the main reasons for accidents involving aeroplane hull losses to CFIT and approach and landing accidents. In recent years, CFIT reduction has been the focus of organizations such as ICAO and the Flight Safety Foundation (FSF). The findings of the FSF approach and landing accident reduction (ALAR) task force resulted in several conclusions and recommendations, and from those, the production of the FSF ALAR Tool Kit.

This paper highlights that deviations from recommended practice are a potential hazard, particularly during the approach and landing phase of flight, and increase the risk of a CFIT event. It also highlights that crew coordination is less than effective if crewmembers do not work together as an integrated team, and that support crewmembers have a duty and responsibility to ensure that the safety of a flight is not compromised by non-compliance with recommended practices.

The potentially serious to catastrophic consequences of a CFIT event remain constant, irrespective of likelihood of the event. The potential risk of CFIT can be diminished by using current technology and equipment, by implementing adequate standard operating procedures, by assessing and managing CFIT risk factors, and by developing effective crew decision-making and risk management processes.

6. Conclusions

On Jan. 31, 2003, at 0621 UTC (1521 local time), an Ilyushin 76TD (IL-76TD) aircraft, registered RDPL-34141, impacted terrain near Caicido village during a landing approach, about 1 nm (1.87 km) to the northwest of Cakung Airport, Baucau, Timor-Leste. The pilot-in-command was the handling pilot during the descent and approaches at Baucau. Impact forces and a severe post-impact fire destroyed the aircraft, and the six occupants were fatally injured.

Australia agreed to assist the Timor-Leste government in the investigation of this accident and assigned the Australian Transport Safety Bureau (ATSB) to conduct the investigation for and on behalf of Timor-Leste, and in accordance with Annex 13 to the Chicago Convention. A relatively small team comprising members of the Directorate of Flying Safety and the Defense Science and Technology Organization conducted the major portions of the investigation. Assistance was also gained from Timor-Leste Department of Civil Aviation, United Nations Mission In Support of East Timor (UNMISET), the aircraft's country of registration (Laos) civilian aviation organization, the Russian operators and owners of the aircraft, and the Russian Interstate Aviation Committee, Air Transport Accident Investigation Commission.

The use of a small team to investigate a complex incident of a large aircraft involving a remote and difficult location, limited support, and complicated international dealings was successfully completed by, in-part, leveraging on new readily available technology and imbedded scientific support. Using a mapping grade GPS unit the team was able to map and categorize approximately 900 items of wreckage in only 5 days. The daily analyses of these maps allowed a plausible scenario to be developed in a timely fashion. Early mapping and witness mark investigation provided a good indication of the aircraft configuration, engine power, and attitude at impact. This has lead to a understanding of the break-up sequence.

The investigation concluded that the incident was due to CFIT, which occurred as the result of a combination of actions involving the crew ignoring published landing procedures in favor of an unapproved approach based on onboard navigation aids, which eliminated all the risk-mitigation strategies under pinning safe aviation and calls into question the level of oversight being applied to small, underresourced charter operations out of countries with less-developed governmental control over civil aviation operations than developed countries

Safety recommendations from many investigations of CFIT events and serious incidents have related to the prevention of CFIT and approach and landing accidents. The ATSB and CAD Timor-Leste endorse those recommendations and their implementation.

6.1 Safety actions

6.1.1 Most significant findings

As a result of this investigation a large number of findings and safety actions were recommended[2]. While this paper does not address the details of the investigation it is worth noting the following as the most significant findings. The safety actions recommended are also included

1. The flight crew did not comply the published non-precision instrument approach and/or missed approach procedures at Baucau during flight in instrument meteorological conditions.
2. The flight crew conducted user-defined non-precision instrument approaches to Runway 14 at Baucau during flight in instrument meteorological conditions.
3. The pilot-in-command permitted the aircraft to descend below the MDA(H) published on both the Jeppesen and CAD Runway 14 instrument approach charts during flight in instrument meteorological conditions.

4. The flight crew did not recognize the increased likelihood and, therefore, risk of CFIT.
5. The flight crew did not recognize or treat that risk in a timely manner.

Safety actions recommended for *CAD Timor-Leste*

1. As a result of the recommendations made by the Australian (ATSB) accredited representative and his advisers to the government of Timor-Leste on Feb. 9, 2003, CAD issued a NOTAM that contained information that with the exception of UNMISET aircraft and aircraft operating on behalf of the UN, aircraft were not permitted to conduct NDB approaches at Baucau. The NOTAM included advice that all approaches and landings at Baucau were to be conducted in VMC, and that the Baucau NDB could only be used for homing or tracking.
2. On Feb. 10, 2003, CAD notified Jeppesen that the location of the runway in relation to the NDB and the aerodrome reference point (ARP) was incorrectly depicted on the Jeppesen charts and asked Jeppesen to withdraw the charts.
3. CAD issued a new NOTAM that contained information that QNH for Baucau was only available to aircraft operated by and on behalf of UNMISET during periods that ATS was available for aircraft engaged in UN troop rotations.
4. CAD issued a new NOTAM that contained information that UNMISET NDB instrument approach and landing charts for Runways 14 and 32 at Baucau, and an aerodrome chart for Baucau, dated Feb. 20, 2003, were available from UNMISET. The NOTAM included advice that the use of those charts was restricted for use only by UNMISET aircraft and aircraft operated on behalf of the UN. The NOTAM also included advice that PREVIOUS NDB IAL CHARTS RUNWAY 14/32 [Baucau] ARE HEREBY WITHDRAWN.
5. CAD advised that it had put in place arrangements to ensure that it is the single point of contact with the Royal Australian Air Force and Jeppesen for East Timor aeronautical data to prevent the possibility of incorrect or conflicting data being used in the preparation of instrument approach and landing charts.
6. CAD advised that it has amended the existing coordination procedures between Timor-Leste and the Australian and Indonesian ATS units to ensure that
a. Comoro approach would become the central point of coordination for aircraft entering Timor-Leste airspace and
b. crews of all aircraft entering Timor-Leste airspace would be required to contact Comoro approach on the appropriate very high-frequency radio (VHF) channel, irrespective of their destination, notwithstanding that Comoro air traffic control's responsibility was confined to the Dili control area.
7. CAD advised that with respect to CAD safety action 6, the amended procedures would ensure that Comoro ATS unit was made aware of all known aircraft entering East Timor airspace, and that by being in contact with an air traffic control (ATC) unit, aircraft crews could be provided with a level of ATS service.
8. CAD also advised that with respect to CAD safety actions 6 and 7, because of VHF range coverage, communication with Comoro approach could not be ensured if aircraft were operating at low levels, and that the amended procedures would not affect the existing TIBA arrangements until East Timor could establish its own Flight Information Service.
9. CAD advised that it was examining how Baucau QNH could be relayed to Dili so that Comoro Approach could relay that QNH to aircraft other than UNMISET aircraft or aircraft operated on behalf of the UN operating into Baucau.
10. CAD advised that preparation of the Timor-Leste aeronautical information publication (AIP) was nearing completion and that it was intended that the AIP would contain information specifying that pilots shall not use "user defined" GPS procedures instead of published procedures to conduct instrument approaches.
11. CAD advised that it had issued completely updated aerodrome and instrument approach and landing charts for Runways 14 and 32 at Baucau in October 2003, and that those charts were in compliance with ICAO standards and recommended practices.

Jeppesen Sanderson, Inc.

1. At the request of CAD Timor-Leste, Jeppesen issued Airway Manual Services Revision Letter Number 5-03 on Feb. 28, 2003, which provided details of revisions to material in the Pacific Basin edition of the manual, and included instructions that the Baucau 16- 1 and 16-2 charts were to be destroyed.

United Nations Mission of Support in East Timor Air Operations

1. On Feb. 12, 2003, UNMISET Air Operations commissioned a survey of the Baucau aerodrome to establish its actual elevation above mean sea level.
2. As a result of UNMISET safety action 1, the instrument approach and landing charts for Runways 14 and 32 at Baucau, and the aerodrome chart for Baucau, were amended with effect Feb. 20, 2003, and issued by UNMISET Air Operations; the charts contained information on the corrected elevations established by the survey, and were restricted for use by UNMISET and UN aircraft.
3. UNMISET advised that the UN would consider, on a case-by-case basis, providing ATS, including notification of QNH, at Baucau to aircraft on humanitarian flights, other than UNMISET aircraft or aircraft operated on behalf of the UN.

7. References

1. International Civil Aviation Organization, Convention on International Civil Aviation, Annex 13 "Aircraft Accident and Incident Investigation," Ninth edition July 2001.
2. Republica Democratica de Timor-Leste, Ministry of Transport, Communication, and Public Works, Aircraft Accident Report "Controlled Flight into Terrain, Ilyushin IL-76TD, RDPL-34141 Baucau, Timor-Leste Jan. 31, 2003. To be released.
3. Molent, L., and Barter, S., "Wreckage Examination of the IL-76 Aircraft Crash at Baucau East Timor," DSTO-TR-1423, Apr 2003.
4. Barter, S.A., and Molent, L., "Trial of Global Positioning System Based Field Wreckage Plotting and Analysis Equipment Using Data from a USMC F/A-18 Aircraft Accident," DSTO-TR-0828, June 1999.
5. Barter, S.A, "A Rapid Mapping and Analysis System for Use During Aircraft Accident or Incident Field Investigation," DSTO-TR-0780, March 1999.

Footnotes

1Air Vehicles Division, Defense Science and Technology Organization, 506 Lorimer Street, Fishermans Bend 3207, Australia. ISASI member No. CP0134
2Australian Transport Safety Bureau. ISASI member No. CP0092
3Directorate of Flying Safety, RAAF. ISASI member No. CP0075

Endnotes

[1] Given a typical landing speed for this aircraft of approximately 300 km/hr, then the rate of roll (from a few degrees left wing down to a few degrees left wing up) is considered achievable.

WYSIWYG—Or Is It?

The Need for a Standard for Secure Digital Photography in Accident Investigation

By Corey Stephens and Chris Baum, Air Line Pilots Association, International

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__Chris Baum__ is the manager of Engineering and Accident Investigation Section in the Engineering and Air Safety Department of the Air Line Pilots Association, International (ALPA). He supervises all support activities associated with ALPA's accident investigation efforts. He has been with ALPA for 8 years and has served in several positions in the Engineering and Air Safety Department. Prior to coming to ALPA, Baum spent 23 years in the U.S. Air Force in a variety of operational and staff positions.

1. Introduction

One has only to stop and look around at any contemporary major accident investigation site to realize that digital devices are in widespread use in the accident investigation community. Among these are an ever-increasing number of digital cameras, in many cases outnumbering film cameras as the tool of choice for recording the entire spectrum of accident scenes, from close-ups of failed components to aerial views of the accident site. Notwithstanding the completely valid school of thought that advocates disposable film cameras over any other type (cheaper, simpler, readily available, zero maintenance, no training required, low probability of error, etc.), digital cameras appear to be here to stay—at least until replaced by the next quantum leap in photographic technology.

Similarly, one has only to review current published government guidance on the conduct of an investigation to realize that no specific accommodations are generally being made to account for the different character of the digital medium vis-à-vis the optical (film) one. In the United States and Canada, there are no specific chain-of-custody requirements to ensure that the computer file representing the digital image is not copied illicitly, altered, or destroyed. Similarly, there is no guidance on use of any particular format for digital imaging, and no format yet exists that would allow investigators or other users of digital photography to positively check the validity of an image and identify any changes made to it (as well as when such changes were made, what they were, and who made them).

This paper will attempt to address the need for such a standard to verify the authenticity of digital photographs. We will begin with a discussion of how film cameras have been used and misused in investigations of various types over time, and how digital cameras have come to be used in the field of aircraft accident investigation today. We will attempt to identify at a high level some of the problems the authors perceive in the use of digital photography, including the possibility of undetectable alteration leading to erroneous conclusions. We will review the current state of various other agencies' (e.g., law enforcement) research and concerns in the subject because for a "secure" digital standard to be developed, it will be necessary, if for no other reason than efficiency, to enlist the participation of a variety of disciplines that can be considered stakeholders in this discussion. We will look at part of the spectrum of existing file formats in use for digital photography at both the amateur and professional level and attempt to describe how these or other formats would need to accommodate the needs of the investigation community to be able to have high confidence that the image they are viewing months after the accident is the same as the one viewed by investigators on scene. Finally, we will propose that the solution to developing a set of standards for camera, recording media, and related processes is for government and industry to work cooperatively to review the need, identify the requirements, and set the processes in motion that will lead to such standards

2. History of film cameras in investigations and film photo fakery

The following is quoted from a review of the book *Photo Fakery: The History and Techniques of Photographic Manipulation* by Dino A. Brugioni. The review was found posted on FCW.com (Federal Computer World).

Since the early 19th century, people have come to accept what they see in photographs as reality. The adage that "the camera never lies" has come to be accepted as historical fact, buttressed by the faith taken daily by all who read a newspaper or magazine that what is depicted in photos actually happened....

The art of producing fake photography predates the computer by almost a century, and some of America's well-known and most beloved figures have not gone unscathed, according to Brugioni.

For example, when photographer Matthew Brady first photographed President John Calhoun, he had no idea that an eager entrepreneur would later take a reversed image of Abraham Lincoln's head and graft it onto Calhoun's body for a new engraving. Not only was Lincoln's head also substituted on the bodies of Alexander Hamilton and Martin Van Buren, but the famous photo of "The Martyr Lincoln," which depicts Lincoln in his casket, has since been proven to be fraudulent, Brugioni writes.

Other well-known doctored photographs include the recently debunked 1934 depiction of the Loch Ness monster that appeared in a London newspaper; a studio portrait of American literary giant Walt Whitman that was used as the frontispiece to Leaves of Grass; and an 1865 portrait of Union Army Gen. William Sherman and his staff. More recent examples of tampering illustrated by Brugioni include the controversial darkening of O.J. Simpson's face on the cover of Time magazine and the less sinister yet commonplace touchups done to the faces, teeth, and bust lines of today's supermodels.

According to Brugioni, "the invention of the Eastman portable camera in 1888, followed by the box camera, opened photography to people in all walks of life." Now, a little more than 100 years later, the same can be said of the computer. Brugioni's book appears at a time when the technology is readily available for almost anybody with a modicum of computer skills to retouch, change, or forge photos....

Likewise, Brugioni uses the mind-boggling pace of technology to paint a bleak picture of the future. "We can see how photo fakery has made most of us doubters rather than believers," Brugioni writes. "With the new and expanding technology, faith in photography as the purveyor of truth has been weakened, and, in the future, it will be further weakened rather than strengthened."

Brugioni suggests that in this age of the "electronic darkroom," ethics must become "an important part of a course in digital imaging taught at DOD's Joint Defense Photography School in Pensacola, Fla." The concern, according to Brugioni, is that the ability to alter photos through electronic manipulation raises moral, legal, and ethical issues for members of the intelligence community who are responsible for providing imagery intelligence to high-level decision-makers in government, including the President.

Readers are left hanging, however, wondering what, if anything, can be done to avoid a future where nothing can be believed. Brugioni puts forth a strong argument in favor of distrusting the pictures shown in newspapers, in magazines, on television, and on the Internet.... [1]

It should not come as a surprise to any accident investigator working today that the idea of presenting a photograph to support a textual or other description of some aspect of an investigation is not new. Virtually any modern major aircraft accident investigation will have photographs of wreckage, ground scars, general overview of the accident site, and so on. Such use of photography has become routine and is expected. However, a review of the published accident investigation manuals of the United States, Canada, and ICAO reveal that surprisingly little is written in these texts regarding the use of photographs in the course of an investigation. All the aforementioned works refer to photography, suggesting that its use is expected and condoned, but none of these manuals make any mention of the need to verify the validity of photographs prior to using them to support analysis and develop conclusions as to accident causation. The maturity of all these documents suggests that this omission is not an oversight, but rather a reflection of a presumption on the part of the State that the investigator-in-charge will be able to exercise sufficient control over the investigation that he or she will, through the normal investigative process, have confidence that photographs taken in the field will be controlled sufficiently to prevent fraudulent use of altered photographs. This is likely a valid assumption in the case of traditional optical photographs. While it would not be impossible to take optical photographs of, for example, a suspect component, and in about the same time as would be required for normal developing, remove the film and surreptitiously alter the photograph, the normal processes for controlling access to evidence would tend to prevent such activity (or at least make it obvious). Conversely, however, the expanding use of digital photography in investigations does not have the same inherent characteristics that resist tampering. Accident sites at most recent major investigations are virtually awash in computers and related equipment. Each and every one of these devices is potentially an "electronic darkroom" that can be used, in real time, to retrieve, retain a copy of, and display digital photographs. That fact alone means that the possibility of a digital photograph being altered, through either a deliberate act, carelessness, or honest error is far greater than in the optical photography case.

Add to this the fact that digital cameras are increasing in popularity, increasing in capability, and decreasing in price and the fact that computer software whose legitimate purpose is to *change* digital photographs is doing the same thing, and it becomes easy to see that a potential problem exists that must be managed.

3. How are digital cameras used in the field today and what are the benefits?

Clearly, photography in general has established its place as a valuable investigative tool. It's difficult to imagine any modern investigation being conducted without photo documentation of the overall site, individual failed components, and so forth. Digital photography, however, is a subset that is still evolving. Subjectively, it appears that in the early years of the technology, it was viewed by investigators as simply a new type of camera, and it was too soon to tell if the legacy would be "state of the art" or "flash in the pan." Early models were expensive and the quality was inferior to optical cameras. Nevertheless, as investigators became more and more used to using automation in their daily business, and then in the field, the appeal of a device that would allow the immediate review of photographs as well as the ability to copy and move them easily, was compelling. The emerging prevalence, if not the advantages, of digital photography made it evident to investigative agencies that this technology had a place in field work. The problem, of course, was that this was not a decision driven by the needs of investigators, but rather one reacting to the marketing blitz that accompanied the emergence of digital cameras.

On a very basic level, digital cameras are used in essentially the same manner as their optical cousins. The camera as an investigative tool is used to record pertinent details of fractures, burns, scars, switch positions, and so forth. It is used to help the investigator recall the overall orientation of objects, and to enable study of views that may only be obtainable in a transient manner (such as an overhead view from a helicopter). Beyond that, however, there are significant differences between digital and optical that should be examined and understood if the risks and benefits are to be properly balanced.

Perhaps the most evident benefit of digital photography is tha it gives the photographer/investigator the ability to immediately see what he or she has just shot, evaluate the picture, make adjustments, and reshoot if necessary. Some later-model cameras have this capability built in to the programming and can automatically take a short series of photos, varying the exposure or other parameters slightly for each shot. In theory, this should result in photographs that are generally more useful to the investigator. On the other hand, however, this same capability introduces some new variables. Optical processing in general results in a relatively consistent product. Digital images, however, may vary considerably based only on the output device (e.g., the camera's own LCD screen vs. a laptop's processed video signal vs. a printer's "version" of the image). Depending on the desired subject of the image, these differences may or may not be significant.

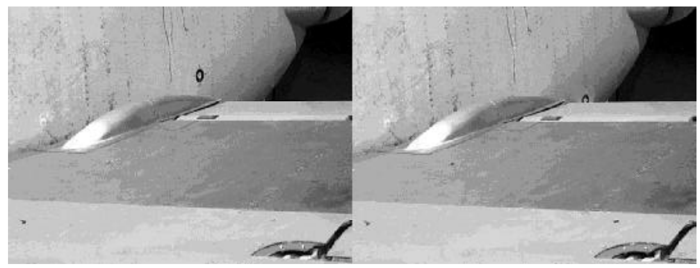
Another feature of digital cameras (generally viewed as an advantage) is the elimination of the need for film. In reality, however, the digital device has essentially the same limitations as the optical device—there is a finite amount of storage for the images and when that is used up, the photographer must take some action. The difference, of course, is in scale. The capacity of storage media continues to go up and the price continues to go down. At the same time, however, the capability of the camera to use large quantities of storage also continues to skyrocket. This is, on balance, a benefit. The upper limit of quality of digital photography (in terms of the image resolution—megapixels) continues to climb, allowing digital images to be made that are nearly indistinguishable in quality from the optical versions and are generally more than satisfactory for most investigative uses. The net result of the advances in picture quality (as indicated by pixel density) and storage availability clearly favors digital. The photographer can use media that allow recording of tens, if not hundreds, of pictures on devices that can be stored in a pocket, are more robust than traditional film cartridges, can be emptied of their data contents and reused, can be shared among users almost at will (although it is sometimes necessary to have a reading device), and have virtually no expiration date.

4. What are the potential problems?

With so many advantages in capacity, immediacy, and portability, one might be inclined to look at digital photography as an invaluable investigative tool. That may well be, but as with any other beneficial item, costs exists that must be balanced and drawbacks exist that must be evaluated to see if they should be mitigated before using the technology.

On a very basic level, the problems associated with digital photography are essentially the same as for optical photography in investigations. For example, it is equally important, whether the medium is film or digital, to ensure that photographs taken as evidence that leads to determinations of an accident cause can be preserved for proper use by safety investigators, can be validated, and their authenticity verified, and so on. There are few new protocols that need to be developed for use of digital photography. Implementing those protocols, however, may be significantly more difficult when using digital media.

Image manipulation is perhaps the biggest threat to the use of digital photography. If one were to set out to falsify optical photographs convincingly, one would likely need to have (or have access to) relatively sophisticated darkroom equipment and would also require the expertise to use it. On the other hand, current software is available for relatively little money that not only enables even a novice to alter digital photographs but also will frequently perform the task itself! If one wanted to be in the business of altering digital photographs and was willing to make an investment in that process, far more sophisticated software is available. One of the photographs taken below was taken to illustrate the relationship between the aircraft elevator trailing edge and a manufacturer's alignment mark installed to enable proper elevator rigging. The other was adjusted to change the position of the alignment mark relative to the elevator. The adjustment required software available at any retail computer store and about 15 minutes of effort. Granted, this is a simplistic example, and in an actual investigation, there would likely be a number of ways the deception could be uncovered. If the photos were electronically embedded in the document and the document was retained electronically, it might actually be possible to enlarge each photo and clearly see the changes. However, if the photos were printed in a report, such recovery would not be possible. In spite of the simplicity of this example, it illustrates the ease with which a photograph, taken to illustrate a point, can be changed to create an impression quite different from reality.



As with any piece of evidence, a chain of custody is important to ensure that the evidence remains under the control of the investigator-in-charge or other official of the State investigative agency. With physical objects, this is a straightforward process. Even with conventional photographic film, the process that generates a photographic negative can be monitored and the negatives can then be retained for safekeeping. Such a chain of custody is not as simple or straightforward with digital media. Given that the "photograph" takes the form of a computer file, duplicates of which can be indistinguishable from the original, identification of source material from copies becomes a significant issue. Even the storage device itself may not be identifiable as an original unless measures are taken initially to do so (e.g., initialed by an investigator or placed in a container with a tamper-evident seal). The file that contains a digital image can be moved both from and to many types of storage. As a result, it is possible to capture an image with a camera, store it to a digital storage medium, move it from that medium to a computer for processing, change it and move it back to the storage medium as a different image. Most computer users realize that files have attributes, and among those attributes is a date and time. This is frequently the information used to distinguish one version of a file from a later, presumably changed, version. This feature may be of value in determining if a file has a date and time consistent with its "status" as an original investigation artifact. However, depending on the software used, the file date and time on a computer may be the date and time the file was downloaded off the medium onto a computer for legitimate investigative use, even if the file was unchanged. Thus, the presence of a date and time later than the field phase of the investigation is not explicitly indicative that the file has been changed.

Finally, one must consider the volatility and fragility of a digital image. As a rule, digital storage media are robust and relatively resistant to mechanical damage. They are, however, not impervious to mistakes, mishandling, or other hazards. If a role of conventional photographic film is somehow damaged, portions of the images on the film may be recoverable. If the digital medium is mechanically damaged, it is far less likely that any information is recoverable. In addition, as most computer users know, there is the distinct possibility of human error causing loss of data. The difference between "Erase All—Yes" and "Erase All—No" may be so slight as to allow the user to defeat the manufacturer's safeguards. And as every computer user also knows, once a file is truly gone, it is generally gone forever.

5. How are other organizations and agencies handling this?

Aviation accident investigators are not the only ones facing these problems. The Federal Bureau of Investigations in the United States has been looking at these same issues. An examiner in the FBI Laboratory's Special Photographic Unit, Special Agent Douglas A. Goodin described in February 1996 in a paper entitled "Image Security and Integrity," "The ease with which images can be changed is the central issue in image integrity. The impermanent recording of an image by rearranging a bunch of magnetic particles and corresponding pixels seems to lack the security and integrity of good old film." Special Agent Goodin believes that at a crime scene when a digital camera is used, a greater problem for law enforcers may surface. "The photographer may have been the only one there at the time. A particularly damning piece of evidence could be later undetectably inserted into the images through an image-processing program. As digital photography becomes more widespread in law enforcement, I could see this becoming a problem for overzealous or dishonest officers." In a recent case in the United States, the prosecution team in a trial was accused of photo manipulation. During the O.J. Simpson murder trial, prosecutors entered into evidence a picture of Simpson wearing the now infamous Bruno Magli shoes. The defense claimed Simpson didn't wear those shoes and the photograph was manipulated, and thus objected. Expert witnesses were then called in. Two experts gave their analysis of the photos, but each gave a different view. This issue was finally settled when a roll of film that contained pictures of Simpson wearing the Bruno Maglis was discovered and entered into evidence. If not for that roll of film, or had the original image been digital, the original photograph probably wouldn't have held up as evidence.

In June 2002, the Scientific Working Group on Imaging Technologies (SWGIT), of which the FBI is involved, released Version 1.2 of its recommendations and guidelines for the use of digital image processing in the criminal justice system. The Group's objective is "…to ensure the successful introduction of forensic imagery as evidence in a court of law." Its work includes brief descriptions of advantages, disadvantages, and potential limitations of each major digital imaging process. It sees digital image processing as a necessary and accepted practice in forensic science. The SWGIT Group feels that any changes to an image made through digital image processing are acceptable in forensic applications provided the following criteria are met:

- The original image is preserved.
- The processing steps are logged when they include techniques other than those used in a traditional photographic darkroom.
- The end result is presented as an enhanced image, which may be reproduced by applying the logged steps to the original image.

SWGIT has continued its work by releasing "Minimum Best Practices for Documenting Image Enhancement-Version 1.1" on March 4, 2004. The purpose of this document is to describe the "best practice" documentation of image enhancement used in the criminal justice system. The objective of SWGIT with these standards is to provide laboratory personnel with instruction regarding the level of documentation that is appropriate when performing enhancement operations on still images, regardless of the tools and devices used to perform the enhancement. SWGIT is using this documentation of image enhancement techniques to help satisfy the legal requirements for the introduction of forensic images as evidence in a court of law. SWGIT has developed two categories by which images can be enhanced—Category 1 and Category 2. Category 1 images include "images utilized to demonstrate what the photographer or recording device witnessed but not analyzed by subject matter experts." This would include General crime scene or investigative images, surveillance images, autopsy images, documentation of items of evidence in a laboratory, and arrest photographs ("mug shots"). Category 2 images include "images utilized for scientific analysis by subject matter experts." This would include latent prints, questioned documents, impression evidence, Category 1 images to be subjected to analysis, and patterned evidence. SWGIT suggests that Category 1 images need only rudimentary documentation that would describe what type of enhancement(s) was used. Category 2 images require a more detailed description of the enhancement, so that any changes would be clearly spelled out to an expert. SWGIT has also developed a number of standard operating practices (SOPs) for digital and film-based photography. These SOPs cover issues such as first responder photography, surveillance photography, tactical survey photography, HAZMAT scene photography, aerial photography, and accident scene photography.

The FBI and other agencies have already done much work, and we can benefit from that. ISASI could develop SOPs and "best practices" documentation for the accident investigation community. By using this work as a foundation, we can make digital photography more beneficial and reliable as evidence.

6. Current file formats

There are some file formats that currently support supplemental information about the recorded image. These include joint photographic experts group (JPEG), tagged image file format (TIFF), exchangeable image file format (EXIF),and TIFF extensions. The need for a uniform file format standard for image data stored by digital still cameras has increased as these cameras have grown in popularity. At the same time, with the broadening application of this technology, a similar need has arisen for uniformity of the attribute information that can be recorded in a file. We will not go into a history of JPEG and TIFF file formats here, but we will discuss the EXIF and TIFF attribute information that can currently be recorded.

EXIF was developed by the Japan Electronic Industry Development Association (JEIDA) to be used in digital still cameras and related systems. Version 1.0 was first published in October 1996. Over time, changes have been made to make improvements to the EXIF format for greater ease of use, while still allowing backward compatibility with products of manufacturers currently implementing EXIF Version 1.x or considering its future implementation. Version 2.1 contains the current recommended EXIF standards. The file recording format is based on existing formats. Compressed files are recorded as JPEG (ISO/

Tag Name	Field Name	Tag ID Dec	Tag ID Hex	Type	Count
A. Tags relating to image data structure					
Image width	ImageWidth	256	100	SHORT or LONG	1
Image height	ImageLength	257	101	SHORT or LONG	1
Number of bits per component	BitsPerSample	258	102	SHORT	3
Compression scheme	Compression	259	103	SHORT	1
Pixel composition	PhotometricInterpretation	262	106	SHORT	1
Orientation of image	Orientation	274	112	SHORT	1
Number of components	SamplesPerPixel	277	115	SHORT	1
Image data arrangement	PlanarConfiguration	284	11C	SHORT	1
Subsampling ratio of Y to C	YCbCrSubSampling	530	212	SHORT	2
Y and C positioning	YCbCrPositioning	531	213	SHORT	1
Image resolution in width direction	XResolution	282	11A	RATIONAL	1
Image resolution in height direction	YResolution	283	11B	RATIONAL	1
Unit of X and Y resolution	ResolutionUnit	296	128	SHORT	1
B. Tags relating to recording offset					
Image data location	StripOffsets	273	111	SHORT or LONG	*S
Number of rows per strip	RowsPerStrip	278	116	SHORT or LONG	1
Bytes per compressed strip	StripByteCounts	279	117	SHORT or LONG	*S
Offset to JPEG SOI	JPEGInterchangeFormat	513	201	LONG	1
Bytes of JPEG data	JPEGInterchangeFormatLength	514	202	LONG	1
C. Tags relating to image data characteristics					
Transfer function	TransferFunction	301	12D	SHORT	3 * 256
White point chromaticity	WhitePoint	318	13E	RATIONAL	2
Chromaticities of primaries	PrimaryChromaticities	319	13F	RATIONAL	6
Color space transformation matrix coefficients	YCbCrCoefficients	529	211	RATIONAL	3
Pair of black and white reference values	ReferenceBlackWhite	532	214	RATIONAL	6
D. Other tags					
File change date and time	DateTime	306	132	ASCII	20
Image title	ImageDescription	270	10E	ASCII	Any
Image input equipment manufacturer	Make	271	10F	ASCII	Any
Image input equipment model	Model	272	110	ASCII	Any
Software used	Software	305	131	ASCII	Any
Person who created the image	Artist	315	13B	ASCII	Any
Copyright holder	Copyright	3432	8298	ASCII	Any

Figure 1

Tag Name	Field Name	Tag ID Dec	Tag ID Hex	Type	Count
A. Tags Relating to Version					
Exif version	ExifVersion	36864	9000	UNDEFINED	4
Supported FlashPix version	FlashPixVersion	40960	A000	UNDEFINED	4
B. Tag Relating to Image Data Characteristics					
Color space information	ColorSpace	40961	A001	SHORT	1
C. Tags Relating to Image Configuration					
Meaning of each component	ComponentsConfiguration	37121	9101	UNDEFINED	4
Image compression mode	CompressedBitsPerPixel	37122	9102	RATIONAL	1
Valid image width	PixelXDimension	40962	A002	SHORT or LONG	1
Valid image height	PixelYDimension	40963	A003	SHORT or LONG	1
D. Tags Relating to User Information					
Manufacturer notes	MakerNote	37500	927C	UNDEFINED	Any
User comments	UserComment	37510	9286	UNDEFINED	Any
E. Tag Relating to Related File Information					
Related audio file	RelatedSoundFile	40964	A004	ASCII	13
F. Tags Relating to Date and Time					
Date and time of original data generation	DateTimeOriginal	36867	9003	ASCII	20
Date and time of digital data generation	DateTimeDigitized	36868	9004	ASCII	20
DateTime subseconds	SubSecTime	37520	9290	ASCII	Any
DateTimeOriginal subseconds	SubSecTimeOriginal	37521	9291	ASCII	Any
DateTimeDigitized subseconds	SubSecTimeDigitized	37522	9292	ASCII	Any
G. Tags Relating to Picture-Taking Conditions					
See Table 5					
H. Tags Relating to Date and Time					
Pointer of Interoperability IFD	Interoperability IFD Pointer	40965	A005	LONG	1

Figure 2

G. Tags Relating to Picture-Taking Conditions					
Exposure time	ExposureTime	33434	829A	RATIONAL	1
F number	FNumber	33437	829D	RATIONAL	1
Exposure program	ExposureProgram	34850	8822	SHORT	1
Spectral sensitivity	SpectralSensitivity	34852	8824	ASCII	Any
ISO speed rating	ISOSpeedRatings	34855	8827	SHORT	Any
Optoelectric conversion factor	OECF	34856	8828	UNDEFINED	Any
Shutter speed	ShutterSpeedValue	37377	9201	SRATIONAL	1
Aperture	ApertureValue	37378	9202	RATIONAL	1
Brightness	BrightnessValue	37379	9203	SRATIONAL	1
Exposure bias	ExposureBiasValue	37380	9204	SRATIONAL	1
Maximum lens aperture	MaxApertureValue	37381	9205	RATIONAL	1
Subject distance	SubjectDistance	37382	9206	RATIONAL	1
Metering mode	MeteringMode	37383	9207	SHORT	1
Light source	LightSource	37384	9208	SHORT	1
Flash	Flash	37385	9209	SHORT	1
Lens focal length	FocalLength	37386	920A	RATIONAL	1
Flash energy	FlashEnergy	41483	A20B	RATIONAL	1
Spatial frequency response	SpatialFrequencyResponse	41484	A20C	UNDEFINED	Any
Focal plane X resolution	FocalPlaneXResolution	41486	A20E	RATIONAL	1
Focal plane Y resolution	FocalPlaneYResolution	41487	A20F	RATIONAL	1
Focal plane resolution unit	FocalPlaneResolutionUnit	41488	A210	SHORT	1
Subject location	SubjectLocation	41492	A214	SHORT	2
Exposure index	ExposureIndex	41493	A215	RATIONAL	1
Sensing method	SensingMethod	41495	A217	SHORT	1
File source	FileSource	41728	A300	UNDEFINED	1
Scene type	SceneType	41729	A301	UNDEFINED	1
CFA pattern	CFAPattern	41730	A302	UNDEFINED	Any

Figure 3

IEC 10918-1iv). Uncompressed files are recorded in TIFF Rev. 6.0v format. By using existing formats, photos taken using a digital still camera or related system can be read directly by commercial applications (i.e., Adobe PhotoShop) and makes viewing and manipulating of the images possible. Related attribute information for both compressed and uncompressed files is stored in the tag information format defined in TIFF Rev. 6.0. Information specific to the camera system and not defined in TIFF is stored in private (manufacturer) tags registered for EXIF. The reason for using the TIFF Rev. 6.0 tag format in the compressed file is to facilitate exchange of attribute data between EXIF compressed and uncompressed files. A feature of EXIF image files is their compatibility with standard formats in wide use today, enabling them to be used on personal computers and in other information systems. The intention of JEIDA is to promote widespread use of digital still cameras. Figure 1 below shows what data are recorded under the TIFF Rev. 6.0 Attribute Information tags. Figures 2 and 3 show the fields that are recorded under EXIF. For a full description of all fields, please reference Digital Still Camera Image File Format Standard (Exchangeable image file format for Digital Still Camera: EXIF), Version 2.1, JEIDA-49-1998).

EXIF allows more than just the recording of image specific attributes. EXIF also allows the recording of specific location information acquired by a GPS receiver. This is feature can be very beneficial in an accident investigation. Not only is latitude and longitude information captured, but other references such as GPS time (atomic clock) and reference points used to determine direction of movement and direction of image are captured. Figure 4 shows a complete list of GPS attributes that can be recorded under EXIF.

While EXIF and TIFF extensions are very useful, they do have some limitations. If the images are opened in an application that does not support the readout of attributes, and then saved, the information will be lost. If that is the only copy of the image, then all electronically recorded history of that file will be lost. Another limitation is garbage-in garbage-out (GIGO). If the settings in the camera (i.e., time and date) are not correct, then the values will be recorded incorrectly. Also, many camera manufacturers release firmware updates to fix minor "bugs" in the camera's operating system. If there is a firmware problem, it is possible the correct data will not be recorded. Likewise, the GPS location information will be limited to the accuracy of the data source. If a differential GPS system is not used, then the investigator runs the risk of the photos not matching up with the survey locations.

7. What is needed is a standard for investigations

Now that we have looked at the attributes that are currently recordable for digital photos, let's look at what attributes would be considered essential for accident investigation. These include date and time the photo was taken, camera settings (exposure, etc.), where taken (GPS info), the name of the photographer, notification of any alterations of the file, and a layer of the image that shows the original unaltered image.

Date and time are important and easily recorded. Validity of the data, however, must be assured as well and is not quite as straightforward. The source of the data can be the camera's internal clock or GPS input. The GPS input would be preferable as it cannot be set incorrectly. If the internal clock is used, then it should be adjusted to the same time format and zone that the investigating agency is using (i.e., local or ZULU). Camera (equipment type) information is recorded under both the TIFF extensions and EXIF, but camera settings and condition information

Tag Name	Field Name	Tag ID		Type	Count
		Dec	Hex		
A. Tags Relating to GPS					
GPS tag version	GPSVersionID	0	0	BYTE	4
North or South Latitude	GPSLatitudeRef	1	1	ASCII	2
Latitude	GPSLatitude	2	2	RATIONAL	3
East or West Longitude	GPSLongitudeRef	3	3	ASCII	2
Longitude	GPSLongitude	4	4	RATIONAL	3
Altitude reference	GPSAltitudeRef	5	5	BYTE	1
Altitude	GPSAltitude	6	6	RATIONAL	1
GPS time (atomic clock)	GPSTimeStamp	7	7	RATIONAL	3
GPS satellites used for measurement	GPSSatellites	8	8	ASCII	Any
GPS receiver status	GPSStatus	9	9	ASCII	2
GPS measurement mode	GPSMeasureMode	10	A	ASCII	2
Measurement precision	GPSDOP	11	B	RATIONAL	1
Speed unit	GPSSpeedRef	12	C	ASCII	2
Speed of GPS receiver	GPSSpeed	13	D	RATIONAL	1
Reference for direction of movement	GPSTrackRef	14	E	ASCII	2
Direction of movement	GPSTrack	15	F	RATIONAL	1
Reference for direction of image	GPSImgDirectionRef	16	10	ASCII	2
Direction of image	GPSImgDirection	17	11	RATIONAL	1
Geodetic survey data used	GPSMapDatum	18	12	ASCII	Any
Reference for latitude of destination	GPSDestLatitudeRef	19	13	ASCII	2
Latitude of destination	GPSDestLatitude	20	14	RATIONAL	3
Reference for longitude of destination	GPSDestLongitudeRef	21	15	ASCII	2
Longitude of destination	GPSDestLongitude	22	16	RATIONAL	3
Reference for bearing of destination	GPSDestBearingRef	23	17	ASCII	2
Bearing of destination	GPSDestBearing	24	18	RATIONAL	1
Reference for distance to destination	GPSDestDistanceRef	25	19	ASCII	2
Distance to destination	GPSDestDistance	26	1A	RATIONAL	1

Figure 4

are only available under EXIF. This type of data includes exposure time, F number, ISO speed rating, shutter speed, flash, exposure program, light source, etc. (For a detailed list, see Figures 2 and 3 in the preceding section.) When the image file is opened in an application that supports EXIF, this data can be viewed, making highly detailed log sheets in the field unnecessary. Information such as the exact location of where a photo was taken and direction are also very important to know. With investigations increasingly using more digitized data from the surveys of accident sites, the ability to bring in latitude and longitude information, as well as the direction the photo was taken, becomes even more valuable. Being able to map out the location of a photo in respect to a specific part or piece of wreckage using precise (differential GPS) measurements is very valuable in post-field activities. If the camera is set properly, both TIFF extensions and EXIF can record the name of the photographer. This is very important in investigations involving multiple parties or agencies in order to keep the source known. If all that is left at the end of an investigation is a CD full of JPEG files, and no information on the photographer, you cannot be assured of the chain of custody of the images.

There are two other requirements for digital images used in an investigation that are not currently addressed under these formats. The first is the ability to log any alterations or modifications of the file. Any time there is a modification, or a filter is used on an image in an application, there must be a log of those changes. This would allow anyone in the investigation to determine the authenticity of an image. The second is a "layer" of the image that would remain unaltered. This would be similar to Adobe PhotoShop's layering system, except that the base layer would never change. Notations, filters, or other processes could be done on the photo, but the base photo cannot be changed. This allows all parties to recover the original, unaltered image. By using these two features together, the history of a digital image could be viewed by anyone examining the electronic version of an image. It should be noted, though, that these safeguards would not prevent an illicitly altered image from being printed and represented as accurate. Ultimately, a process would have to be developed that not only made the electronic image's authenticity verifiable, but would also prevented an altered image from being printed without an indication that it had been altered.

8. An industry group is needed to define and develop the standard

In order to address the issues identified above, a series of standards is necessary. These standards would encompass a format for digital media that allows "audit" of the authenticity as well as a number of processes that would ensure that authenticity of both the electronic and printed form of digital photographs could be verified. As noted above, the need for this "secure video" capability extends beyond the aircraft accident investigation community. Any discipline that relies on authentic photographs would be affected. All modes of transportation accident investigation, law enforcement, and insurance companies all have similar interests, as would a variety of government agencies. Representatives of these groups, along with camera and image processing experts, should be brought together in a cooperative government-industry group to develop standards for "secure" digital photographs. These standards and processes would ultimately result in a means to take, store, enhance, clarify, edit, copy, and print digital photographs while maintaining the capability to recover the original image and identify all changes made to it.

Standards setting is never easy—competing interests must be balanced and somebody has to pay for the changes to the status quo. Nevertheless, absence of a means to ensure that photographs taken cannot be altered without irrevocable evidence of that alteration has the potential to result in significant cost to the industry if manufacturing and operations are affected by erroneous conclusions drawn from and investigation based on flawed evidence. As the capability to take extremely high quality digital photographs and distribute them instantly around the world expands, as the capability to make changes to digital photographs becomes evermore sophisticated, and as the potential cost of accidents becomes higher, the need for digital photographs whose authenticity can be positively determined will similarly increase. The characteristics identified by the SWGIT Group and listed in Section 5 are straightforward. The original image must be preserved and be recoverable, change must be allowed but must also be logged or tracked, and the enhanced or changed image must be clearly identifiable as such. Defining the changes necessary to hardware, software, and processes would not be difficult. Implementing them in an industry-standard form would be. A standard is nevertheless needed that can be applied to newly manufactured cameras, retrofit into existing ones, and supported by image editing software. The aircraft accident investigation community has before it an opportunity to take a leadership role in an effort to proactively improve upon a technology to the benefit of all investigations and related activity. We should act on that opportunity now. ◆

Endnotes

[1] "Sometimes Seeing Is Not Believing" By Daniel Verton, Dec. 20, 1999.

Flight Data Analysis Using Limited Data Sets

By Neil Campbell (MO3806), Australian Transport Safety Bureau

__Neil Campbell__ graduated in 1983 with a bachelor of engineering degree (electronics) from the University of Western Australia. In 1986, he joined the Bureau of Air Safety Investigation as a flight recorder specialist. During 1998, he was a member of the ICAO Flight Recorder Panel, which developed changes to ICAO Annex 6. In February 2000, Neil joined the Corporate Safety Department of Cathay Pacific Airways Limited in Hong Kong. During 2001 and 2002, he held the position of manager air safety. In December 2003, he rejoined the Australian Transport Safety Bureau as a senior transport safety investigator.

1. Introduction

The use of computer graphics to animate flight data recorder (FDR) or quick access recorder (QAR) information is well-known. It is a valuable investigation tool as well as a powerful medium to provide communication and education. With newer aircraft, the FDR or QAR will record a comprehensive range of parameters that accurately define its performance and operation. However, with general aviation aircraft, most helicopters, or older-generation air-transport aircraft, there may be no FDR and only a limited number of parameters will be recorded by other systems. At the Australian Transport Safety Bureau (ATSB), animations have been produced using limited data sets including:

- radar data.
- Global positioning system (GPS) data.
- electronic control unit data (e.g., engine data).
- basic FDR parameters.

The case study presented in this paper is from a Bell 407 helicopter accident. Two sources of recorded data were available for this investigation

- ground-based radar data, and
- onboard electronic control unit (ECU) data

2. Radar data

2.1 Background

Primary radar returns are produced by radar transmissions that are passively reflected from an aircraft and received by the radar antenna. The received signal is relatively weak and provides only position information. Primary radars, which are only located near capital city airports, have a nominal range of 50 nm.

Secondary radar returns are dependent on a transponder in the aircraft to reply to an interrogation from the ground. The aircraft transmits an encoded pulse train containing the secondary surveillance radar (SSR) code and other data. Pressure altitude may be encoded with these pulses. As the aircraft transponder directly transmits a reply, the signal received by the antenna is relatively strong. Consequently, an aircraft that has its transponder operating can be more easily and reliably detected by radar. Civilian secondary surveillance radars are located along the east coast of Australia to meet the operational requirement of radar coverage from 200 nm north of Cairns to 200 nm west of Adelaide. Coverage within a 200 nm radius of Perth is also required.

A transponder-equipped aircraft is not always detected by secondary radar. This could be due to one of the following reasons:

- aircraft is outside of the range of the radar,
- transponder is not switched on,
- transponder is unserviceable,
- loss of aircraft power to the transponder,
- terrain shielding, and
- aircraft transponder aerial is shielded from the radar due to aircraft maneuvering.

2.2 Accuracies

The radar rotates at 16.2 RPM giving a scan rate of 3.7 seconds.

The accuracy of the radar position data is proportional to the range of the aircraft from the radar site. Typical accuracies for a monopulse SSR are

Range accuracy: w :± 0.05 nm RMS

Azimuth accuracy: ± 0.05° RMS

The overall accuracy can be affected by terrain or meteorological conditions.

The Mode C pressure altitude data accuracy is determined by the aircraft's encoding altimeter accuracy plus the transponder quantization of 100 feet. An encoding altimeter can suffer from lag when experiencing high vertical speed changes.

3. ECU data

3.1 Background

The Bell 407 was fitted with a Rolls-Royce 250-C47B turbine engine. The ECU is a component of the engine full authority digital electronic control (FADEC) system. The ECU was located forward of the main rotor transmission (refer to Figure 1).

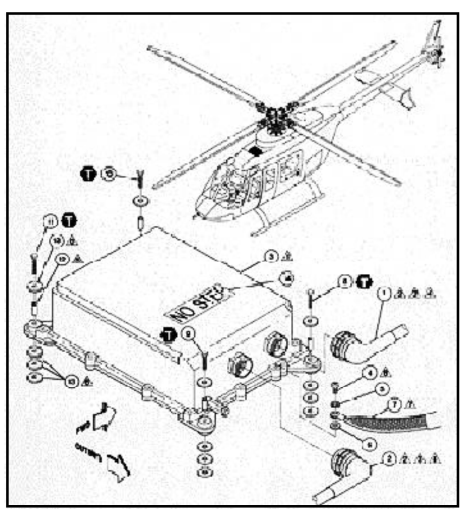


Figure 1

The ECU has a non-volatile memory (NVM) that can store engine and other parameters. When it detects an exceedance, it functions as an incident recorder and is designed to store 60 seconds of data commencing 12 seconds prior to the start of the exceedance.

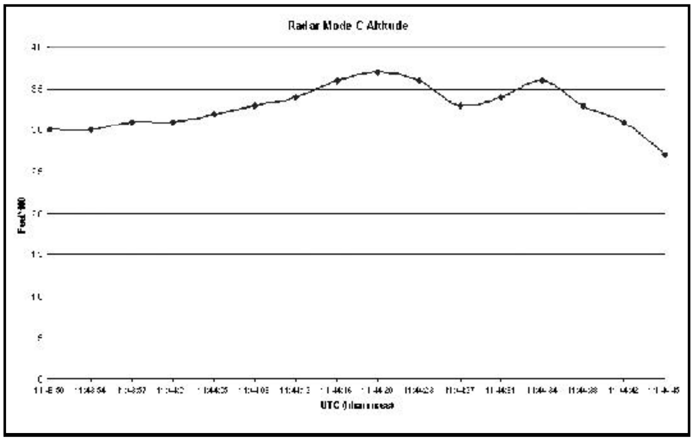


Figure 2

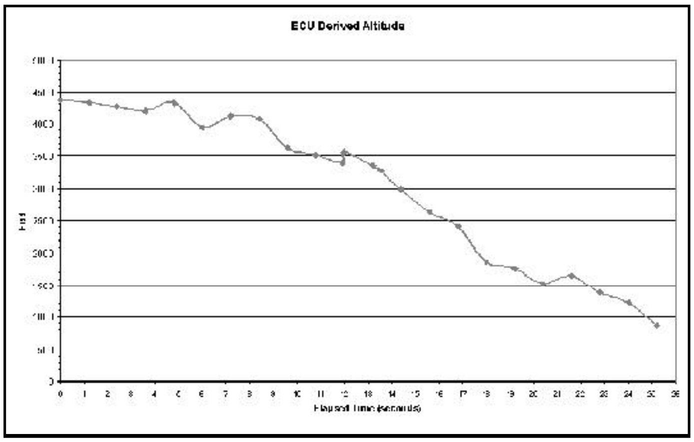


Figure 3

3.2 Parameters

The following parameters were recorded:

Mnemonic:	Name:	Units:
Timestamp	Cumulative Engine Run-time	hhh:mm:ss.sss
Nr	Rotor Speed	%
Ng (N_1)	Gas Generator Speed	%
Np (N_2)	Power Turbine Speed	%
MGT	Measured Gas Temperature	°F
Q	Torque	%
Wf	Fuel Flow	pph
NDOT	Rate of change of Ng	%Ng/sec
P1	Ambient Pressure	psi
Mode	Engine Control Mode (Automatic/Manual)	1=Auto
CP	Collective Pitch	%
PLA	Power Lever Angle	Degrees
T1	Compressor Inlet Temperature	°F

Each parameter was sampled 22 times covering a period of 25.2 seconds.

3.3 Sampling rate

Each parameter was sampled every 1.2 seconds. When an exceedance occurred, an additional sample of each parameter was recorded.

4. Timing overlap

Radar data are time-stamped with UTC that is synchronized with UTC obtained from GPS. ECU data are time-stamped with elapsed time relative to the initiating exceedance. As these two time sources were not synchronized, it was necessary to determine by other means whether an overlap of the two data sets had occurred.

The following observations were made from the radar data:

- The final radar return was recorded at 1144:45 UTC at an altitude of 2,700 feet (Mode C).
- The latitude and longitude of the final radar return was located very near the crash site (within 0.1 nm).
- The final series of returns indicated that a substantial speed had developed.
- The initial loss of returns was probably due to terrain shielding.
- The helicopter subsequently did not climb high enough for radar returns to again be received.

The following observations were made from the ECU data:

- The recording of ECU data ceased when impact occurred.
- The ECU stored data from the last 25 seconds of flight.
- Data latency was small as the engine data recorded by the ECU was directly available and not transmitted by other systems.

Considering the above observations, it was considered highly likely that the radar data and ECU data did overlap in time and that the maneuver leading to the development of the substantial speed, initially captured by radar, was the same maneuver subsequently captured by the ECU.

Pressure altitude was the only common parameter and it was used to try and correlate in time the two data streams.

5. Pressure altitude

5.1 Radar Mode C pressure altitude

Pressure altitude referenced to 1013.2 hPa was recorded with a resolution of 100 feet. The source of the pressure altitude was an altitude encoder in the helicopter. A static source provided static pressure to the encoder. Mode C pressure altitude is monitored by ATC and in comparison with the altitude derived from the ECU it was considered to be accurate but limited by resolution. Refer to Figure 2.

As the reported QNH was 1014 hPa approximately, 30 feet needed to be added to the recorded Mode C values to give pressure altitude referenced to QNH.

5.2 ECU ambient pressure

The ECU recorded ambient pressure that was used for fuel scheduling purposes. It was sourced from an open port on the ECU itself. The port was not connected to a static pressure line. Given its location it was susceptible to pressure fluctuations due to airflow from the main rotor.

Ambient pressure is an accurate indicator of pressure altitude as long as certain assumptions are met. One assumption is that an accurate source of static pressure is available, and, if so, standard conversions can be used to convert pressure to altitude.

This assumption was not satisfied for the ambient pressure data recorded by the ECU, and corrections needed to be applied to convert it to pressure altitude. Refer to Figure 3.

5.3 ECU Pressure altitude offset

The highest Mode C pressure altitude recorded was 3,700 feet, and the highest pressure altitude obtained from the ECU was

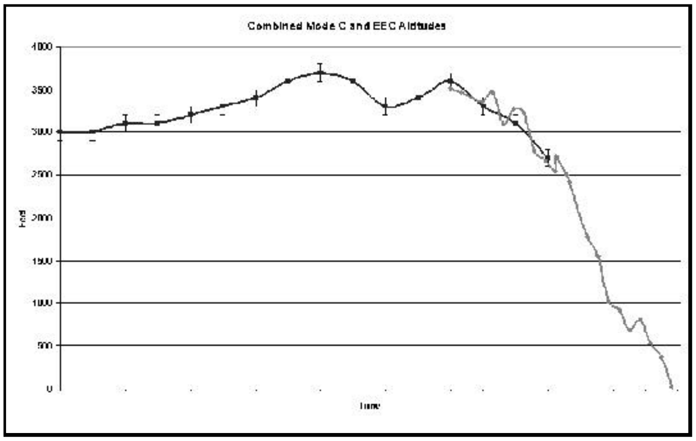


Figure 4

4,370 feet. This indicated that the ECU was over-reading by at least 670 feet.

The final pressure altitude obtained from the ECU was 870 feet. Given the small data latency expected for the ECU, then this value was the approximate sea-level value allowing for the sampling interval of 1.2 seconds.

6. Timing correlation

Overlaying the Mode C and ECU pressure altitude traces showed that a good match was obtained when the ECU altitude was offset by -850 feet and the end of the Mode C trace was overlapped by the start of the ECU trace. The duration of the overlap was approximately 11 seconds. The tolerance of the duration of the overlap is considered to be ± 2 seconds. Refer to Figure 4.

7. Animation of the ECU data

While computer animation is recognized as being a very useful means of assimilating large quantities of information, it is also very useful when analyzing limited data sets such as the ECU parameters.

The ECU data were imported by the ATSB's Hewlett Packard C3000 computer for presentation using RAPS version 5.0 software. A simulated instrument panel was developed to display key parameters in real time. Refer to Figure 5.

While the ECU sampling interval was 1.2 seconds, the frame rate of the animation was much higher, e.g., 100 frames/sec. Intermediate values were linearly interpolated.

Torque instrument:

The pointer and digital display were directly driven by the ECU torque data.

MGT instrument:

After the values in degrees Fahrenheit were converted to degrees Celsius, the pointer and digital display were directly driven by the ECU MGT data.

Ng instrument:

The pointer and digital display were directly driven by the Ng data.

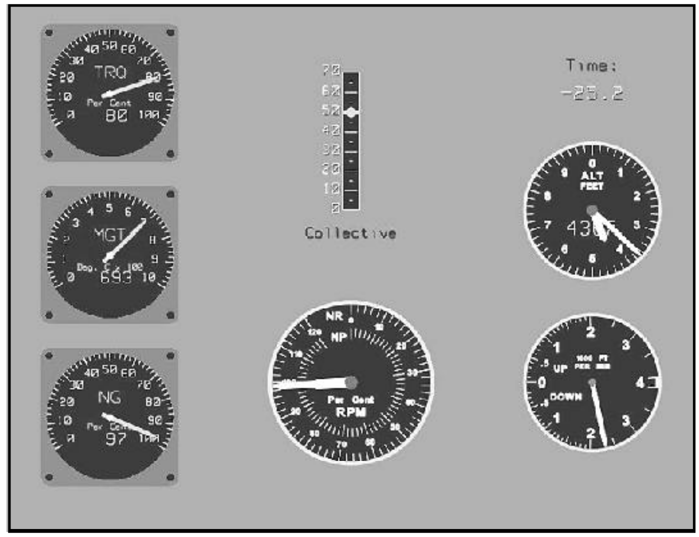


Figure 5

Collective display:

The pointer and digital display were directly driven by the collective data. Rolls-Royce advised that maximum collective corresponded to a recorded value of approximately 60%.

Nr/Np % RPM instrument:

The pointer and digital display were directly driven by the Nr/Np data.

Time:

A time counter in seconds with the zero datum at the end of the ECU recording, i.e., at the time of impact with the water. A value of –25.2 corresponds to the start of the ECU data.

Altimeter:

The ECU ambient pressure data (psi) were converted to pressure altitude. The pressure altitude was smoothed and used to drive the display.

Vertical speed indicator:

Derived from the rate of change of pressure altitude.

The animation was very useful in showing the correlation between parameters, e.g., the relationship between Nr/Ng due to governing. These relationships are not always evident from a data listing. It also put the data into time perspective.

8. Conclusions

Non-FDR data are becoming increasingly available from accidents involving general aviation aircraft and smaller helicopters. While these aircraft do not require an FDR, they are often fitted with avionics that can store data.

Analysis of this data can be very useful to an investigation. Computer animation of these limited data sets can provide valuable information that is not readily apparent from a data listing.

Data obtained from sources other than the FDR may be inaccurate and uncalibrated and require careful analysis. ◆

INVITED PAPER

Managing Fatigue as an Integral Part of A Fatigue Risk Management System

By Professor Drew Dawson and Kirsty McCullough, University of South Australia

(Oral presentation by Professor Drew Dawson.—Editor)

Professor Drew Dawson is currently the director of the Center for Sleep Research at the University of South Australia. He is nationally and internationally recognized for his contributions to the scientific community and to industry in the areas of organizational psychology and human factors, industrial relations negotiations, and the human implications of hours of work. He has worked extensively with the aviation, manufacturing, retail, entertainment, transportation, and mining sectors in Australia and is internationally recognized as a consultant on fatigue in the workplace. He has instigated fatigue management programs, developed shift work and fatigue policy, undertaken pre-employment assessments, and facilitated shift work education sessions. He also regularly presents at national and international conferences and has provided expert witness testimony in several fatigue-related court cases.

No photo available

Kirsty McCullough is a Ph.D. research student at the Center of Sleep Research, University of South Australia.

Abstract

Fatigue has increasingly been viewed by society as a safety hazard. This has lead to increased regulation of fatigue by governments. The most common control process has been compliance with prescriptive rule sets. Despite the frequent use of prescriptive rule sets, there is an emerging consensus that they are hazard control, based on poor scientific defensibility and lack of operational flexibility. In exploring potential alternatives, we propose a shift from prescriptive HOS limitations toward a broader safety management system approach. Rather than limiting HOS, this approach provides multiple layers of defense, whereby fatigue-related incidents are the final layer of many in an error trajectory.

This review presents a conceptual basis for managing the first two levels of an error trajectory for fatigue. The concept is based upon a prior sleep/wake model, which determines fatigue-risk thresholds by the amount of sleep individuals have acquired in the prior 24 and 48 hours. In doing so, managing level one of the error trajectory involves the implementation of systems that determine probabilistic sleep opportunity, such as prescriptive HOS rules or fatigue modeling. Managing level two requires individuals to be responsible for monitoring their own prior sleep and wake to determine individual fitness for duty. Existing subjective, neurobehavioral, and electrophysiological research is reviewed to make preliminary recommendations for sleep and wake thresholds. However, given the lack of task- and industry-specific data, any definitive conclusions will rely in post-implementation research to refine the thresholds.

Keywords

Fatigue, prior sleep, wakefulness, safety, management, prescriptive rules, hours of service

Glossary of terms

Fatigue—For the purposes of this review, all references to fatigue imply mental fatigue unless specifically indicated otherwise
HOS—Hours of service
OH&S—Occupational Health and Safety
SMS—Safety management system
FRI—Fatigue-related incident
FRE—Fatigue-related error
PSWM—Prior sleep/wake model

Background

Mental fatigue associated with working conditions has been identified as a major occupational health and safety risks in most developed nations. In part, this has been driven by scientific evidence indicating an association between increasing fatigue and declines in cognitive function[1,2], impaired performance[3,4], increasing error rates[5,6], and ultimately, reduced safety[7,8]. Accordingly, governments and safety professionals have argued that mental fatigue is an identifiable workplace hazard that warrants regulatory attention.

Traditionally, efforts in fatigue risk management have attempted to reduce fatigue-related risk through compliance with an agreed set of rules governing hours of work. In the U.S. these are generally referred to as hours of service (HOS) rule. At the most fundamental level, regulation has involved the prescription of maximum shift and minimum break durations for individual shifts or work periods. In addition, some industries and organizations have supplemented individual shift rules with supra-shift rules that further restrict the total number of sequential shifts or cumulative hours worked in a given period (e.g., week, month, or year)[9,10]. These limitations have typically been imposed coercively via a regulatory body or "voluntarily" through a labor contract[11,12].

The traditional prescriptive HOS approach most probably derives from earlier regulatory approaches for managing physical rather than mental fatigue. In the early part of the 20th century, OH&S hazards related to physical fatigue were managed

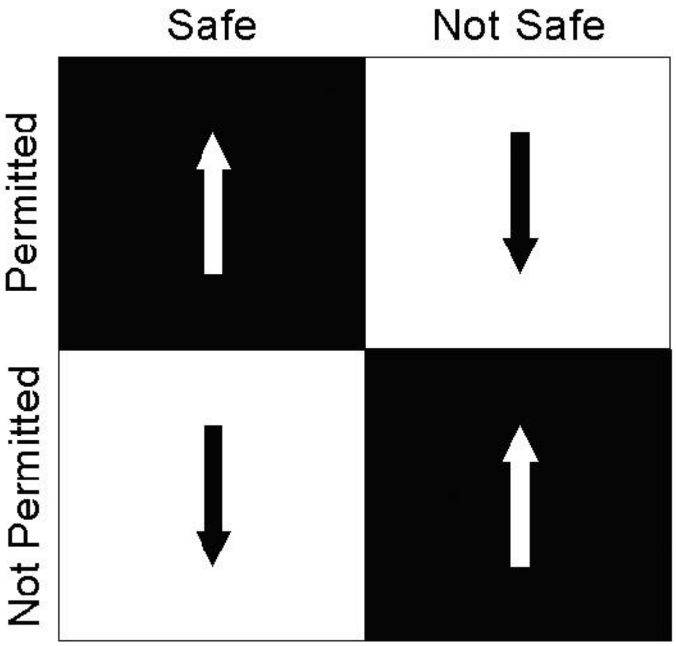


Figure 1. Effective regulatory models should provide congruence between what is safe and permitted as well as what is unsafe and not permitted. This is often not the reality with traditional prescriptive HOS regulatory approaches.

primarily by regulating the duration of work and non-work periods. Previous research had indicated that physical fatigue accumulates and discharges in a broadly monotonic manner with respect to time[13]. As such, managing physical fatigue by limiting work hours and break periods was both scientifically defensible and operationally practical.

While the application of prescriptive duty limitations may have been an appropriate control for physical fatigue, we do not believe the same can be assumed for mental fatigue. It is common to use analogous approaches for the regulation of a new hazard. However, in the case of mental fatigue, this approach incorrectly assumes that the determinants of mental fatigue are similar to those for physical fatigue[14]. While it is true that mental fatigue does, in part, accumulate in a relatively linear manner[15], there are significant additional non-linearities driving the dynamics of fatigue and recovery processes for mental fatigue.

Circadian biology, for example, influences the dynamics of fatigue accumulation and recovery in a way that produces significant non-linearities[16]. For example, prescriptive limitations on shift duration generally assume that a break of a given length has a uniform recovery value with respect to mental fatigue. While this may be relatively true with respect to physical fatigue, it is demonstrably not the case with respect to mental fatigue. Indeed, providing the same length of time off during the subjective day, as opposed to subjective night, will result in a significantly reduced amount of recovery sleep[17].

In our opinion, estimating the level of mental fatigue associated with a given pattern of work is linked more to the timing and duration of sleep and wake within the break, rather than the duration of the break alone. Although there is clear scientific evidence to support this notion, few regulatory models acknowledge it explicitly. As depicted in Figure 1, it is our view that regulatory models based only on shift duration are unlikely to produce congruence between what is safe and what is permitted and what is unsafe and not permitted.

The relationship between the recovery value of non-work periods (vis-à-vis mental fatigue) and the actual amount of sleep obtained has become increasingly complex in recent years. In addition to the biological limitations of this approach, increases in total working hours, lengthening of shift durations from 8 to 12 hours, and concomitant reductions in breaks from 16 to 12 hours[18] have significantly restricted the opportunity for sleep. Furthermore, changes in workforce demographics and the social use of time in and outside the workplace have exerted additional downward pressure on the amount of time individuals choose to allocate for sleep[19].

Recent trends in fatigue management

As outlined above, many of the current approaches to fatigue management have focused on hours of service. However, these approaches may be of limited value in the systematic management of fatigue-related risk. This has been particularly highlighted by recent research and policy initiatives in the U.S.[11], Australia[20-22], Canada[23],and New Zealand[24,25]. In these jurisdictions, there is an emerging, albeit controversial, view that we might more usefully explore alternatives to prescriptive models of fatigue management. Moreover, relative to traditional prescriptive approaches, alternative approaches may hold significant potential for improved safety and greater operational flexibility.

To date, most alternative approaches to prescriptive HOS embed fatigue management within the general context of a safety management system (SMS) and arguably provide a more defensible conceptual and scientific basis for managing fatigue-related risk as well as the potential for greater operational flexibility[26,27]. This is in marked contrast to current HOS models whose roots are inextricably bound up in the history of their labor relations process where the primacy of short-term financial factors has frequently distorted safety outcomes[28,29].

Despite the theoretical attraction of alternative approaches to prescriptive HOS, many commentators have, with good reason, expressed reservations about their actual benefits in practice. For example, an increase in the flexibility of HOS regulation has often been interpreted (by employees and their representatives) as a disingenuous attempt to deregulate or subvert current or proposed HOS rules. Conversely, tightening of the HOS regulation to reduce fatigue has sometimes been interpreted (by employer groups and their advocates) as a disingenuous attempt to leverage better pay and conditions, rather than improve safety[27].

For the last few years, our research group has conducted extensive consultation with industry stakeholders and regulators in several countries and in a variety of industries to understand how fatigue might best be managed using alternative approaches. In doing so, we have canvassed two broad approaches. First, the modification of traditional prescriptive HOS regulations to ensure they address matters related to legal and scientific defensibility as well as operational flexibility. Second, we have considered alternative regulatory models that might be used as the basis of a new approach that meets the previously mentioned goals of scientific defensibility and flexibility.

Our objective was to establish a well-structured view of how fatigue might best be regulated, as well as the most appropriate way in which such reform might be achieved at the practical level.

On the basis of discussions with industry, we believe there is an emerging consensual view that

- given the diversity of modern organizational practice, a traditional prescriptive HOS approach may not be the most appropriate or only way to manage fatigue-related risk.
- alternative approaches to prescriptive HOS for fatigue management have significant potential to improve operational flexibility and safety.
- alternative approaches also hold significant potential to be abused by organizations or individuals for whom regulatory enforcement is a low-probability event and/or the consequences of non-compliance are trivial.
- alternative approaches will require a significant maturation in organizational and regulatory culture if they are to be successful in reducing fatigue-related risks to the community.
- there should be a standard methodology of measuring outcomes and program efficacy.

An alternative approach to prescriptive regulations

On the basis of discussions with key industry and regulatory stakeholders, it is our view that the most appropriate solution for effective fatigue management is to expand the regulatory framework from a prescriptive HOS approach and to permit certain organizations to use a safety management systems (SMS) approach. This would be based on existing occupational safety and health standards, practices, and principles (e.g., Canadian OH&S Act; the OHSAS 18001; the Australian/New Zealand standard for occupational health and safety management systems AS/NZS 4801:2001) [30-32]. From this perspective, fatigue would be managed as an "identifiable OH&S hazard" and would be one part of a more general organizational SMS.

It may also be useful to expand our use of a prescription/compliance perspective to include approaches that emphasize outcomes. That is, rather than prescribing one universal rule set the management of safety risks could be effectively achieved in a variety of organization- or industry-specific ways. In doing so, it would be the responsibility of each organization or industry to develop a fatigue risk management "code-of-practice," and through formal review processes, continue to refine and improve the safety environment vis-à-vis fatigue. According to this view, the role of regulation would be to legislate for an outcome (e.g., a reduction in fatigue-related risk) rather than assume that compliance with a prescriptive HOS standard implies, and ensures, a given level of safety.

To date, most examples of outcome-based systems for fatigue risk management have been developed within the transportation sector. These include the Transitional Fatigue Management Program, developed by Queensland Transport [33], the Australian Civil Aviation Safety Authority (CASA) Fatigue Risk Management System [22-27], Fatigue Risk Management Programs of a number of Australian rail organizations [21], and the North American Federal Railroad Administration [11]. In addition, air traffic controllers in both Australia and New Zealand have used hybrid prescription/outcome-based approaches for several years [24].

Initial pilot studies or projects using outcome-based fatigue risk management have had mixed results with early evaluations suggesting the approach has considerable potential but significant risks associated with poor enforcement and assessment [27]. Furthermore, there has been minimal work assessing their longer-term efficacy or enforceability. Until such projects mature and evaluative research is published, the scientific safety community should continue to develop and refine the conceptual framework that underlies such systems.

Traditionally, and particularly within Europe, it has been common for policymakers (often in conjunction with relevant researchers) to develop recommendations on what are considered acceptable shifts and/or patterns of work. For example, forward rotating shifts [34], maximum number of sequential working days [35], length of shift (8, 10, or 12 hours) [36,37], and minimum number of days off required for recovery [16]. These, in turn, have been published and subsequently held up as *de facto* standard. Using these standards, shifts are constructed as either stable roster patterns or flexible rosters that are constructed from preapproved scheduling features (e.g., no more than four night shifts in a row, or no break less than 8 hours). Using this approach, a roster or schedule is deemed acceptable if it does not contain any unapproved features.

The advantage of this approach is that it treats the roster as an integrated whole. The disadvantage is that it makes it difficult to generalize to novel or innovative rosters or schedules. Furthermore, it fails to identify individual differences in fatigue-related risk. This approach assumes, at least implicitly, that the effects of a given shift system are similar for all individuals. That is, it fails to address potential interactions between the shift system and employee demographics. A final criticism is that it fails to distinguish between work-related causes of fatigue and fatigue due to non-work-related causes. That is, it is possible for an individual to arrive at work fatigued due to inappropriate use of an adequate recovery period.

To gain the generalizability and flexibility of a feature-based approach, without the disadvantages of inadvertent interaction between features, we would propose a novel methodology for defining the degree of fatigue likely to be associated with a particular roster or schedule. Before we address that approach in detail, it is essential to place the discussion in context. It is particularly important to understand the way we have traditionally approached fatigue management. Notably, that it has been addressed primarily as a labor relations, rather than a safety management issue.

Developing a conceptual framework for fatigue management

Most regulatory frameworks to date have not considered fatigue as a hazard to be managed as part of a safety management system. Instead, fatigue has been managed through compliance with a set of externally imposed prescriptive rules. While this is understandable, there is no reason, other than historical bias, that precludes the use of the same SMS principles that would apply for any other identifiable safety hazard.

Furthermore, we would suggest that this framework provides a sounder conceptual basis for managing fatigue-related risk fatigue management. In addition, it could easily sit within the preexisting and emerging SMS frameworks currently advocated by regulators and safety professionals.

This methodology can be represented using Reason's (1997) [38] hazard-control framework. A fatigue-related accident or incident (FRI) is seen as only the final point of a longer causal chain of

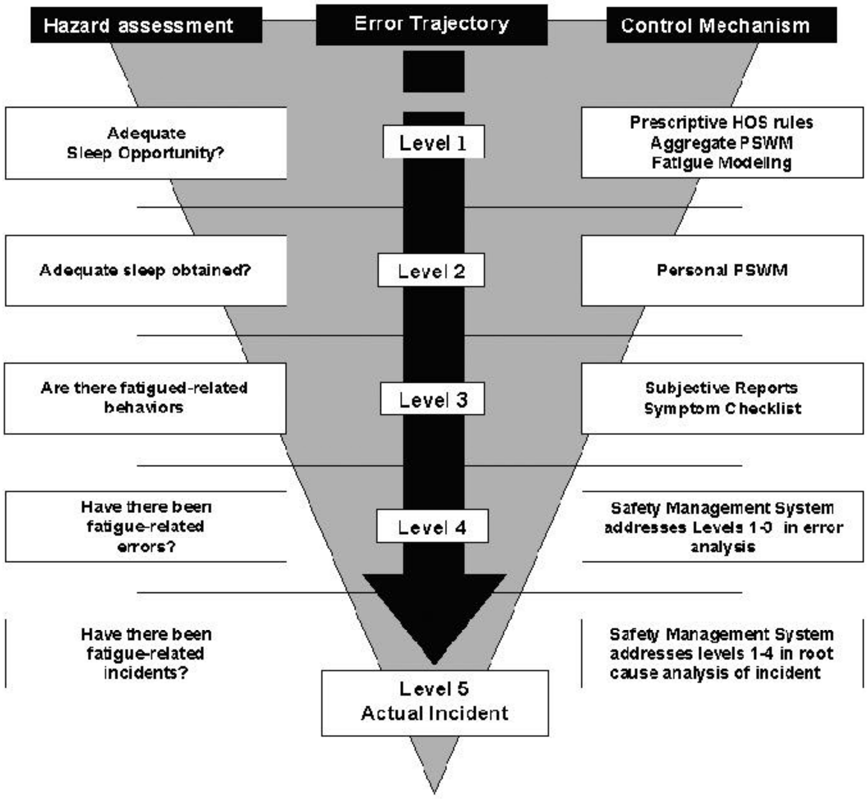


Figure 2. Fatigue risk trajectory. There are multiple layers that precede a fatigue-related incident, for which there are identifiable hazards and controls. An effective fatigue risk management system should attempt to manage each layer of risk.

events or "error trajectory." An examination of the error trajectory associated with a FRI will indicate that there are four levels of antecedent event common to any FRI.

From Figure 2, a FRI is merely the end point of a causal chain of events or "error trajectory" and is always preceded by a common sequence of event classifications that lead to the actual incident. Thus, a FRI is always preceded by a fatigue-related error (FRE). Each FRE, in turn, will be associated with an individual in a fatigued state, exhibiting fatigue-related symptomology or behaviors. The fatigued state in the individual will, in turn, be preceded by insufficient recovery sleep or excessive wakefulness. Insufficient sleep or excessive wakefulness will be caused by either (a) insufficient recovery sleep during an adequate break (e.g., fail to obtain sufficient sleep for reasons beyond their control, choosing to engage in non-sleep activities or a sleep disorder) or (b) by an inadequate break. (e.g., the roster or schedule did not provide an adequate opportunity for sufficient sleep).

Each of the four steps in the general error trajectory for a FRI provides the opportunity to identify potential incidents and, more importantly, the presence (or absence) of appropriate control mechanisms in the system. It is also often the case that many more potential incidents (i.e., "near misses") will occur than actual incidents and that these could, if monitored, provide a significant opportunity to identify fatigue-related risk and to modify organizational process prior to an actual FRI.

Potentially, this framework would enable us to identify the root causes of many potential FRIs in a logical and consistent manner. In addition, we can systematically organize and implement effective hazard control measures for fatigue-related risk at each "level" of control using a systems-based approach. The figure also implies that we can reduce the incidence of fatigue-related incidents by more coordinated or integrated control of the antecedent events or behaviors that constitute potential or "latent" failures of the safety system[38].

Effective management of fatigue-related risk requires a fatigue risk management system (FRMS) that implements task and organizationally appropriate control mechanisms for each point in the theoretical error trajectory. Where an organization fails to develop appropriate controls at each level of the hierarchy, it is unlikely that, overall, the system will be well-defended against fatigue-related incidents.

The figure also provides a useful way of understanding (1) the piecemeal and uncoordinated nature of many regulatory approaches to fatigue management to date and (2) why unintegrated approaches to managing fatigue related risk (such as sole use of prescriptive HOS rules) may not be entirely successful.

In general, accident investigations have focused primarily on later segments of the error trajectory when trying to identify whether fatigue was a contributing factor. Conversely, when framing regulatory responses to fatigue-related incidents (as a control measure), there have rarely been systematic attempts to address all levels and few, if any, directed to lower levels of the error trajectory. In doing so, policymakers have assumed that compliance with prescriptive HOS rule sets and other relevant labor agreements constitutes an effective control measure for fatigue-related risk. As such, even if individual organizations were to achieve explicit compliance (admittedly a farcical assumption in many industries), they implicitly (and erroneously) assume that

- a rule set can determine reliably whether an individual will be fatigued (or not), and
- individual employees always use an ostensibly adequate opportunity for sleep appropriately and obtain sufficient sleep.

Since, in many situations, these two assumptions are demonstrably untrue, an effective FRMS must provide additional levels of controls for those occasions when the preceding levels of control prove might ineffective.

As can be seen from recent alternative systems-approach initiatives, there can be very different intellectual and emotional perspectives on the appropriateness and relative merits of different control mechanisms at a single level of the diagram. For example, in recent years there has been considerable discussion as to the relative merits of fatigue-modeling[39] and the more traditional HOS approaches[34,37]. From the perspective in Figure 2, both are only level 1 control strategies that attempt to ensure that employees are given, on average, an adequate opportunity to gain sufficient sleep. Since this is only a probabilistic determination and no hazard-control mechanism is perfect, neither will prevent all error trajectories in Figure 2 projecting beyond level 1. Thus a system with little or no hazard controls at level 2 or beyond may be quite poorly defended against FREs. Similarly, in a system that has very effective hazard-control strategies at levels

2-4, debates about the relative merits of different level 1 strategies could arguably be considered moot.

The following sections of this paper will focus on describing a novel conceptual basis for the development of appropriate control mechanisms for fatigue-related hazards and the scientific justification for such an approach.

As can be seen from Figure 2, an effective approach to fatigue management will require a variety of control measures applied at each of the four points on the error trajectory. Thus, an effective FRMS would require control procedures at level 1 of the error trajectory that ensure employees are provided with an adequate opportunity for sleep. It would also require control procedures at level 2 that ensure that employees who are given an adequate opportunity for sleep actually obtain it. At level 3 we need to ensure that employees who obtained what is considered, on average, sufficient sleep are not experiencing actual fatigue-related behaviors (e.g., due to sleep disorders, non-work demands, or individual differences in sleep need). The use of symptom checklists or subjective fatigue scales is an example of control procedures at this level. Similarly, we would need control procedures at level 4 to identify the occurrence of FRE that did not lead to a FRI. Finally, an effective FRMS would require an incident analysis and investigation procedure to identify those occasions when all the control mechanisms failed to prevent an FRI.

The development of appropriate control procedures at level 3 and above is beyond the scope of this paper. These will be addressed in subsequent publications. In this review, we will focus on levels 1 and 2. In particular, we will propose a novel conceptual framework for the design and implementation of control procedures at levels 1 and 2 of the error trajectory outlined in Figure 2. That is, control methods for determining whether

- a roster or schedule provides, on average, an adequate opportunity to obtain sufficient sleep, and
- if so, whether an individual has actually obtained sufficient sleep.

Existing efforts of higher-order fatigue risk management

Historically, the principal level 1 control mechanism has been the development of prescriptive HOS rule systems that purport to provide adequate opportunity for sleep. In recent years there has been an emerging scientific and regulatory consensus that many of our prescriptive shift work rules do not provide a reliable control mechanism that prevents fatigued individuals from unsafe working practices[11,40]. This is due primarily to a failure to distinguish between

- non-work and sleep time in determining the recovery value of time off, and
- the failure to take into account the time of day at which shifts or breaks occur[41].

As a consequence, there has been a strong move toward developing different approaches to ensuring an adequate average opportunity to obtain sleep for fatigue risk management. Broadly speaking these can be divided into two groups

- modified prescription, and
- fatigue modeling.

From a practical perspective, it is important to determine whether a given shift system, on average, enables an individual to report fit for duty. That is, whether the particular pattern of work provides adequate opportunity for sleep. Recently, fatigue modeling has provided an appealing alternative to traditional prescriptive approaches in that it appears more "scientific" and it provides a reliable method to determine whether a pattern of work adequately limits waking time and provides adequate opportunity for sleep. For a comprehensive review of existing models, see the 2004 issue of *Aviation, Space, and Environmental Medicine*[42].

While some of the models are extremely useful for predicting average levels of fatigue at the organizational level, they are not particularly useful for determining whether a given individual is fit for duty on a given occasion. Specifically, such approaches are unlikely to provide conclusive indications of whether an accident or incident was due to fatigue, because they can tell us nothing about individual behavior on a given day. Thus, while modeling approaches to fatigue risk management represent a significant potential improvement in our capacity to assess general aspects of a schedule, they do not provide controls any higher than level 1 in the error trajectory. Most importantly, they provide little or no guidance for determining the likelihood of fatigue and, therefore, fatigue-related risk on a day-to-day basis for individuals within the organization.

There have been some attempts to develop control mechanisms for fatigue at higher levels in the error trajectory. For example, in some regulatory environments individuals have been assigned the right and/or responsibility to override prescriptive guidelines where they believe it is appropriate (e.g., Civil Aviation Order 48[10]). The difficulty with this requirement is the reliability of self-assessment of fatigue. Although people can estimate their level of fatigue or alertness with some degree of reliability, we have very little scientific evidence to support the notion that individuals can use this information to make reliable subjective judgments about the concomitant level of risk or safety and relative fitness for duty. It also ignores the very real potential for coercive financial, social, and operational pressures to distort effective decision-making in this area.

In other jurisdictions, we have seen enthusiastic attempts to introduce the requirement to train and educate employees about fatigue. These initiatives, while well-intentioned, assume that training and education in itself will produce beneficial changes in individual and organizational safety behavior with respect to fatigue-related risk. Despite significant spending in this area, to date, there is little or no published evidence to support the hypothesis that improved knowledge of the determinants of fatigue and potential countermeasures leads to improved hazard control[43].

Given the shortcomings of fatigue modeling and subjective self-estimations of fatigue, we propose a behaviorally based methodology for assessing fatigue. The model proposed in the remainder of this paper outlines methods for predicting average levels of fatigue at the organizational level, as well as control mechanisms for the more specific, day-to-day risk of fatigue at the individual level within organizations.

Prior sleep and wake as the basis for a generalized approach to assessing fatigue

The first point we would make is that we do not yet have a detailed understanding of the relationship between increasing fatigue and risk for many industries and occupations. There is a significant body of laboratory research indicating that increasing fatigue is associated with increases in the probability and/or frequency of certain types of performance degradation on standard measures of neurobehavioral performance[3,4,44-46]. However, the

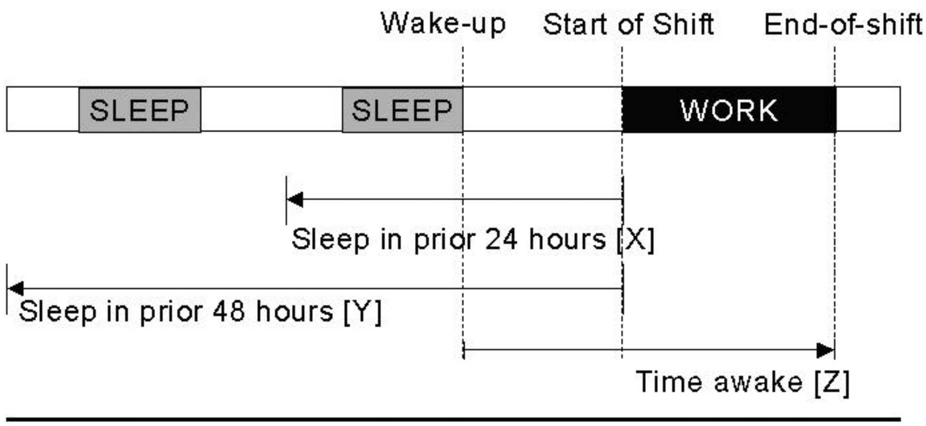


Figure 3. *Prior sleep wake model (PSWM). Fitness for work at levels 1 and 2 of effective fatigue risk management can be determined by an algorithm that is comprised of three simple calculations: prior sleep in the last 24 hours, 48 hours, and length of wakefulness from awakening to end of work.*

best that can be said with particular regard to safety is that increasing fatigue is typically thought to be associated with increasing likelihood of error[5,47]. Thus, we are not yet at a point where research can be used to clearly articulate the likelihood or typology of errors for specific tasks and/or workplace settings.

At best, we can suggest that based on the published literature

- error rates increase exponentially with linear increases in psychometric measures of fatigue[4].
- errors are broadly comparable in nature and frequency with other forms of impairment (e.g., alcohol intoxication)[48,49].
- we can make only general predications about the susceptibility of certain types of tasks to fatigue-related error.

In view of our lack of a detailed understanding of workplace or task specific risk associated with fatigue, any set of guidelines should be considered provisional, tentative and subject to ongoing refinement on the basis of post-implementation evaluation.

With this caveat in mind, we would suggest that knowledge of the frequency distribution of prior sleep and wake could form a rational basis for determining the level of fatigue an individual is likely to experience within a given shift. Furthermore, there is potential for both individuals and organizations to use this information as the basis for rational decision-making with respect to fatigue-related risk. Within this framework, there are two main questions that should be asked. First, is the individual fit for duty and acceptably rested to commence work? The second question is predicated on the answer to the first. That is, if an individual is acceptably alert to commence work, for what period of time can he be reasonably expected to work before fatigue subsequently creates an unacceptable level of risk?

As a starting point for this decision, we suggest that a rational FRMS should be based on prior sleep and wake rules, linked to an evaluation of the adequacy of prior sleep and wake. The reasons for this are straightforward.

- Unlike subjective estimates of fatigue, prior sleep and wake are observable and potentially verifiable determinants of fatigue.
- Prior sleep and wake provide a way of integrating individual and organizational measures of fatigue (levels 1 and 2) since systems-based approaches can deal with probabilistic estimates of sleep and wakefulness, and individual employees can make clear determinations of individual amounts of actual prior sleep and wakefulness.
- Prior sleep and wake measures can be set or modified according to the risk profile associated with specific tasks or work groups.

In order to determine whether an employee is likely to be fatigued and the required degree of hazard control, we propose a simple algorithm based on the amount of sleep and wake experienced in the 48 hours period prior to commencing work.

As can be seen above in Figure 3, the algorithm is comprised of three simple calculations. That is

Prior Sleep Threshold—Prior to commencing work, an employee should determine whether they have obtained
a) X hrs sleep in the prior 24 hours, and
b) Y hrs sleep in the prior 48 hours.

Prior Wake Threshold—Prior to commencing work an employee should determine whether the period from wake up to the end of shift exceeds the amount of sleep obtained in the 48 hours prior to commencing the shift.

Hazard-Control Principle—Where obtained sleep or wake does not meet the criteria above, then there is significant increase in the likelihood of a fatigue-related error and the organization should implement appropriate hazard control procedures for the individual.

A critical aspect of the rules defined above is to create appropriate threshold values for the minimum sleep values for the prior 24 and 48 hours to commencing work and the amount of wakefulness that would be considered acceptable. It is important to note that the thresholds could potentially vary as a function of fatigue-related risk within a workplace. For example, if a given task has either a greater susceptibility of fatigue-related error or there are significantly greater consequences of a fatigue-related error, the threshold values may be adjusted to a more conservative level.

From this perspective, fatigue-related accidents or incidents are seen as the final segment in a causal chain of events or error trajectory. Within the error trajectory there are four identifiable segments common to all fatigue-related incidents. At the earliest levels of the error trajectory are segments related to (1) the provision of an adequate opportunity to sleep and (2) appropriate utilization of a sleep opportunity (break period). In this review we have proposed a novel methodology that enables organizations to take an integrated approach to determining whether they have appropriate control procedures at level 1 or 2 of the proposed fatigue-related error trajectory.

The basis to this methodology is the prior sleep wake model (PSWM). The conceptual basis to this model is that fatigue is better estimated from prior sleep/wake behavior than from patterns of work. Using this model, an organization can define task-specific thresholds for sleep and wakefulness based on the amount of sleep obtained in the 24 and 48 hours prior to commencing work. Where aggregate or individual sleep/wake values fail to reach pre-designated thresholds, the increased likelihood of fatigue would require a greater level of hazard control to prevent an actual incident from occurring (levels 3 and 4).

At level 1 of the error trajectory, organizations are required to manage the opportunity for sleep probabilistically. In general, prescriptive rule sets or fatigue modeling are the most common ways in which an organization can determine prospectively whether a pattern of work is likely to provide employees with an adequate opportunity to obtain sufficient sleep (vis-à-vis the defined threshold). Using this approach, an acceptable roster or schedule is one that is associated with a certain percentage of people on average (e.g., > 95%) having an adequate opportunity to gain the requisite amount of sleep.

At level 2 of the error trajectory, individuals use the PSWM to determine whether they have had sufficient sleep. Since level 1 control mechanisms will allow a predetermined percentage of employees insufficient sleep (e.g., 5%) the personal PSW calculation will allow them to identify themselves and report this information, and the organization can engage in appropriate control procedures at level 3 and above in the error trajectory.

In determining appropriate threshold values for sufficient sleep, this review acknowledges that currently there is a dearth of organization- and/or task-specific data sufficient to answer this question definitively. Indeed it is our view that such data will be collected by organizations in the post-implementation phase.

In defining this threshold, we caution readers that particular occupational tasks may well be more susceptible to fatigue-related error or the consequences of fatigue-related error are so severe as to require threshold values greater than we have specified. Furthermore, any initial values should be viewed as a starting point and subject to revision in the light of actual workplace experience. However, where thresholds are inappropriate, we should see the systematic projection of error trajectories beyond level 2. That is, despite achieving the requisite threshold levels of sleep the FRMS would continue to observe either

- level 3 factors indicating the occurrence of fatigue-related behaviors or symptoms,
- level 4 factors related to the occurrence of fatigue-related errors, or
- level 5 issues related to the occurrence of actual fatigue-related incidents.

Level 3 of the error trajectory is characterized by the presence of fatigue-related behaviors. There will inherently be individual differences in the experience of fatigue as a direct consequence of sleep. That is, even if an individual complies with the organization's minimum sleep thresholds (as set out in levels 1 and 2), it is possible, due to specific work environment or life circumstances, that they may still experience fatigue symptomology. Thus, the observance of fatigue-related behaviors acts as an additional layer of defense, to avoid fatigue-related errors or accidents. The types of controls we would envisage at this level would include subjective reports of fatigue from individuals to managers, or the presence of symptoms from a "fatigue symptom checklist," which would be provided to employees by the organization.

While levels 1-3 of the error trajectory take a proactive approach to fatigue risk management, levels 4 and 5 take a more reactive approach. They are more concerned with investigative procedures when failures have occurred at the earlier levels of the error trajectory. Level 4 is defined by the occurrence of a fatigue-related error. Such an error may not necessarily lead to an actual accident or incident. However, if it is detected, an investigation should be conducted to determine the cause of the error, and prevent similar occurrences from happening again. Specifically, the investigation should focus on levels 1-3 to determine deficiencies in the control processes. This would be performed as a part of the safety management system error analysis framework.

Level 5 is the final level in the error trajectory, whereby a fatigue-related error results in an incident or accident. In reality, it is unlikely that such an event would be solely caused by fatigue and could be linked to several different causal factors. However, to determine the extent to which fatigue was specifically involved, the investigation should focus on levels 1-4 of the error trajectory to determine deficiencies in the control processes. This would be performed as a part of the safety management system accident/incident investigation framework. ◆

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HFACS Analysis of Military and Civilian Aviation Accidents: A North American Comparison

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(Oral presentation by Dr. Shappell.—Editor)

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Over the past several years, the Human Factors Analysis and Classification System (HFACS) has been used to analyze nearly a decade of accidents involving the U.S. military, U.S. scheduled and nonscheduled commercial air carriers, and U.S. general aviation (GA) aircraft. The results of these analyses have yet to directly compare the similarities and differences in human error trends across these seemingly diverse aviation communities. The purpose of this paper is to provide that comparison. A meta-analysis of over 16,000 accidents involving the U.S. Navy/Marine Corps (1990-1998), U.S. Air Force (1991-1997), U.S. Army (1992-1998), U.S. commercial air carriers (1990-1998), and U.S. general aviation aircraft (1990-1998) was conducted. Across all types of operations, skill-based errors were the primary human cause of these accidents, followed by decision errors, violations, and perceptual errors. Analyses revealed some differences between operation categories in terms of error trends across the years. This study provides the first ever comparison of human error causes of accidents across different types of U.S. aviation operations. These findings have direct implications for the development and sharing of safety programs that address specific types of human error in aviation.

Introduction

The last half-century has witnessed tremendous strides in aviation safety as technology and science have combined to dramatically reduce the rate of aviation accidents. However, over the last three decades that dramatic decline has slowed, reaching almost asymptotic levels. Some have even argued that the current rate of aviation accidents is "simply the cost of doing business." To hear them describe it, perhaps what we are witnessing is a random accident rate that cannot be reduced constantly below current rates.

That being said, almost everyone agrees that somewhere between 70-80% of aviation accidents are attributed, at least in part, to human error (Wiegmann & Shappell, 2003). By definition then, human error is preventable and accident rates *can* be reduced still further. But how? What is that 70-80% of human error?

Since the mid-1990s we have examined the human causal factors associated with military and civilian aviation accidents (Wiegmann & Shappell, 2003). As part of that effort, we developed the Human Factors Analysis and Classification System (HFACS) to "put a face on human error." The balance of this report will present our findings from the military and civilian aviation sectors in an attempt to determine the human causal factors associated with aviation accidents in the United States.

HFACS

It is generally accepted that like most accidents, those in aviation do not happen in isolation. Rather, they are often the result of a

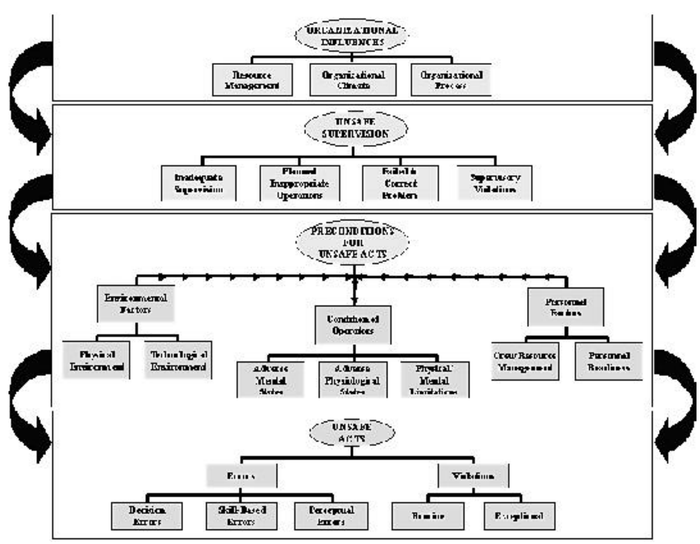

Figure 1. The HFACS framework.

chain of events often culminating with the unsafe acts of aircrew. Indeed, from Heinrich's (Heinrich, Peterson, & Roos, 1980) axioms of industrial safety to Reason's (1990) "Swiss cheese" model of human error, a sequential theory of accident causation has been consistently embraced by most in the field of human error. Particularly useful in this regard has been Reason's (1990) description of active and latent failures within the context of his Swiss cheese model of human error.

In his model, Reason describes four levels of human failure, each one influencing the next. Included were 1) organizational influences, 2) unsafe supervision, 3) preconditions for unsafe acts, and 4) the unsafe acts of operators. Unfortunately, while Reason's seminal work forever changed the way aviation and other accident investigators view human error; it did not provide the level of detail necessary to apply it in the real world.

It wasn't until Shappell and Wiegmann (2000, 2001) developed a comprehensive human error framework, HFACS, that folded Reason's ideas into the applied setting. The HFACS framework includes 19 causal categories within Reason's (1990) four levels of human failure (Figure 1). Unfortunately, a complete description of all 19 causal categories is beyond the scope of this brief report. It is, however, available elsewhere (Wiegmann and Shappell, 2003).

Particularly germane to any examination of aviation accident data are the unsafe acts of aircrew. For that reason, we will briefly describe the causal categories associated with the unsafe acts of aircrew. A detailed discussion of the other tiers of HFACS (i.e., the preconditions for unsafe acts, unsafe supervision, and organizational influences) can be found elsewhere (Wiegmann & Shappell, 2003).

Unsafe acts of operators

In general, the unsafe acts of operators (in the case of aviation, the aircrew) can be loosely classified as either errors or violations (Reason, 1990). Errors represent the mental or physical activities of individuals that fail to achieve their intended outcome. Violations on the other hand, are much less common and refer to the willful disregard for the rules and regulations that govern the safety of flight.

Errors

Within HFACS, the category of errors was expanded to include three basic error types (decision, skill-based, and perceptual errors).

Decision errors. Decision-making and decision errors have been studied, debated, and reported extensively in the literature. In general, however, decision errors can be grouped into one of three categories: procedural errors, poor choices, and problem-solving errors. Procedural decision errors, otherwise known as rule-based mistakes, occur during highly structured tasks of the sorts, if X, then do Y. Aviation is highly structured, and consequently, much of pilot decision-making is procedural. That is, there are very explicit procedures to be performed at virtually all phases of flight. Unfortunately, on occasion these procedures are either misapplied or inappropriate for the circumstances often culminating in an accident.

However, even in aviation, not all situations have corresponding procedures to manage them. Therefore, many situations require that a choice be made among multiple-response options. This is particularly true when there is insufficient experience, time, or other outside pressures that may preclude a correct decision. Put simply, sometimes we chose well, and sometimes we do not. The resultant choice decision errors, or knowledge-based mistakes, have been of particular interest to aviation psychologists over the last several decades.

Finally, there are instances when a problem is not well understood, and formal procedures and response options are not available. In effect, aircrew find themselves where they have not been before. Unfortunately, individuals in these situations must resort to slow and effortful reasoning processes—a luxury rarely afforded in an aviation emergency—particularly in general aviation.

Skill-based errors. Skill-based behavior within the context of aviation is best described as "stick-and-rudder" and other basic flight skills that occur without significant conscious thought. As a result, these skill-based actions are particularly vulnerable to failures of attention and/or memory. In fact, attention failures have been linked to many skill-based errors such as the breakdown in visual scan patterns and inadvertent activation of controls. Likewise, memory failures such as omitted items in a checklist and forgotten intentions have adversely impacted the unsuspecting aircrew.

Equally compelling is the manner or technique one uses when flying an aircraft. Regardless of one's training, experience, and educational background, pilots vary greatly in the way in which they control their aircraft. Arguably, such techniques are as much an overt expression of ones personality as they are a factor of innate ability and aptitude. More important, however, these techniques can interfere with the safety of flight or may exacerbate seemingly minor emergencies experienced in the air.

Perceptual errors. While, decision and skill-based errors have dominated most accident databases and have, therefore, been included in most error frameworks, perceptual errors have received comparatively less attention. No less important, perceptual errors occur when sensory input is degraded or "unusual," as is often the case when flying at night, in the weather, or in other visually impoverished conditions. Faced with acting on inadequate information, aircrews run the risk of misjudging distances, altitude, and decent rates, as well as responding incorrectly to a variety of visual/vestibular illusions.

Violations

By definition, errors occur while aircrews are behaving within the rules and regulations implemented by an organization. In contrast, violations represent the willful disregard for the rules and regulations that govern safe flight and, fortunately, occur much less frequently (Shappell and Wiegmann, 1996).

Routine violations. While there are many ways to distinguish between types of violations, two distinct forms have been identified, based on their etiology. The first—routine violations—tend to be habitual by nature and are often tolerated by authority (Reason, 1990). Consider, for example, the individual who drives consistently 5-10 mph faster than allowed by law or someone who routinely flies in marginal weather when authorized for VMC only. Often referred to as "bending the rules," these violations are often tolerated and, in effect, sanctioned by authority.

Exceptional violations. In contrast, exceptional violations appear as isolated departures from authority, not necessarily characteristic of an individual's behavior nor condoned by management (Reason, 1990). For example, an isolated instance of driving 105 mph in a 55-mph zone is considered an exceptional violation.

Likewise, flying under a bridge or engaging in other particularly dangerous and prohibited maneuvers would constitute an exceptional violation.

Method

Source of data

Military and civilian data were obtained from the cognizant database repositories. Military data were obtained from the Navy, Army, and Air Force Safety Centers. For civilian aviation, data were obtained from databases maintained by the National Transportation Safety Board (NTSB) and the Federal Aviation Administration's (FAA) National Aviation Safety Data Analysis Center (NASDAC). In total, 16,077 aviation accidents associated with human error were extracted for analysis.

For comparison purposes the Navy/Marine Corps data were further divided into fixed-wing tactical (TACAIR) and rotary-wing (helicopter) accidents.[1] In this way, USN/USMC TACAIR accident data could be compared to USAF TACAIR accident data, and USN/USMC helicopter accident data could be compared to U.S. Army helicopter accident data. A complete breakdown of the data is presented in Table 1.

Table 1. Accidents associated with human error

Type of operation	*Frequency*
USN/USMC TACAIR	138
USN/USMC Rotary Wing	60
U.S. Air Force TACAIR	72
U.S. Army Rotary Wing	62
14 CFR Part 121 & 135 Scheduled Air Carrier	165
14 CFR Part 121 & 135 Non-scheduled Air Carrier	452
14 CFR Part 91—General Aviation	15,128
Totals	*16,077*

Data from these different sources have been presented elsewhere in a variety of forums, although never together and none has been published. Consequently, the years involved in the analysis varied depending on when the original analysis was conducted (note, however, that the authors were involved in the analysis and collection of all the data reported in this study). Therefore, this report represents a meta-analysis of the military and civilian findings. The timeframe of each set of data is presented in Table 2.

Table 2. Accident data time frame

Type of operation	*Time Frame*
USN/USMC TACAIR	FY 1990-98
USN/USMC Rotary Wing	FY 1990-98
U.S. Air Force TACAIR	FY 1991-97
U.S. Army Rotary Wing	FY 1992-98
14 CFR Part 121 & 135 Scheduled Air Carrier	CY 1990-98
14 CFR Part 121 & 135 Non-scheduled Air Carrier	CY 1990-98
14 CFR Part 91 General Aviation	CY 1990-2000

FY—Fiscal Year (October 01—September 30)
CY—Calendar Year (January 01—December 31)

Classification of accident causal factors using HFACS

The detail of the accident reports and manner in which causal factors were reported varied with the data sources. In addition, there were slight differences in the manner in which causal factors were coded within the HFACS framework. For instance, for all civilian accidents, GA, and commercial aviation pilots were recruited from the Oklahoma City, Okla., and Urbana, Ill., area as subject-matter experts (SMEs). In the case of the military data, SMEs included a group of airframe-rated pilots, flight surgeons, aerospace physiologists, and/or aerospace psychologists from the respective services. All SMEs received training on the HFACS framework (roughly 16 hours) and were checked to ensure that a firm understanding of the HFACS causal categories was attained.

After training, SMEs were assigned accidents such that at least two separate SMEs analyzed each accident independently (typically more with the military data). Using narrative and tabular data obtained from the various safety centers, the SMEs were instructed to classify each human causal factor using the HFACS framework. Note, however, that only those causal factors identified within the accident reports were classified. That is, SMEs were instructed **not** to introduce additional casual factors that were not identified by the original investigation. To do so would be presumptuous and only infuse additional opinion, conjecture, and guesswork into the analysis process.

After our SMEs made their initial classifications of the human causal factors (e.g., skill-based error, decision error, etc.), the independent ratings were compared. Where disagreements existed, the corresponding SMEs were instructed to reconcile their differences, and the consensus classification was included in the final database for further analysis. In the end, all human causal factors associated with both civilian and military data were reliably classified within the HFACS framework, and the resulting consensus database was submitted to further analysis.

Inter-rater reliability averaged roughly 80% agreement with a Cohen's Kappa in the 70s. For a complete accounting of the reliability data, see Wiegmann & Shappell, 2003. Regardless of inter-rater reliability, however, all disagreements were resolved through consensus ratings.

Results and discussion

Although the accidents were associated with causal factors at all levels of the HFACS framework, this examination of the data was limited to the unsafe acts of operators.

Analysis of skill-based errors

An analysis of the data revealed that, in general, the percentage of skill-based errors associated with GA and non-scheduled commercial operations were higher than all other types of aviation (Figure 2, page 138).[2] It was not surprising that the largest percentage of skill-based errors were associated with GA accidents given the relative amount of flight time and training logged by GA pilots. Indeed, while there are certainly exceptions, most would agree that the average GA pilot does not receive the same degree of recurrent training and/or annual flight hours that the typical commercial or military pilot receives.

It was also interesting that the percentage of skill-based errors associated with non-scheduled (also referred to as "on demand") air carrier accidents were next highest among the aviation operations examined. One explanation for this finding may be the relative experience of these pilots as well. This is not to say that these pilots are inexperienced, just that relative to their military and scheduled air-carrier counterparts, there may be less opportunity to maintain proficiency or less overall experience. On the other hand, the increase in the percentage of skill-based errors

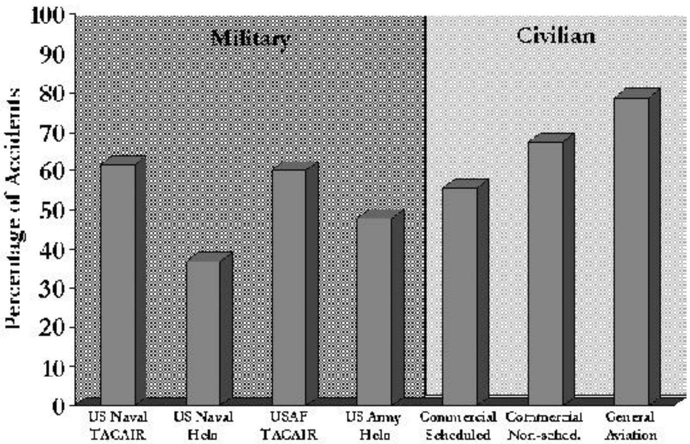

Figure 2. Percentage of military and civilian accidents associated with skill-based errors by type of operation.

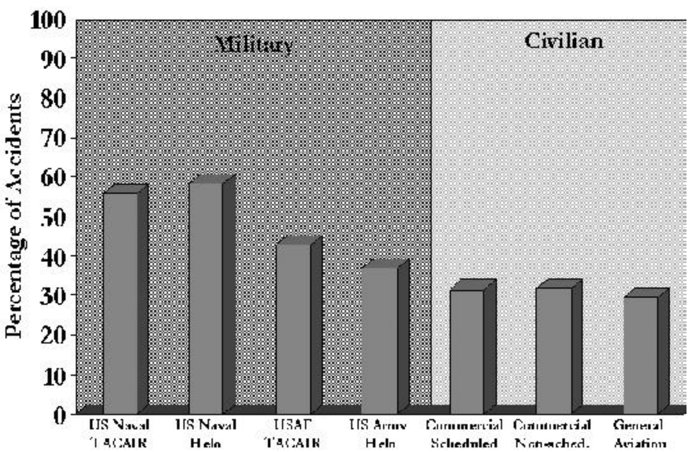

Figure 3. Percentage of military and civilian accidents associated with decision errors by type of operation.

may reflect inherent differences in the aircraft being flown, since many of these pilots fly smaller, less-sophisticated aircraft than scheduled air carriers or the military.

Curiously, the percentage of skill-based errors associated with USN/USMC and USAF TACAIR accidents were very similar to scheduled commercial air carriers accidents (albeit, the latter was slightly less). Exactly why that was the case is difficult to say. However, there were even fewer skill-based errors associated with U.S. Naval and Army rotary-wing accidents than in any other type of operation. While we have not fully explored this issue directly, it is interesting to note that most USN/USMC and U.S. Army helicopters are piloted by two pilots. Furthermore, all scheduled air carrier aircraft have at least two qualified pilots in the cockpit. Perhaps this can explain the lower percentage of skill-based errors in these communities as the second pilot can back up the first—lending some credence to the view that "two sets of eyes are better than one."

Analysis of decision errors

The percentage of decision errors associated with each type of operation is presented in Figure 3. In general, fewer decision errors were associated with civilian aviation accidents than seen with military aviation accidents. What's more, there were only

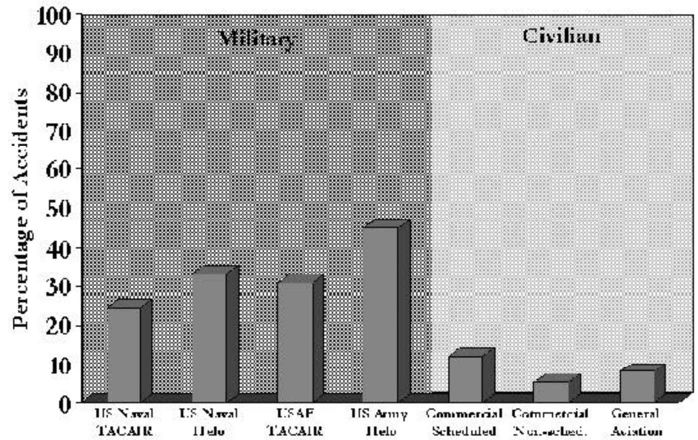

Figure 4. Percentage of military and civilian accidents associated with perceptual errors by type of operation.

small differences observed between GA and both types of commercial operations. In contrast, there was wide variability associated with the different military operations examined.

One explanation why military accidents were more often associated with decision errors may be the relative number and type of decisions made in typical military operations. That is, while both military and civilian pilots have to make decisions regarding takeoff, landing, diverting to alternates, and other standard aviation decision-making, military pilots are also confronted with a variety of tactical decisions not seen in typical civilian aviation (e.g., low-level flight, high-g force maneuvering, etc.) thereby reducing the margin for error. This may artificially inflate the number of decision errors associated with military aviation accidents just by sheer exposure—something that is difficult, if not impossible, to control for in our data.

While it is somewhat understandable why military aviation in general is more often associated with decision errors, it is much less obvious why this difference is even more evident when USN/USMC aviation is considered. One explanation may be that many naval operations occur over water or at sea where options are limited if trouble arises and recovery from errors may be less likely. Indeed, aviation at sea is inherently more dangerous than flying ashore and much less forgiving. To some extent, this is borne out in the data as many of the decision errors observed in Navy/Marine Corps accidents occurred while operating at sea.

Analysis of perceptual errors

Upon examination of the data associated with perceptual errors (Figure 4), two things stand out. First, while perceptual errors appear rare within civilian aviation operations, within the military they continue to be a source for concern. Second, perceptual errors appear to be more prevalent among accidents involving helicopters, particularly within the U.S. Army.

It would appear then that at least for civilian operations that issues like spatial disorientation and visual illusions (although still common) are not as large a problem as they once were. Perhaps this is due to the enormous effort being put forth to educate civilian pilots about the hazards associated with flight into weather and other visually impoverished environments. On the other hand, the nature of civilian aviation, where most flying occurs in low-g environments and involve relatively less dynamic flight than seen

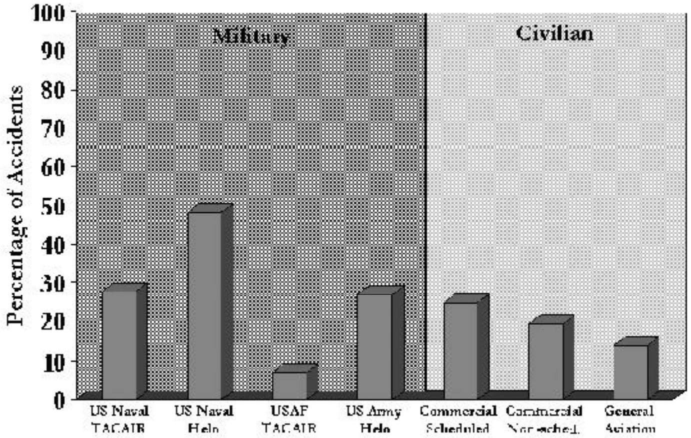

Figure 5. Percentage of military and civilian accidents associated with violations by type of operation.

in the military, may make perceptual errors less likely.

Within the military, perceptual errors continue to be associated with roughly 30% (on average) of all human-error-related aviation accidents. However, it appears to be more of a problem with the helicopter community—particularly the U.S. Army, where nearly 50% of the accidents examined were associated with a perceptual error.

Upon closer inspection, most of the perceptual errors that involved military helicopters can be attributed to the effects of spatial disorientation and wire strikes. Given the latter, it is not surprising that the prevalence of perceptual errors is elevated among U.S. Army helicopter operations since many of their missions are flown at low levels (below 1,500 ft AGL). In contrast, very few fixed-wing aircraft are routinely flown at these levels except during takeoff and landing. This may provide more time for TACAIR pilots to recover from spatial disorientation and thereby avoid an accident. This hypothesis is supported by the observation that when perceptual errors occur during TACAIR operations, they typically occur while flying in visually impoverished environments or during occasional low-level, terrain-following evolutions.

Analysis of violations

Because it was particularly difficult to reliably classify causal factors *post hoc* as either routine or exceptional violations, we chose instead to analyze the parent category of violations. Anecdotally, however, the majority of the violations observed in the accident data appeared to be routine violations (habitual departures from the rules/regulations condoned by management).

The percentage of military and civilian aviation accidents associated with a willful disregard for the rules and regulations of aviation safety (i.e., violations) are presented in Figure 5. As can be seen, the percentages varied across all types of aviation operations examined ranging from a high of roughly 50% observed with USN/USMC helicopter operations to a low of less than 10% associated with USAF operations. It should also be noted that the percentage of violations associated with civilian aviation accidents declined consistently as one moved from scheduled air carrier accidents to non-scheduled air carrier accidents and GA. This latter trend may be more a reflection of the fact that there are fewer rules and regulations governing GA than commercial flight and, therefore, may not represent a differential problem in commercial aviation.

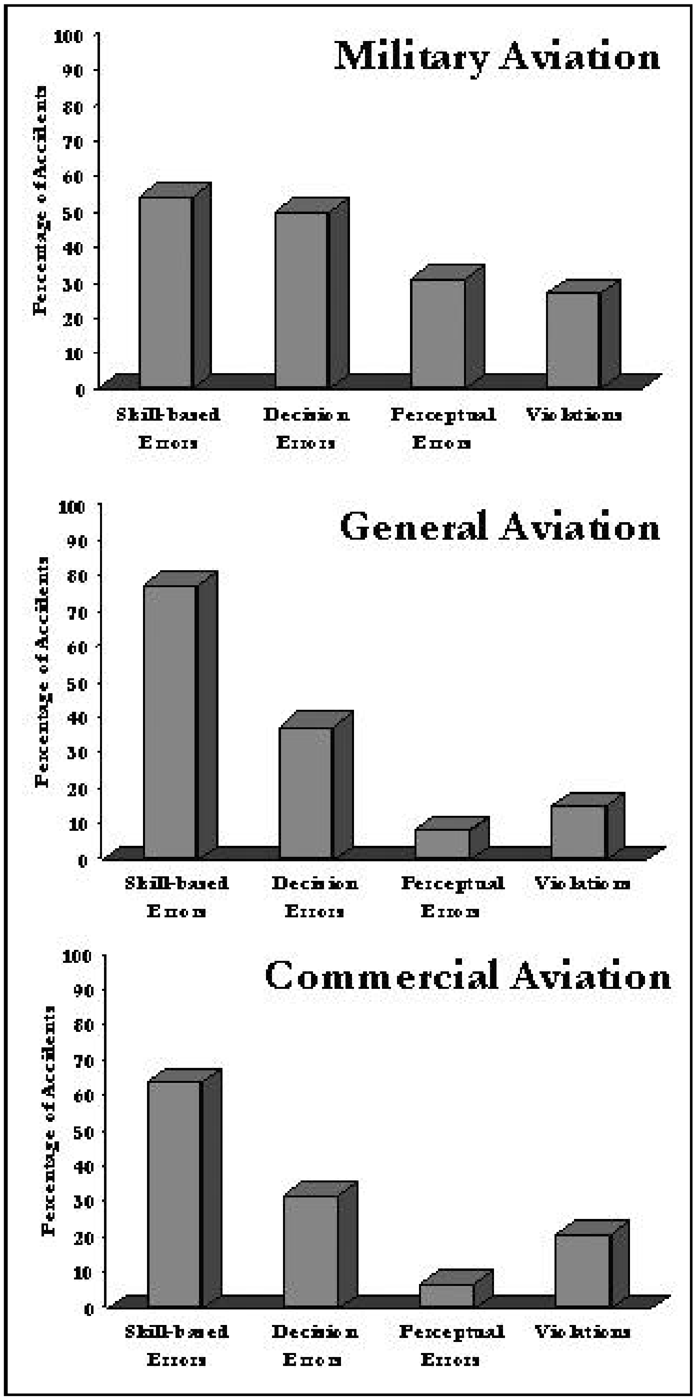

Figure 6. Comparison of the percentage of accidents associated with the unsafe acts of operators by type of operation.

Within the military, the percentage of accidents associated with violations is a mixture of good and bad news. On the bad side of the coin, nearly 50% of all U.S. Navy/Marine Corps accidents were associated with at least one violation of the rules. This was particularly alarming to the Navy and Marine Corps when this problem first surfaced in the late 1990s. Later it was revealed that the problem was largely the result of a small subset of naval aviation that has since been addressed (Wiegmann & Shappell, 2003). The good news is just that. Since our initial report of the violation data associated with USN/USMC aviation, accidents associated with this particular unsafe act have been reduced across the board to less than 15% in 2002 (Webster & White, 2004).

Further good news is seen in the low percentage of accidents associated with violations in the USAF. Some have argued that this may reflect an under-reporting of violations by the USAF. However, this argument was not supported by the data we examined. More likely, the lower percentage of accidents associated with violations reflects a policy within the USAF of zero tolerance for violations of the rules and regulations of safety.

Conclusion

In some ways, these data lend support to previous beliefs, while in others they have provided new information. For instance, it has long been held that GA pilots receive less training and, therefore, may not be as proficient or skilled as their commercial and military counterparts. To the extent that the accident data reflect the state of GA in the U.S., such beliefs appear to be warranted. That is, more GA accidents are associated with skill-based errors than any other type of aircraft operation.

But why would a comparison between GA, commercial, and military aviation accidents be important? Consider this, prior to the late 1980s and early 1990s most commercial aviation pilots were recruited from the U.S. military that was actively downsizing after the Cold War. However, with recent global events, recruitment bonuses, and longer commitments after initial flight training, fewer military pilots are leaving the service for the lure of commercial aviation.

So if not the military, where are commercial aviation pilots coming from? Increasingly, today's commercial aviation pilots are receiving their training from within the GA sector. The question is how this will impact commercial aviation safety. Or perhaps the better question is, "Does commercial aviation resemble GA where skill-based errors are elevated, or does it look more like military aviation?" In fact, given that many of the decision errors seen in military aviation are specific to military operations and perceptual errors are inflated due to the dynamic flight seen in the military, would you rather have commercial aviation look more like the military or GA?

Regardless of your answer, the truth is that human errors associated with commercial aviation look more like GA than the military (Figure 6). As a result, it is now more important than ever to address human error associated with GA, particularly that associated with basic flight skills. These data should prove as a foundation for addressing those concerns.

At a minimum, however, these data represent the first time that commercial and military data have been compared beyond simply reporting overall accident rates or the overall percentage of accidents associated with human error. The HFACS framework provides a reliable and valid means to compare human error associated with seemingly disparate aviation communities. Notably, this analysis did not require major changes within any of the communities involved. That is, all the aviation communities still have their separate means of investigating accidents and corresponding databases. To date, only the U.S. Navy/Marine Corps utilize HFACS to actually conduct the original accident investigation. However, that is currently under revision as the U.S. Department of Defense is currently considering requiring a modified version of HFACS for use during accident investigation and analysis throughout all branches of the service.

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Endnotes

[1] At the time of this writing, the civilian data were not broken out but will be for presentation purposes.

[2] Note that percentages within type of operation will not add up to 100% since accidents are typically associated with multiple causal factors. These data reflect the percentage of accidents associated with "at least" one instance of a particular HFACS causal category.

Who Moved My (Swiss) Cheese? The (R)Evolution of Human Factors In Transport Safety Investigation

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(Oral presentation by Steve Shorrock.—Editor)

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No photo available

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No photo available

__Capt. John Faulkner__ is adjunct associate professor of aviation safety, having retired as manager of flight safety at Qantas after a distinguished career in both civil and military aviation.

No photo available

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Abstract

When it comes to incidents and accidents, the popular template adopted for human factors investigations has been Reason's "Swiss cheese" model (e.g., Reason, 1990, 1997). One of the main implications of this has been the tenacious and dogmatic search for latent conditions leading up to the incident. Overzealous implementation of the theoretical model has led to an illusion of management responsibility for *all* errors. While this may very often be the case for major accidents, in other cases the retrofit seems contrived and untenable. This paper reviews a variety of prominent case studies to illustrate the contention that human action at the sharp end can play a more significant role than we have recently assumed. A critique of Reason's organizational accident model is presented, with a focus on the problem of identifying latent conditions in hindsight. In conclusion, we believe that the focus on latent factors such as management and regulation has gone too far, and perhaps we should redress some of our efforts back to the human in control.

The evolution of accident causation

Transport disasters, such as the Tenerife runway collision in 1977, or the Glenbrook rail crash in 1999, are mercifully rare. However, public concern over such events is inversely proportional to their frequency and probability of harm (Singleton, 1989). Oft-quoted statistics reveal that more than two-thirds of these accidents involve "human error" as a major contributory factor (e.g., Boeing, 1996; Dekker, 2002; Hawkins, 1993; IATA, 1993; Wiegmann and Shappell, 1999), and the popular press puts this quotient closer to 90%.

Data such as these have been instrumental in raising the profile of human factors, within training, research, and investigations (e.g., the laudable movement towards crew resource management, or CRM). In response, we have been driven to determine why humans are so fallible, and the discipline of human factors has grown from modeling individual cognitive failure to investigating the organizational contribution to accidents (e.g., Perrow, 1999; Reason, 1990; 1997). The popularization of this way of thinking is largely thanks to the work of James Reason (ibid.), whose Swiss cheese model of accident causation is now adopted as a model for investigation in many industries. Indeed, in aviation, it has become the accepted standard as endorsed by organizations such as the Australian Transport Safety Bureau (ATSB) and the International Civil Aviation Organization.

Reason's (ibid.) distinction between the active, operational errors and the latent, organizational conditions effectively makes human error a contributory factor in 100% of accidents and incidents. Reason asserts that these latent conditions are the true causes of disasters—typically, the operator merely inherits a defective system, and active errors are seen as the consequence, rather than the cause, of the accident chain. The term "operator error" became taboo, and it thus became the duty of incident investigators to look at the psychopathology of organizations in the search for clues.

Pathogens in the cheese

As a momentary aside, the story *Who Moved My Cheese?* (Johnson, 1998) is a simple parable about adapting to change. In the story, four characters (two mice and two "little people") live in a maze and look for cheese to nourish them and make them happy. "Cheese" is a metaphor for a goal in life—a job, relationship, health, peace of mind, or perhaps accident prevention. The "maze" is where you look for it. The story shows what happens to the characters one day when the cheese has been moved to another part of the maze. Some are prepared for it and adapt. Others are surprised by it and have a difficult time, for instance always looking in the same place for the cheese. The cheese within the maze of accident investigation, then, may not always be found in the same place.

To apply the metaphor, one of the main implications of the organizational approach has been the often-tenacious search for latent conditions leading up to the incident. However, we believe that some high-profile accident investigations have revealed flaws in such prescriptive implementation. While the importance of analyzing human factors throughout the accident sequence is not in question, the dogmatic insistence on identifying the latent conditions could and should be challenged in cases where active errors have played a major part.

Interestingly, in two separate aviation human factors conferences in late 2003, Reason (2003a, b) himself stated some concerns with the ever-widening search for the upstream or "remote factors" in safety investigation. The main points were as follows:

- they have little causal specificity,
- they are outside the control of system managers, and mostly intractable,
- their impact is shared by many systems,
- the more exhaustive the inquiry, the more likely it is to identify remote factors,
- their presence does not discriminate between normal states and accidents; only more proximal factors do that.

While acknowledging the significant contributions of the organizational approach, Reason (2003a, b) suggested that we might be reaching the point of diminishing returns with regard to prevention. Significantly, he stated, "…*perhaps we should revisit the individual* (the heroic as well as the hazardous acts). History shows we did that rather well." (emphasis added)

In the present paper, we take this statement as licence to pass a critical eye over the application of Reason's (1990, 1997) organizational model to incident investigations. When viewed in this light, textbook case studies display a continuum of latent and active failures. With the *Challenger* space shuttle, for instance, is a classic Reason-esque organizational accident. Latent conditions were traced back 9 years before the event, and there was nothing the shuttle crew could do to prevent the explosion. The capsize of the *Herald of Free Enterprise*, on the other hand, can be seen as having significant contributions from both latent conditions and active failures. Finally, the nuclear accident at Chernobyl highlights the salient contribution of active failures to a disaster. In a disastrous series of active errors, the reactor was not shut down, and all safety systems were disconnected as they arose to ensure continuance of an experiment. It is also notable that all of the inquiry recommendations were, in one way or another, aimed at reducing the possibility of active errors.

The above discussion leads us to question whether the focus on latent errors has become too strong, and whether we should redress some of our efforts back to the human at the sharp end. It should be made clear at the outset that this is in no way an effort to reapportion blame or change the focus of investigations (i.e., to prevent future accidents). Rather, it is in direct keeping with such philosophy that we are trying to elucidate all of the relevant causes of an accident. We now go on to examine a recent aviation incident in order to demonstrate that the front-line operator can often hold the answer.

Bangkok—a disorganizational accident

On Sept. 23, 1999, a Boeing 747 aircraft overran a runway while landing at Bangkok International Airport in Thailand. "The overrun occurred after the aircraft landed long and aquaplaned on a runway which was affected by water following very heavy rain. The aircraft sustained substantial damage during the overrun, but none of the three flight crew, 16 cabin crew, or 391 passengers reported any serious injuries.… These events and conditions can be described in many different ways, the most common being the model of organizational accidents as outlined by James Reason and others." (ATSB, 2001; p. v, xii)

Although this investigation was conducted in accordance with standard practice by adopting the organizational model, it is our contention that the assumptions and conclusions of this investigation were flawed, primarily because the Bangkok accident *did not fit the Reason model*. The most critical event in the accident sequence was, arguably, an active and "irrational" error. That this was not sufficiently acknowledged in the investigation report, the rest of the findings were distorted.

The critical event referred to is the captain's late and incorrectly handled cancellation of the go-around. Due to a troubled final approach, the aircraft was just about to land when the captain instructed the first officer to go around. This was a perfectly normal decision and corresponds with required flight procedures. The next action by the captain was not normal. Some 4 seconds later, the captain retarded the thrust levers "…because he decided to continue the landing rather than go around. The captain gave no verbal indication of this action or of his intentions and did not take control of the aircraft from the first officer." (ATSB, 2001; p. 9)

In assessing the decision to go around, the report states: "It is very widely accepted that a decision to conduct a go-around should not be reversed.… The captain's rejection of the go-around appeared to be a considered but rapid response to a unique situation." (ATSB, 2001; p. 44). It is not clear why the report concluded that the captain's actions were "considered," and the situation only became unique when the aircraft ran off the end of the runway.

That there were latent factors at work in this accident is not in question. The investigation report (ATSB, 2001) identified deficiencies in company procedures and training for landing on waterlogged runways. However, these latent conditions pale in significance when contrasted with the events at the sharp end. The key point of the inquiry should have been in determining why the captain acted as he did in cancelling the go-around. This action was contrary to the pilot's training and experience. More importantly, this single act precipitated the whole event. If one accepts that an irrational act occurred then none of the latent failures are relevant. Every organization can be investigated, and there will always be room for improvement. This, however, does not necessarily contribute to incidents, which is implied by the report's use of the term "latent failures." The point is that the inquiry attempted to force this accident into the Reason model when it was probably inappropriate given the evidence.

Needless to say, there were clearly reasons why the captain acted in this manner, and the aim of the investigation should have been in uncovering those in order to prevent a recurrence. While the identification (and presumed rectification) of latent conditions undoubtedly served to improve the safety health of the organization, it is hard to see how these conditions had a significant influence on the ultimate active error.

Railway accidents—the one true pathogen?

In addition to aviation and nuclear power, the Reason model has been adopted in railway industries around the world as a template for incident investigations. While we maintain that such use of the model could still fall prey to an excessive focus on latent conditions, a review of major railway accidents reveals that this industry may actually exemplify the organizational model better than any other. The key systemic deficiencies contributing to railway accidents would appear to lie in design and maintenance. Some of the most high-profile fatal accidents in the U.K. of recent years have been a result of inadequate track or signal maintenance (e.g., Clapham Junction, Hatfield, Potters Bar).

The most recent major fatal rail accident in Australia can also be attributed to latent failures, this time in the design of the train protection systems. The Waterfall inquiry (Ministry of Transport, 2003) found the design of the deadman system to be deficient, in that the weight of the driver's legs was sufficient to maintain the footpedal in the suppressed position. Further evidence uncovered at the inquiry revealed that some drivers (although not the driver of the Waterfall train) had been deliberately circumventing the system by forcing a handsignaller's flagpole into the footwell, thereby keeping the pedal suppressed. This suggests that the design was not only deficient in failing to achieve its intended purpose, but also in being a hindrance to drivers such that they felt the need to commit a "necessary" violation (in Reason's terms).

Although these brief case studies have focused on the most pertinent latent conditions involved, there were undoubtedly further organizational failings underlying the errors in each case. However, the point is that there was nothing that the drivers of any of the trains involved could have done to prevent the accidents. That is, in terms of occurring in close temporal and spatial proximity to the event, there were no identifiable active errors.

Not all rail crashes fall into this category either, though. The increased public and media concern with SPADs lately has inevitably been the result of fatal accidents caused by trains passing signals at danger. In the U.K., the collisions at Southall in 1997 and at Ladbroke Grove 2 years later were both the result of drivers passing a red light. Again, there were clear organizational problems in each case—most notably concerning the train protection systems and driver training—resulting in an extensive set of recommendations from the joint inquiry of Professor Uff and Lord Cullen. The accident at Glenbrook in 1999 was partly the result of verbal communication failures when the signaller (correctly) authorized the driver to pass a failed red light.

Clearly, SPADs are another category of accidents for which active errors are a necessary and sufficient component in the accident chain. This is not to say that there were no organizational failures at Southall, Ladbroke Grove, or Glenbrook, nor that any of the drivers were necessarily "at fault," but that a key error on the front line was essential to complete the accident chain.

Moving the Swiss cheese

In light of the above cases, the remainder of this paper asks whether the organizational accident model is still valid for describing, investigating, and preventing accidents, or whether the approach to safety investigation needs to evolve further rather than revolve.

It is indisputable that the ultimate and necessary (though not always singly sufficient) cause of all technological disasters relates to human actions—i.e., error. Reason (e.g., Maurino et al., 1995) contends that an error can consist of mostly latent failures, mostly active failures, or a combination of both. As we have argued through the various case studies above, though, the accident without a significant contribution from active failures is a relatively rare event (*Challenger* being one such example, and the rail industry providing a generic exception). Accidents occur due to varying proportions of predisposing factors and precipitating events, and many require an active "trigger" to keep the window of accident opportunity open.

Most major accidents are rife with errors of commission, including Three Mile Island and Chernobyl. Such extraneous actions were brought into focus in the early 1990s, but did not receive the kind of attention they deserve, except at surface level. Kirwan (1994) notes that the problem with such errors is twofold. First, extraneous actions are difficult to predict, being rooted in misconceptions, knowledge inadequacies, or misleading indications. Predicting what people could fail to do (errors of omission) based on a task analysis is much easier than identifying what *else* people could do. Second, such errors can have a dramatic impact. Reason (1990) noted the difficulties faced in detecting mistakes. The person making the error can often only detect it from the adverse consequences, since before that point everything is going according to plan, which happens to be faulty.

A more contentious issue concerns the ironic susceptibility of Reason to his own "hindsight bias" in many of the case studies he presents. In the analysis of the BAC 1-11 windscreen accident (Maurino et al., 1995; ch. 4), the authors cite a series of latent failings—such as insufficient stocks and poor labeling of stock drawers—which formed the accident chain. Similarly, an emergency landing by a Boeing 737 at Daventry in 1995 (Reason, 1997; ch. 2) occurred as a result of understaffing and communications errors during maintenance activities. While these may well be organizational failings, the establishment of causality is only really evident in hindsight at best (Dekker, 2002), and even then subject to interpretation—as Reason (2003a, b) himself has recently noted.

Top-down investigations (as advocated by Maurino et al., 1995 and Reason, 1997), working retrospectively from the event outcome, could easily be influenced by knowledge of the consequences. Latent conditions are often present all the time anyway, and it is only the unfortunate occurrence that reveals their pathogenic status (Boston, 2003). Instead, a bottom-up approach, investigating the contextual factors and working forward along the time line toward the event (cf. Dekker, 2002), might give a more unbiased view of the relevant factors. Many of these factors would doubtless seem insignificant to the actors—or even the industry regulators, whom Reason (1997) also criticizes (see Endnote 1)—in the pre-event scenario, and it is, therefore, harsh to judge them as latent failures *post mortem*.

The revolution in accident prevention?

The point we are trying to make here is not that Reason's Swiss cheese model is irrelevant or outdated—indeed, it has clearly revolutionized incident and accident investigations worldwide and put human factors well and truly on the map. However, it may be the case now that industries and organizations have latched on to the model in a far-too-rigid and dogmatic fashion. As a consequence, investigations based on the Reason model can easily turn into a desperate witch hunt for the latent offenders when, in some cases, the main contributory factors might well have been "human error" in the traditional sense.

Considering these as "irrational acts," then, we can be even more revolutionary and focus on the emotive influences on behavior, which have been neglected in human factors to date. Various performance-shaping factors such as stress and fatigue can exacerbate these cognitive errors. Emotion, however, is hardly a word in the human factors nomenclature. Just to illustrate, a search of human factors literature in Ergonomics Abstracts Online (accessed May 2004) revealed 266 hits on emotive *or* affective, versus 5,224 hits on the word cognitive, and 139 hits on the word emotion versus 636 hits on the word cognition. This is a crude comparison, but is illustrative of the focus in the literature. Many in the human factors community simply seem not to know where to start when it comes to emotion. One of the present authors had experience in developing an incident investigation tool and was warned against including classification terms that hinted at emotion or motivation.

It may be that emotion is simply seen as uncontrollable, unpredictable, and unfathomable. Indeed, many models often used in the study of human performance make no mention of emotional factors (e.g., Endsley, 1995; Norman, 1986; Reason, 1990; Wickens, 1992). Again, it seems that the paradigm pendulum has swung too far, extending the computer metaphor of the human beyond acceptability. Attempts to find references to "panic" in NTSB reports have come up with little (Wheeler, 2003), although one would intuitively think that panic must play a role *sometimes*. The captain at Bangkok must have been under stress, he was almost certainly fatigued, and perhaps his cancellation of the go-around was to some extent a panic response. Should we consider such emotional acts to be "irrational," or can we as psychologists address this very human side of behavior too?

Conclusion: the "human" in human factors

In summary, the position in this paper is not that Reason's Swiss cheese model should be discarded as a model for accident and incident investigations, despite the seemingly negative tone. On the contrary, since it has clearly proven value in a range of high-risk industries—and perhaps holds most validity in the railways. Our argument is simply that it is sometimes not as applicable as has been thought and that it can be misapplied in some cases as a prescriptive investigation technique, rather than a theoretical model. The fixation on latent conditions can then result in the sidelining of active errors, which may have had much more direct implications for the outcome. Even in those cases, the search for latent conditions has resulted in recommendations that undoubtedly improve the safety health of the organizations concerned, despite these conditions arguably having only tenuous connections to the actual event.

As we noted earlier, these thoughts have been aired by James Reason himself at two recent conferences (Reason, 2003a, b). Even in his book, Reason (1997) gives fair acknowledgement to the role of active errors, but still argues that "identifying and eliminating latent conditions proactively still offer the best routes to improving system fitness." (p. 237) Again, we cannot argue with this point. Looking only at active errors is a symptomatic approach, and the symptoms of emotional or "irrational" acts are difficult to decipher.

The aim of this paper has not been to criticize James Reason, or to throw his Swiss cheese to the mice. We would just like to see an increased awareness among investigators of the spirit of the model, rather than following the letter of Reason's "bibles" so dogmatically. Without wanting to return to the dark ages of "human error" being the company scapegoat for all accidents, there is a balance to be redressed in accounting for the role of active errors. Latent conditions may be significant, but occasionally people really do just slip up. ◆

Endnotes

[1]Reason (1997) does, though, make the very valid point that industry regulators have suffered from goal conflicts in the past. The Australian Civil Aviation Authority was implicated in the crash of a Piper Chieftain at Young, New South Wales, in 1993, being at the time part financed by its stakeholders. This led to the formation of the Civil Aviation Safety Authority. However, a similar situation has recently emerged in the U.K. with the formation of the Rail Safety and Standards Board, which is wholly funded by its members, the industry stakeholders. As a consequence, all new safety standards and interventions are subject to consultation by the entire industry—so the Board must beware not to rock the commercial boat while trying to improve safety.

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Analysis of Aircraft Propulsion System Failure

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Abstract

Engineered structures form the basis of the air transport industry—an industry society expects to be safe. Safe operation of a complex vehicle cannot be ensured by simple means. The safety systems that have been developed are comprised of a variety of constraints, agreed limitations, and multilayered defenses. Safety systems are developed in response to expectations, employ the concept of risk, and are modified in the light of reality. Complexity is present at many levels in an aircraft and, in particular, an aircraft propulsion system. Complexity plays a major role in the difficulty of matching reality with expectations.

The focus of this paper is the analysis of repeated structural failures of reciprocating engines used to power low-capacity regular public-transport aircraft. The analysis draws on the case of a fatal accident involving a double-engine failure and a number of serious incidents.

An additional broader focus is a discussion of the methodology employed to determine the factors that initiate failures of technical systems. The process of analysis is not simple. It is a process of learning that involves the elements of seeing, evaluating, and communicating.

1. Introduction[1]

Engineered structures form the basis of the air transport industry—an industry that society expects to be safe.

Airframes, powerplants, propellers, landing gear, and other mechanical and electrical systems are essential elements of aircraft. They are designed, manufactured, and maintained with the aim of preventing failure during operation.

Since the time of the Wright Flyer, the design of aircraft structures, powerplants, and systems has evolved, within the general constraint of society's expectations of safety, to the present-day broad range of aircraft (supersonic fighters, jumbo transports, a multitude of medium and small, jet and turboprop, transports, and helicopters). Over this period, failures of engineered structures and systems have resulted in accidents. The lessons learned from these failures have been incorporated into design standards, manufacturing and maintenance standard practices, approval and certification of products and personnel and the prescription of operational limitations—a comprehensive, complex, engineering safety system.

A prime goal in the design and operation of transportation systems is the avoidance of threats to safety—safety of operators, passengers, and bystanders.

Design has its first and foremost objective the obviation of failure[2].

However, there are other objectives that must be satisfied if the design is to progress from the drawing board or prototype—purchase price, lifetime cost, running cost, ticket price, operational life, maintainability, performance (speed, payload).

Present-day transport aircraft are complex assemblies. Jumbo jets have been described commonly as 6 million parts flying in formation. Aircraft have additional complexity in that they operate as both land and air vehicles.

The run up to takeoff is a metamorphosis: here is a pile of metal transforming itself into an airplane by the power of air itself, each takeoff is the birth of an aircraft.[3]

The safe operation of a complex vehicle cannot be ensured by simple means. The safety systems that have been developed comprise of multilayered defenses covering all aspects of design, construction, and operation. Despite our best efforts, and the present-day safety systems, failures and accidents still occur. Why? Clearly, safety systems are not ideal and continued learning and adjustment are required.

To make flight "natural," it had been necessary to formalize it as far as possible, to draw up a complicated grammar of rules and exceptions, a body of procedures and precedents, corrected and emended over the decades in the light of errors and catastrophes, because errors in this grammar were paid in cash, and at top price.[4]

Safety systems are developed in response to **expectations**, employ the concept of **risk,** and are modified in the light of **reality**.

2. Expectations

Everyone has expectations regarding the performance of transportation systems. These expectations are not consistent across all sections of society and may change within a group with time or as the result of personal experience. Expectations are colored by the perceptions, views, understanding, prejudices, and biases of each section of society.

Commercial aviation, nuclear power, petrochemical industries, and marine transportation are considered by the general public to be hazardous industries. These industries are expected to operate without mistakes—or at least the sorts of mistakes that have no catastrophic consequences. While other industries develop through trail and error, hazardous industries are expected to develop through trial without error.

The view of a wide section of society is captured by Penelope Layland's article in the *Canberra Times* July 29, 2000, "Prefer to Be Bitten if You're Shy To Fly" following the Concorde accident, July 25, 2000.

I know the statistics. I am far more likely to die after being bitten by a dog, having the wound turn septic, then having an adverse reaction to an overdose of the wrong antibiotic delivered by a homicidal nurse, than I am to die in an aeroplane crash.

So what? I'm not scared of dog bites and homicidal nurses. Yet every time I board a plane I am convinced that I am embarking on the final minutes of my life.

Dogs and homicidal nurses are on my level—ground level. Planes fly. It is unnatural. A few hundred years ago, pilots would have been burned at the stake, and a good thing too.

To fly one must entirely suspend one's understanding of gravity. Not that my understanding of gravity is particularly sophisticated, I'll grant you, but life experience tells me that if I accidentally drop a particularly cherished vase, there is a very good chance it will break when it hits the floor. The same life experience tells me that several tons of metal hurtling through the atmosphere will probably fall, too, if something goes wrong with the engines that push them through space.

2.1 Pressures for learning

The call to learn from incidents, accidents, deaths, disasters, and catastrophes in order to save lives has become a catch cry of our time. Articles in professional journals and newspapers all call for increased efforts in learning.

"More and more it's to learn some lesson from a particular death to save lives," Mr. Dingwall, an ACT magistrate, said. "It's learning from mistakes of the past." [5]

The call for learning from threats to safety come at a time when there are calls for increased learning in organizations to strive for improvements in management, service provision, and product quality to achieve efficiencies, increased profits, and greater competitiveness.

The expectations of society create the driving force for learning in the air transport industry in two areas:

- Safety, based on the perception of threats to individual and group well-being posed by air transport.
- Economic, based on the willingness to pay for tickets, the desire to travel more quickly, and the availability of alternate modes of transport.

3. Risk

The concept of risk introduces the sense of a hazard or threat and the likelihood or probability of encountering the hazard.

Traditionally, scientists and engineers have viewed risk as a purely technical issue, one that can be boxed off from the rest of technology and handled separately. It is one more technical issue to be solved. Risk decisions have been made inside the system[6]. However, it is now understood that when risk is involved technical and non-technical issues get tangled to a point that they are impossible to separate[7].

In the past, safety issues were addressed by eliminating hazards; however, as industries, systems, and machines became more complex, the way in which people think about safety has changed. It is no longer thought to be possible to engineer for complete safety, to determine the maximum credible accident and then ensure that it won't threaten anyone.[8] The best that can be done is to try to make dangerous accidents very unlikely.

The development of risk assessment/management has evolved with experiences in the nuclear power industry. Initially, the threat of a nuclear reactor to public safety was ensured by a simple scheme: put the reactor far away from where people lived—the larger the plant the larger the exclusion zone.

An engineered solution that eliminated the need for an exclusion zone was the construction of a "containment" building—a building that would prevent the escape of radioactive materials in the case of an accident. The design of the containment building was based on a determination of the worst possible accident and the impact this would have on structural integrity. The most difficult to resolve issues centered on the so-called loss-of-coolant accident, dubbed the "China Syndrome." Safety now was ensured by the performance of active safety systems and features such as emergency core cooling systems. Reactor safety design changed from being "deterministic" to "probabilistic." Risk was evaluated by taking into account the probability of safety system failure and the consequences, in terms of fatalities, of that system breakdown.

Probabilistic assessment relies on calculating the probabilities of chains of events that may lead to an accident. A major weakness is the need to identify all potential failure modes and sequences and assigning probabilities for all events.

An initial estimate of the probability of a reactor core meltdown was once in every million years of reactor operation. A more rigorous assessment documented in the Rasmussen report[9] concluded that the probability of a meltdown could be expected only once in every 17,000 years of reactor operation. Less than 5 years after the Rasmussen study was completed, on March 28, 1979, unit 2 of the Three Mile Island nuclear plant had a major accident. The reactor core melted partially and some radioactive material was released into the atmosphere.

The partial meltdown has reshaped thinking on risk in complex technologies[10].

4. Reality

4.1 The need for prediction in engineering[11]

An underlying feature of engineering design is the need to predict future behavior and quantify risk. Will it work safely and will it continue to work safely?

In this less-than-perfect world our understanding of materials, structures, and mechanisms, in the face of complex loading and environmental interactions, is not complete. Engineering design effort still requires human judgment and insight (especially in decisions regarding safety). Structural analysis is done in support of, not in place of, the creative process of design.[12]

If it looks right it, will fly right!

Our mathematical models have limitations—they are approximations of reality. The danger is that mathematical models can hide our lack of knowledge. The properties of materials and some loads encountered during operation vary in a random manner, creating uncertainties.

Against a background of uncertainty, design goals are expressed in terms of probability of failure. For critical aircraft structures and systems, the probability of failure is required to be "extremely remote." In the face of the expectation of an extremely remote probability of failure, the challenge is to establish a design basis, to determine the hard values of strength and stress that allow structures and systems to be constructed.

The consequence of uncertainty and variation is the need to apply safety factors to design values. A design is an approximation, hopefully a conservative approximation to an effective structure or system.

While conservative design is necessary for safety, it creates a conflict between the other objectives of an engineered structure or system; cost effectiveness, structural efficiency, improved performance. This conflict results in the process of fine-tuning.

The disparate nature of the goals imposed on the creators of aircraft make learning from operational experience a process of fine-tuning safety factors.

People are almost certain to reduce some safety factors after creating a system, and successful experiences make safety factors look more and more wasteful.[13]

People may cut safety factors while designing a sociotechnical system. Large safety factors may render projects prohibitively expensive or technically impossible and thus prevent the solving of serious problems or the attaining of important goals. When they extrapolate actual experiences into unexplored domains, safety factors may also inadvertently create hazards by introducing unanticipated risks or by taxing other components to their limits.[14]

The danger of fine-tuning a system that has multiple and conflicting goals is that changes can always be justified and generate a benefit in one area while having an unrecognized effect in another area. The effect of system fine-tuning on safety is usually discovered by analyzing accidents and disasters.

4.2 The learning process

In reality, there will always be a tension between the desire for decreased threat to life and the willingness to pay. The state of balance between safety and profitability depends on the ability of the creators, operators, and regulators of a complex sociotechnical transport industry to learn.

The rate at which learning is achieved is dependent on the immediate goals of the various players in the industry, e.g., driven by a need to satisfy a market, compete with alternatives, or in reaction to a disaster.

Adjustments from learning in one area may result in consequences that are not immediately apparent in another. The connection between cause and effect in different areas may occur over widely different timeframes. Learning may also have to wait for developments in the understanding of physical phenomena.

The need to learn—its easy to say. What do we need to learn and how do we learn it? How do we know when we have learned it?

5. Analysis—how we learn

From the perspective of safety it is desirable that air transport systems are examined, tested, and analyzed to determine when the process of fine-tuning is approaching the boundaries of safe operation, rather than waiting for the boundary to be crossed and analyzing the results of accidents.

Traditionally, investigation involved the gathering of facts, what happened, what failed, how did it happen, how did it fail. More recently, there has been a greater emphasis placed on determining why failures occur.

To determine why a failure occurred, why an error was made appears to be a logical step and sounds easy, but how do you know if the critical question has been answered? Why do failures still occur? If critical observations and critical questions are not answered then the root causes of system deficiencies and errors will not be determined, the analysis will not be effective, and the opportunity to prevent recurrence will be lost. There is a need to examine every level of a system, not just the final outcome, all defenses, and not just the final defense.

Analysis is a process of learning. Learning implies the gaining of knowledge. In the case of failure analysis, it is the gaining of knowledge that allows judgments to be made that result in the right corrections to the engineering safety system in order to fulfill the requirement for future safe operation.

The process of gaining knowledge is a key variable.

Analyses that achieve effective learning involve the processes of **seeing**, **evaluating,** and **communicating**.

All day and every day we are receiving information from our sense organs. The decisions and judgments we make based on the information received and the ways in which we adapt to and deal with new information are the essential features of learning. It is in these processes that variability in learning arises.

Some information sensed is immediately useful and is acted on. Much is not immediately useful: we are aware of receiving it but we do nothing about it. Other information is received without any conscious awareness.

The tools of a scientist, simple lens, electron microscope, thermometer, etc., are designed to present to the eye information that is otherwise not available to it.

Every person has a store of information. As a result of seeing, listening, reading, reflecting on our experiences, and reasoning, we acquire both information and misinformation. Every person also has persistent deep-rooted ways of classifying information, thinking, perceiving, and behaving. A person's prior information and behavioral modes determine what we see and how we evaluate information and respond. The process of recognition is the process of matching observations with our prior store of information.

During the investigation of accidents and disasters, there is a need to develop an understanding of why the prediction of safe operation was inaccurate. There is a need to analyze issues that were previously unknown.

Successful detectives differ from less successful ones in their ability to perceive as relevant to the solution of their problem pieces of information that the rest of us ignore, regard as irrelevant, do not see![15]

Important discoveries in science provide clear examples of making use of information that had previously been regarded as unimportant or useless. The ability to address new problems depends on the ability to make new associations between information where, previously, there have been no conventional or traditional relationships.

Successful analysis comes from the conscious consideration of many possibilities rather than jumping to a conclusion without considering the evidence for alternate ones.

5.1 Failure of analyses

If the success of analyses depends on the mental processes and knowledge of the analyst then, the failure of analyses to prevent recurrence of accidents and disasters is also related to the mental processes, the knowledge of the analyst, and the transfer of knowledge to those who are in a position to implement corrective action. There is a need to develop a comprehensive understanding of an industry and its safety system.

The shortcomings of analyses have more to do with mental processes, how information is gathered and used. In the present "information age," it is not a matter of more information, more training, which only involves the transfer of information from teacher to student, but the how information is gathered (seeing), evaluated, and communicated.

Classification

Classification provides a link to a greater store of information, experiences, and understandings relating to an event. The classification of a fracture links it with a mechanism that has been established by research and allows causal factors to be identified.

[G.H. Lewes, 1879] And the new object presented to Sense, or a new idea presented to Thought, must also be soluble in old experiences, be recognized as like them, otherwise it will be unperceived, uncomprehended.[16]

The process of classification can cause great difficulties. The effect of own assumptions and preconceptions can lead to the incorrect classification of information, incorrect hypotheses, and an incorrect prediction of future events.

Communication

Complex technologies are designed, manufactured, operated, and regulated by complex organizations employing many people. No one person is responsible for all the actions required to design, monitor, and modify safety systems. Effective communication is essential.

Technical descriptors (be it one word or a phrase) serve a vital role in communication about complex phenomena. The common understanding associated with the descriptor allows communication to occur.

The shortcomings of the use of technical descriptors lie in the, sometimes, imperfect connection between descriptor and phenomenon, leading to differing understandings by various people when a descriptor is used. Additionally, especially during investigation processes, the interpretation of the evidence of phenomena may lead to inconsistencies in classification—different technical descriptors may be applied to one phenomenon. For example, the use of the term "failure" may sometimes be taken to refer to component fracture, loss of function of a component or mechanism, or a change from the normal function of a component, mechanism or process.

It is recognized that no one definition of a technical descriptor is necessarily adequate. It is also recognized that multiple definitions do lead to misunderstandings.

Culture

Cultural issues have a significant effect on the communications between the originators of new ideas (analysts) and those who are in a position to implement corrective actions or changes (managers). Additional communication difficulties are created when investigations are fragmented across a broad range of engineering disciplines. Each group has its own culture, preconceptions, and, possibly, biases.

Culture may also provide a resistance to change and a barrier to new thoughts.

In periods of stability or of slow change the broad outlines of the pattern of culture are accepted by the majority almost unthinkingly and without challenge, and the principles that should govern behavior are so thoroughly inculcated that they hardly need verbal reinforcement or even expression.[17]

Occasionally, the time must be right for learning to spread to those who are in a position to implement change.

[On Young (Young's modulus)] a man of great learning, but unfortunately he never even began to realize the limitations of comprehension of ordinary minds.[18]

The effect of complexity

Complexity is not merely a matter of the number of parts of the system. If system parts interact in a simple linear fashion, that is there is a simple linear dependency between the parts, a system with many parts is not complex.

The defining feature of a complex system is how its parts interact. If the behavior of any part of the system depends or is influenced by the behavior of other parts, the system is considered to be complex—the more interaction and the increased multiplicity of interaction, the more complex the system.

The greatest effect of complexity is on the prediction of system behavior and the less likely control will be reliable.

Complex industries operating complex machines have developed, over time, a multiplicity of overlapping and mutually supporting defenses that make these industries largely proof against a single failure of a defense. However these "defenses in depth" are a mixed blessing. They make the overall safety system more complex, more opaque, and make a buildup of minor failures go unnoticed, weakening the entire system, making a catastrophic accident more likely[19].

The analysis of the Three Mile Island accident revealed that beyond individual errors and component failures and shortcomings in probabilistic risk assessment, the complexity of the system created a situation where a number of seemingly minor events could interact to produce a major accident[20].

People have also come to appreciate how complexity changes the risk equation, how it makes risk harder to calculate by making it difficult to understand all the ways that things can go awry. But equally important, complexity can amplify risk. The more complex a technology, the more ways something can go wrong, and in a tightly coupled system, the number of ways that something can go wrong increases exponentially with the number of components in the system. The complexity makes a system more vulnerable to error. Even a tiny mistake may push the system to behave in strange ways, making it difficult for operators to understand what is happening and making it more likely they'll make further mistakes[21].

6. Aircraft propulsion systems, a complex system

Complexity is present at many levels in any industry, from wide organizational arrangements to seemingly simple components whose apparent simplicity belie an underlying complexity in factors that determine their successful operation and effect on other closely coupled components.

An essential element of an aircraft is the propulsion system. That system provides the forward thrust necessary for flight. While gas turbine engines are the basis for propulsion systems for many aircraft, especially large civil transport aircraft, reciprocating engines coupled to propellers are used to provide the propulsive force for many smaller aircraft types. The high-power variants of horizontally opposed, six-cylinder, air-cooled reciprocating engines coupled to constant-speed propellers are used to power many aircraft employed in low-capacity public-transport operations.

It is important to recognize that, in reciprocating engine installations, the engine and propeller form an interdependent system. Constant-speed propellers are coupled with high-power reciprocating engines in installations that allow the propeller speed and engine power to be set separately to obtain the best combination of performance and fuel economy for all phases of flight.

Just as the engine and propeller form an interdependent system, the engine and fuel consumed in the engine form an interdependent system. Engine performance and fuel properties are closely linked. The history of engine development has been a process of mechanical refinement to extract the available energy contained in a fuel (aviation gasoline) under controlled combustion conditions and a concurrent refinement of gasoline formulation to allow advantage to be taken of mechanical refinements.

Finally, it is important to realize that the pilot and maintenance engineer, through their actions and knowledge, also form an interdependent system with the engine and propeller.

6.1 Expectations of reciprocating engines

The safe operation of aircraft relies on the correct operation of all the systems that combine to allow aircraft to function. The propulsion system is one of these systems.

Propulsion systems must have a high power-to-weight ratio, they must be economical, but above all they must be reliable.

The capability of an engine to produce the power specified by the engine manufacturer reliably throughout flight is a fundamental requirement of safe operation. Conversely, the failure of engines to produce specified power levels or the complete failure of an engine during flight is a threat to safe operation. That expectation is expressed simply in the design standard for aircraft engines, e.g., Federal Aviation Regulations Part 33 Airworthiness Standards: Aircraft Engines: Engine design and construction must minimize the development of an unsafe condition of the engine between overhaul periods.

And the International Standards for Airworthiness of Aircraft contained in Annex 8 to the Convention on International Civil Aviation (the Chicago Convention). Annex 8: The engine complete with accessories shall be designed and constructed so as to function reliably within its operating limitations under the anticipated operating conditions when properly installed in the aeroplane.

6.2 Reciprocating engine risk management

The confidence that an aircraft engine will perform reliably, that risks are managed, is achieved by regulatory authority certification that the engine has passed an extensive testing program combined with approved instructions for operating limits, lubrication, inspection, component replacement, testing, and adjustment. These design requirements form the basis of a comprehensive safety system.

The impact of the need for structural efficiency

Structural efficiency in design is necessary to achieve high power-to-weight ratios. The requirement that an engine design is reliable, within defined operating limitations, is demonstrated by performing the test program contained within the engine design standard (FAR 33). Instructions for maintenance are designed to ensure continued airworthiness under operational conditions. Operating limitations are determined for horsepower, RPM, and manifold pressure at rated maximum continuous power. Items such as fuel grade, oil grade, cylinder head temperatures, oil temperatures, turbine inlet temperatures, and component life are specified.

The strength and robustness of engine components and mechanisms, within the defined engine operating limits, is achieved by using materials that comply with standard specifications (to guarantee that the properties of the materials used match those assumed in design), and by a comprehensive test program.

The engine must be designed and constructed to function throughout its normal operating range of crankshaft rotational speeds and engine powers without inducing excessive stress in any of the engine parts because of vibration and without imparting excessive vibrational forces to the aircraft structure[22].

Further demonstration of the adequacy and robustness of the engine is provided by an endurance test (FAR 33, Subpart D, Section 33.49). Engines are subjected to blocks of engine operation under a variety of operating conditions to a total of 150 hours of operation. At the conclusion of the endurance test the condition of components and mechanisms is assessed during a teardown inspection. Each component must retain the functioning characteristics that were established at the beginning of the test.

The structural requirements of propellers are addressed by other sections of the aviation regulations (FAR Part 35).

The impact of combustion abnormalities

Combustion in spark ignition engines is designed so that a flame front moves across the premixed fuel-air charge in the combustion chamber resulting in a controlled increase in gas pressure. Under certain conditions, rapid oxidation reactions occur at many locations within the unburned charge, leading to very rapid combustion throughout the volume. This essentially volumetric heat release in an engine is called autoignition, and the very rapid pressure rise leads to the characteristic sound of engine knock[23]. Within the aviation industry, this process of autoignition or knock is referred to as "detonation." Detonation can cause mechanical damage through the creation of abnormal loads. It can also cause component overheating and melting by its effect on heat transfer mechanisms.

Detonation of the fuel-air charge in a reciprocating engine is the principal factor limiting the maximum power that can be produced by an engine. Its importance is recognized in engine design standards, e.g., FAR 33, Subpart D, Section 33.47, which requires that each aircraft engine type must be tested to establish that the engine can function without detonation throughout its range of intended conditions of operation.

Avoidance of detonation is achieved primarily by the use of fuel with a known resistance to detonation (octane or performance number rating scales) and limitations on engine operating parameters.

6.3 Reciprocating engine reality

In reality, components of propulsion systems do fail and flight safety may be threatened by the total loss of thrust, partial loss of thrust, damage to other structures, and systems by the effects of fire or impact. Because of the complexity of the systems, the consequences of a component failure may be benign or it may be catastrophic.

Operational experience is a test of safety system design—does reality match expectations, has the management of risk matched expectations.

Feedback on actual engine performance/behavior is an essential element in determining the adequacy of the safety system and, if necessary, making adjustments to the safety system. Component failure, unless considered to be the consequence of normal operation, indicates a weakness or deficiency in the safety system.

Effective feedback depends on effective analysis. Effective analysis requires the consideration the effects of complexity and knowledge of the safety system.

A dilemma has been created by the need to quantify risk. The act of quantifying risk results in the acknowledgment of a finite probability of failure. If failure occurs, is this the failure predicted by statistics? If a predicted, extremely rare, event occurs can it be argued that analysis to prevent recurrence is unnecessary because of the small probability of recurrence?

The view taken from a safety standpoint, in contrast to a reliability standpoint, is that the system should be analyzed on the basis of potential consequences, not on the basis of likelihood of occurrence[24].

In reality, in the light of recurrent component failure do expectations change?

Recurrent failure may change views of normality. Those within the safety system may come to view certain failures as normal; their expectation may change from one of reliability to one failure. If a fracture control plan isn't working, is it because of some statistical variation created by some unknown microstructural variation? This subtle change in expectation may lead to the establishment of latent failures in the safety system. Those outside the safety system may not share the subtle change in expectation and may judge things differently in the light of accidents.

Numbers of failures do not provide a good measure of the health of the safety system. In the case of components, the probability of failure when subjected to a tensile stress is given by the overlap of the distributions of the tensile strength of the component and magnitude of the applied tensile stress[25]. The numbers of failures don't give complete information regarding the nature of the distributions, just the margin between the weaker components and the higher stresses. It doesn't give any information regarding the shape of the distributions and whether the current distributions are the same as those assumed during design. In a similar manner, numbers of failures of a safety system may be considered to represent the overlap of distributions of system strength and system stress.

The robustness of a safety system relies on all levels of the system functioning as planned, the prevention of latent system failures, and an effective analysis and feedback process to correct deficiencies strengthen weakness.

6.4 Reciprocating engine failure analysis

A recent study by the ATSB[26] of the structural failure of high-power reciprocating engines (greater than 300 HP) has revealed that failures are not restricted to one component.

The study found that the factors initiating a series of events that result in the failure of a power train component can be grouped according to several fundamental physical, chemical, and thermal processes. For example, mechanical loads created by the pressures developed in the combustion chamber are a result of the combustion process. Component temperatures are a result of the heat balance between the component and its environment, which, in turn, depends on resistances to heat transfer. Bearing damage is a function of the process of lubrication and frictional heating. Bolted joint behavior depends on the nature of deformation (elastic or plastic) between abutting components.

Component fracture or failure to perform its function occurs when the controls or limits on these fundamental processes have been exceeded or been ineffective. For example, component stresses arising from the pressures developed in the combustion chamber will be affected adversely by combustion abnormalities. The boundary between normal and abnormal combustion depends on factors that may be controlled by the pilot (power, mixture, temperature, and RPM setting), specified operational procedures (power, mixture, RPM, and temperature), maintenance personnel (the actions and procedures involved in adjustment, calibration, repair, and overhaul), and fuel supply (octane rating).

Gaining an understanding of why the controls and limits had been exceeded or ineffective forms the basis for prevention of further failures

7. Concluding remarks

The major effect of complexity is its impact on our ability to predict the future behavior of sociotechnical industries. Complexity affects all levels of these industries, from human interaction and operation to the design and behavior of mechanical systems and structures.

Complexity increases the demands on failure analysis. There is a need to move from one-dimensional analyses or compartmentalized analyses to analyses based on a multidimensional understanding of safety systems and identify weaknesses and deficiencies in the safety systems.

The process of analysis is not simple. It is a process of learning that involves the elements of seeing, evaluating, and communicating. The effectiveness of analysis is built upon the process of increasing individual information stores, developing mental processes that allow new problems to be addressed, gaining an awareness of factors that limit learning, and developing strategies for communicating.

On the issue of communication, it is important to be aware that mere logical reasoning will not be enough to achieve acceptance of the findings of an analysis by everyone. People may have non-logical reasons for believing the things they do. Compassion, honesty, and tact are as important as logic in gaining the acceptance of findings[27].

The safety of complex, risky technology lies in human hands; however, the complexity of the technology guarantees that there will always be surprises. And in the case of surprises, the best defense is human competence, expertise, and imagination[28]. ◆

…Therefore, go forth, companion: when you find
No highway more, no track, all being blind,
The way to go shall glimmer in the mind.

Though you have conquered Earth and charted Sea
And planned the courses of all Stars that be,
Adventure on, for the littlest clue
Has come whatever worth man ever knew;
The next to lighten all men may be you…..
—John Masefield[29]

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The Myth of the Unstable Approach

By Dr. Ed Wischmeyer, Embry-Riddle Aeronautical University, U.S.A.

***Dr. Wischmeyer** has 6 years of experience in direct flight safety research, 5 years of experience developing advanced FOQA systems, and 20 years of software and user interface development experience. He has flown nearly 150 makes and models of light aircraft, including the P-51, and has flown simulators for current production Boeing aircraft. He also has observed 50 airline flights from the jumpseat.*

Introduction

Forty years ago, the term "pilot error" was commonly used in accident taxonomy. Eventually it was realized that this term, while technically correct, did little to explain accident causes or prevent recurrences. Pilot error then became an invitation to more deeply explore, to more carefully classify, and to eventually articulate and address the underlying phenomena. The generalization pilot error is now largely replaced by more concise, more useful, and more well understood concepts. The term "unstable approach" is now ready to begin that same evolution, and is an invitation to new discovery.

This paper begins by exploring a number of interesting parallels between unstable approaches and pilot error. Next, multiple independent sources demonstrate that almost no unstable approaches end catastrophically, and, thus, it is inappropriate to consider unstable approach as a causal factor. Rather, unstable approach is almost always correctable, and/or a symptom of other phenomena. Lastly, a number of concepts and ideas are explored that are first attempts to accept that invitation to more deeply explore, more carefully classify, and finally address the underlying phenomenon. These concepts and ideas may have value in seeding new taxonomies and techniques for accident and incident analysis.

Parallels between pilot error and unstable approach

Consider the following points of similarity between the pilot error concept of the 60s with the contemporary "unstable approach" concept (see Table 1).

Table 1

Definition succinctly defines what occurred?	**Pilot Error No, inclusive definition**	**Unstable Approach No, inclusive definition—Flight Safety Foundation's definition has nine elements**
Is an occurrence operationally acceptable?	No	No
Occurrence increases risk?	Yes	Yes
Happens all the time?	Yes	Yes (discussed below)
Is a premeditated pilot action?	No	Not always
Have to recover from it?	Yes	Yes
Pilots almost always get away with it?	Yes	Yes
Sounds good on television?	Yes	Yes
Usually a symptom of other factor(s)?	Yes	Yes
Indicates need to find those other factors?	Yes	Yes
Gave rise to a number of valuable studies?	Yes—CRM, fatigue, human factors	Not yet…
Concept is still used for accident analysis?	No	Starting to fade

No one doubts the operational benefit of a stable approach, just as no one doubts that aircrew should not commit pilot errors—the issue is the value of the term unstable approach in safety analysis. Just because pilots should not make unstable approaches does not mean that this vague generalization is appropriately used in accident and incident analysis.

Prevalence of unstable approaches and research history

A number of diverse, independent sources all indicate that while unstable approaches may increase the risk of a bad landing outcome, that risk is still so low that the concept unstable approach can only rarely, if ever, be meaningfully be used in accident and incident causal analysis.

The research on the prevalence of unstable approaches was performed at Boeing Commercial Airplane Group in 2001. My initial position was that unstable approaches were a direct cause of landing accidents, and that providing an unstable approach alert would directly and immediately reduce accidents. Thus, the researcher's initial bias was in direct opposition to the final result. In fact, this unstable approach research was initially done strictly pro forma, as we all knew the "correct" outcome already.

The first data set examined was from NASA Aviation Safety Reporting System reports. Although it is well-known that meaningful rate of occurrence statistics cannot be generated from voluntarily submitted reports, this does not mean that no meaningful statistical analyses can be performed. Rather, the analysis performed had two parts

1. Determining what the motivating event was for each report submission. For example, an unstable approach would be a motivating event, but landing at O'Hare would not be considered motivating.
2. From sets of reports with the same motivating event, meaningful conditional probabilities could be generated with the condition being the presence of that motivating event.

Because I had the experience of working in the NASA ASRS office for several years, including performing the final check on several hundred reports before they were entered into the ASRS database, I was confident of my ability to determine motivating events and the integrity of the reports.

Reports were analyzed both where unstable approaches were the motivating event, and in which unstable approaches were significant features of the narrative. Similarly, reports were chosen where the motivating event was a landing outcome unacceptable to the flight crew. Approach instability was tabulated by the altitude (if any) at which the approach became stable, and similarly, the altitude at which the approach became unstable.

The results of these analyses were that bad landings (the motivating event) were frequently observed from stable approaches, and good landings were frequently observed from unstable approaches—and these initial, poorly understood observations were unsettling. These results also brought to mind a sampling theorem from quality control that states that, in effect, if you are expecting a phenomenon to be rare (such as good landings from unstable approaches), but a small initial sample shows a high rate of occurrence (many good landings from unstable approaches in a small, initial sample set), then you can reject the hypothesis of rarity without further sampling.

The next step was to seek quantitative verification from FOQA data. A carefully worded e-mail to a David Wright in the CAA, who had access to large quantities of FOQA data, cautiously breached the possibility that approach parameters and touchdown parameters might not be well correlated. A few days later, a return e-mail said, in effect, "our data show that, too, and we don't believe it either."

With quantitative verification in hand, it was time to generate plausible hypotheses to explain the unanticipated results. Three were prominent.

- Because the commonly accepted high correlation between unstable approaches and bad landing outcomes was generated from accident data only, that high correlation was a result of sampling bias, in the epidemiological sense.
- There is some other phenomenon present that is tentatively named "pilot involvement factor." This hypothesized factor states that if the pilot who was flying was highly involved in flightpath control, then appropriate skill and experience would be applied and the landing outcome would be successful regardless of approach stability. Conversely, if the pilot were inattentive or not completely in the loop, this state of low involvement could manifest itself in a bad landing outcome, regardless of the approach stability.
- Because many of the definitions of approach stability called for a go-around by at least 500 feet (150 meters) HAT (height above touchdown) if the approach was not stable, those definitions effectively ended at 500 feet. Yet, ASRS data (and later, accident and incident data) indicated that significant atmospheric effects would be encountered at 300 feet (100 meters) HAT and below. The perturbations caused by these low-level atmospheric effects would affect landing outcome statistics but would be encountered regardless of approach stability.

All of these hypotheses were discussed with peers, colleagues, management, and company pilots. None of these hypotheses were widely accepted, perhaps because the underlying premise was contrarian. More significantly, there were no successful or even substantive challenges to these hypotheses.

A number of additional quantitative sources provided privileged information. Highlights of that privileged information include:

- three independent sources of airline approach data, with no overlap of airlines sampled, report that the rates of occurrence of unstable approaches for each of these sources were 1.6%, 3%, and 15%.
- data from one of these sources show that, for runway overruns, a stable approach is 60 times safer than an unstable approach, and a chi-square test shows this result is statistically highly significant. On the other hand, this same data shows that if an unstable approach is used as a criterion to predict a runway overrun, it will give a false alarm 49,999 times out of 50,000.

Table 2

Flight Sub-Phase	Goal	Comments
Rollout and turnoff	Decelerate from touchdown speed, then transition to taxiing on the airport	
Flare and touchdown	Touchdown on runway within safety and comfort parameters, with room for rollout and touchdown	
Final visual alignment	Position the airplane visually for start of flare.	In Cat III, this phase does not appear. On a visual approach, this phase may be lengthy.
Inside the final approach fix	Maneuver the airplane so that when visual contact is established, the flight crew can manually fly the airplane to a successful landing.	
Outside the final approach fix	Maneuver to cross the final approach fix (FAF) at an acceptable speed and altitude	Crossing the FAF with excessive energy is common

- data from one of these sources show that statistics generated on approach are very poorly correlated with statistics generated on landing, if at all. For some approach measurements, grouping that approach measurement would also group some landing parameters, but the distributions of those landing parameter groups overlapped so much that touchdown measurements could not be used to determine approach parameter measurements.

With ASRS and these three other sources all giving consistent results, and with plausible analysis to explain the observed results, it can be reasonably concluded that unstable approaches do not usably predict bad landing outcomes.

My management approved these results, and then asked—you've shown what can't be done, now show what can be done.

Ideas for future analysis directions

Just as pilot error opened the doors to further research that brought into prominence human factors, fatigue, and CRM, unstable approach can and should open the doors for the safety community to identify new areas of study. The unstable approach research done to date suggests these interesting starting points for these new flight safety theories, or support for theories already under development

- five sub-phases to replace "approach and landing"
- severity-last event taxonomy
- guidance vs. judgment
- outcome taxonomy to replace approach and landing, accident, and incident
- unstable approach as a symptom

Five sub-phases to replace approach and landing

Analysis of accident, incidents, and events suggests that the superficially convenient temporal grouping approach and landing in fact groups flight sub-phases with greatly differing characteristics.

The five sub-phases are listed below in reverse chronological order. The goal of each sub-phase is to position the aircraft so that the subsequent sub-phase can be successfully completed (except the last sub-phase, of course. See Table 2.).

Unstable approach thus invites us to look more closely at approach and landing, and to identify the variety of tasks and techniques that are encompassed. These five flight sub-phases will be shown to have value in flight analysis.

Severity-last event taxonomy

Conventional practice groups events first by the severity of the adverse outcome, and secondly by the kind of event. For example, accidents are the group of events most commonly analyzed for safety purposes, and after events are grouped into accidents, they are then sub-divided into kinds of accidents, such as approach and landing. This research suggests that more meaningful analysis may be possible if events are first sorted by kind of event (e.g., touchdown, using the five flight sub-phases), and secondarily by severity of outcome (excellent, acceptable, unacceptable, incident, accident).

There are perhaps several reasons why this kind of taxonomy has not already been implemented. First, it requires that significant bodies of non-accident data be available, including LOSA, anecdotal reports, and possibly quantitative FOQA results. Because the value of non-accident data is only slowly being recognized, and because (at least in the United States) of the reactive nature of public policy, there is insufficient motivation for meaningful incident and anecdotal data collection. GAIN seems limited in its potential because data is preselected and preprocessed before being shared, as opposed to all of the raw data.

Secondly, there seems to be a common misperception that incidents are precursors to accidents in the sense that if only one more event were present in an error chain, there would have been an accident, and therefore incidents are of less analytical value than accidents. However, incidents frequently had all the ingredients to be accidents, but a defense (in the sense of Reason's model) mitigated the event. In the case of unstable approaches, it seems likely that the pilot involvement factor hypothesized above may be a common "defense" against adverse consequences of unstable approaches.

Guidance vs. judgment

It is informative to look at what mechanized guidance (meaning both commands and raw data displayed in the cockpit) is available to the pilot during these five sub-phases.

Flight Sub-Phase	Guidance	Comments
Rollout and turnoff	Visual cues centerline and runway remaining, but no steering commands	Relies on pilot skill, judgment, and experience for steering and braking
Flare and touchdown	Visual cues only, neither position nor guidance data used during flare, except possibly radio altitude to start flare	Relies on pilot skill, judgment, and experience
Final visual alignment	Mostly visual cues, although flight instruments may be occasionally referenced or called out	Relies on pilot skill, judgment, and experience
Inside the FAF	Radio navigation technologies or radar vectors.	Full guidance available with flight director, autopilot available
Outside the FAF	Radio navigation technologies or radar vectors.	Full guidance available with flight director, autopilot available

This table makes clear that full guidance is not always available to the flight crew, and that sometimes skill, judgment, and experience are required. Other situations that require such judgment include slam-dunk approaches, circling approaches, managing descent on non-precision approaches, and visual approaches. Observe that these judgment situations are considered to be higher risk than guidance situations, such as ILS approaches.

(It is also worth noting that contemporary alerting systems, such as windshear, TCAS, and complete uninhibited alerts [at least on Boeing aircraft] are less prevalent the closer you get to the runway.)

Just as pilot error was an invitation to seek greater understanding, the phrase unstable approach thus invites us to observe and study the "guidance/judgment" dichotomy in the five landing flight sub-phases.

New outcome taxonomy

A new taxonomy is proposed to replace approach and landing, accident, and incident.

The proposed new taxonomy for landing outcomes is

New concept	Includes
First ground contact off the runway, IMC	CFIT, unstable approach
First ground contact off the runway, VMC	Visual illusions, windshear, unstable approach
Damaged on touchdown	Prolonged flare, visual illusions
Off the end of the runway	Runway overrun, loss of traction
Off the side of the runway	Runway excursion, loss of traction or visual cues

Recall the proposal that the severity of the outcome be secondary to the kind of untoward landing event. This is particularly apt when the common severity of these untoward landing outcomes is considered.

New concept	Common severity
First ground contact off the runway, IMC	100% fatalities, hull loss
First ground contact off the runway, VMC	Few fatalities, hull loss
Damaged on touchdown	Rare fatalities, major damage possible
Off the end of the runway	Rare fatalities, major damage possible
Off the side of the runway	Rare fatalities, minor damage

It is also appropriate to look at whether guidance or judgment is employed during these events.

New concept	Pilot flightpath information processing
First ground contact off the runway, IMC	Guidance
First ground contact off the runway, VMC	Judgment
Damaged on touchdown	Judgment
Off the end of the runway	Judgment
Off the side of the runway	Judgment

Detailed analysis of runway overrun occurrences was performed, including accidents, incidents, and events. Because this analysis included both accidents and non-accidents, it showed that the sole differentiator between an overrun event and an overrun accident was whether the airplane encountered an obstacle, such as an embankment, body of water, or obstruction. However, these obstacles, which are threats to operational safety, are typically not charted. The VP of one charting company told me that such data was not charted because overrun lengths could not be credited towards required landing distance.

His comment, in turn, brings up a second observation. Our profession commonly refers to "flight" safety and to "flight" simulators and to "flight" training. These linguistic idioms may reflect why ground operation safety, such as runway overrun obstructions, receives comparatively little safety and training emphasis.

Unstable approach thus invites us to look more closely runway overruns, and to make these observations for future study.

- Guidance vs. judgment in flight operations.
- That study of non-accident events shows the necessary ingredient for runway overrun accidents.
- That warning of such conditions is not necessarily available to flight crews.
- That, indeed, the common language of aviators and safety analysts (flight safety vs. "aircraft operational safety") biases people to minimize consideration of surface hazards and threats.

Unstable approach as a symptom

Don Bateman's excellent book *Flight into Terrain*, July, 1997, documents 280 CFIT (controlled flight into terrain) and CFTT (controlled flight toward terrain) events during approach and landing. A manual tabulation of those events shows that for those flights where data were adequate to make a determination, the majority of those flights that crossed the FAF failed to do so satisfactorily—they were too high or too low, for example.

This suggests at least these two points:

- What factor(s) were at work to cause the flight crews to inappropriately cross the FAF?
- For those flights in which the FAF was crossed inappropriately, labeling the rest of the approach as unstable contributes nothing to understanding what occurred. Worse, it diverts attention away from those unarticulated factors causing the failure to cross the FAF satisfactorily.

Conclusions

The term unstable approach, like its great grandfather pilot error, is a term worthy of retirement from the safety analyst's vocabulary. However, unstable approach, like pilot error before it, is an invitation to new ways of articulating and then addressing important safety issues.

While the new concepts suggested in this paper may or may not survive critical analysis by the flight safety community, their value is not to be measured by their survival, but by whether the flight safety community accepts their challenge to rethink unstable approach in the same way that pilot error was completely rethought, and whether this rethink ultimately reduces accident and incident rates.

Some of these new ways of analyzing flights for safety may include

- five sub-phases to replace "approach and landing."
- guidance vs. judgment analysis.
- severity-first taxonomy to replace accident and incident.
- unstable approach as a symptom of other phenomena.
- pilot involvement factor.

This paper also demonstrates the clear and obvious value of using data from all of flight operations to improve safety analysis and, ultimately, the safety record of the industry. Failure to expand safety analysis techniques and data collection to new sources of data will result in failure to substantially improve flight safety. As the old adage states, "If you always do what you always did, you'll always get what you always got." ◆

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Human Factors in Stressful Team Situations: A View from an Operational and Training Perspective

By Werner Naef, Air New Zealand

Werner Naef's *career has included being an airline and Air Force pilot in Switzerland and an instructor and fleet and training manager. He did postgraduate work in psychology. His studies and activities centered on training and leadership. He has been involved in international scientific associations/boards and a subject matter expert in human factors with national (Swiss CAA) and international (European JAA) regulatory bodies and with an airline industry body (Association of European Airlines). He was head of the research project "GIHREaviation" (Group Interaction in High Risk Environment/aviation) at the Daimler-Benz Foundation (1998-2004) and a lecturer at ETHZ (Swiss Federal Institute of Technology), at MBA/University Zurich, and at Engineering College at Rapperswil. From 2001 Naef was a consultant and partner in a training company involved in aviation-, rail-, public service-, and medicine-team-training. From August 2003, he has worked as a human factors investigator with Air New Zealand.*

Lessons learned—the SOP

Investigation reports into occurrences, incidents, and accidents—according to the established process—start with a narrative synopsis of what happened. This usually gets supported by factual information and data retrieved from different recording sources. The subsequent analysis then looks into causal factors and the dynamics involved and puts all into context explaining links between the different factors. The findings then give us a clue why the mishap did occur. Finally the recommended actions propose what has to be done in order to avoid another such occurrence and thus improve the overall situation.

Applying models from researchers like James Reason or Bob Helmreich in these process steps helps us to systematize and thus to better understand the dynamics of the events. We understand how defense layers have been penetrated, how well or how badly threats and errors were managed, resulting in risk levels that—according to our investigations—then mostly got out of control.

From here and in order to improve, the industry and the regulators implement changes in process, in hardware, and in skill management. We get regulations, procedures, checklists, organizational charts adapted or even newly designed. We get hardware improvements and we get skill training reinforced, adapted, or newly designed as well.

The shocker

Although we strive for continuous improvement on all fronts, again and again we are confronted with another mishap, occurrence or accident. A closer look reveals that in the majority of all cases it is the well-known "human element" that plays a crucial role and thus becomes a key issue for any future improvement.

In medicine they say that with further investments into medical **technology** only a tiny improvement can be achieved. But a systematic investment into "**human factors training**" would have a much greater effect and success. As a well-known research paper has disclosed, in the U.S. between 48-98,000 patients die annually due to medical malpractice in one way or another.

But the microscopic look also reveals that it is not just the technical skill training and the classical "human factors" training that is needed, but beyond yet another training domain needs our attention—the domain of the individual coping with stress, changing gear from functioning in the green range to functioning in the yellow or even in the red range. This paper tries to shed some light onto this domain.

It's not only that an adequate training in threat and error management is badly needed in terms of developing strategies "how we would proceed if…." We need to get a step closer to the individual's reactions under stress, learn and experience individually about our own stress patterns, develop, apply, and modify intervention techniques that can be applied on me and/or on other members of the team involved.

A closer look

Let's have a closer look into a few mishaps in different areas—the list could be endlessly continued:

09/11 investigation commission

Do you remember those words heard from tapes played recently to The National Commission on Terrorist Attacks Upon the United States (also known as the 9-11 Commission), when an FAA official asked some Defense Department official over the phone if they would launch fighters? The response was something like "….uhh….I don't know….uhhh…."

The response was a completely inadequate and failed "professionalism"—but no surprise here; these people had been thrown from business as usual straight into top stress levels without any warning. And that's how it happens.

Management blunder

Remember the collapse of Swissair in 2001? We saw a new CEO, former CFO of a huge corporation, taking command and asking insiders how it came that the former management—being involved in aviation and therefore being familiar with planning items like "alternate planning"—could have gone that far without considering any alternative course of action. Exactly the same person then, later and under increasing stress, did exactly the same—no consultation with any knowledgeable body, lonely wolf behavior, tunnel vision "how to save the company" without considering any alternative…. Stress symptoms in quantity.

Malpractice
Keen to perform, keen to fulfil expectations, keen to compensate for lack of resources—these were the drivers in a recent incident in a Swiss hospital where an 82-year-old patient had the wrong leg amputated and subsequently died. Under the magnifying glass of the investigation all sorts of stress symptoms surfaced.

Aviation
Remember the captain of a Middle-East airline—the aircraft on fire and returning under emergency with open fire and panic in the cabin? On the CVR he was heard singing during final approach—only a closer look revealed that he was citing verses from Koran. Under the extreme stress he reverted to old methods of dealing with stressful situations—completely inadequate with what was expected in the given situation. Stress symptoms in most pure form.

Politics
Remember when President Nixon got under fire about Watergate? Remember those pictures on TV of him exhibiting deep stress patterns?

Common issues in all these cases:
- All key players in these examples were under stress.
- All of them had excellent training and all of them had passed the respective exams—so they basically knew what and how to do it and they all had also quite some practical experience behind them.
- The moment they passed a certain stress level their behavior became narrow-minded, narrowly focussed, and one-sided. Tunnel vision took over.
- Behind their very individual stress-bound behavior (tunnel vision) was a specific driver that delivered the motivation to exactly act the way they did.
- This switch from "operating in the green range" to "operating in the yellow (or even red) range" diverted them from adequately analyzing and assessing situations but made them follow a different "dominant logic."
- The take over of such "dominant logic"—other than the logics we would expect under considerations done in a cognitive level thinking process—has to do with something else than with what we have learned, even what our experience would probably be.

By the way, isn't some of the behavior that we observe sometimes on busy highways (not our own, of course) close to what was just described above?

Backstage
Our behavior, our functioning has several sources. It is an outcome of several layers of our personality, of our skills, of our experience, of our mindset—and of the environment, of course. Taking up a model from psychology will help us understand some of this complex process. Let's have a closer look into how our "human computer," in terms of a functioning input-output system, works.

Interestingly we can model our "computer software" also into a part that might be called "system software" while another part might be called "application software." The "system software" is representing our "self" while the application software represents all that we have acquired in terms of skills. The self represents, e.g., value system, self appreciation, appreciation of others, attitude.

The difference to any technical computer: our personal, human built-in system software cannot be updated anymore once it has gone beyond a certain development stage.

Heredity, childhood experience, and other influences shape our basic personality structure that—at the age of around 7 years—has already reached final development stage, "system software version 3.0." It's with this system software version that we will handle all our future in terms of how we function—there is not much change to this basic structure anymore once we have passed our first 7 years of personality development. What we do change—and we do it at large—is the implementation of all kinds of application software, software we need to run an adequate professional life, to do what we like to do in our spare time etc. But all this takes place on the foundation of that very specific, very individual system software version 3.0.

If we now take a closer look at the phenomena representing specific individual behaviors—specific individual system software—we observe that we have **different modes of functioning** indeed.

Perception
Some perceive the world through thoughts; to do so they need facts and figures, and the ruling principle applied to deal with the world is the principle of logic. Others perceive the world through opinions; to do so they need to trust others, and the ruling principle applied to deal with the world is the principle of value system. Others perceive the world through emotions; to do so they need relationship with others, and the ruling principle applied to deal with the world is the principle of compassion. And so on. Statistically there are some six such different ways how to perceive the world.

Communication
Some communicate in a directive mode ("go get me...," "tell me...") while others do it in a more nutritive way ("so nice to be here...."); there are several ways how to do it.

Psychological needs
Some strife for recognition of work and for time structure, others look for recognition of person and for sensory, others strife for action, other for solitude.... There are also several different specific psychological needs that can typically be found in specific personality structures.

Character strengths
Some are adaptive, persuasive, and charming; others are spontaneous, creative, and playful. Others are dedicated, observant, and conscientious. There are a range of character strengths that differs among various types of personalities.

Stress patterns
For us the most important differentiation among various types of personality is the specific reactions of the individual to stress. These stress patterns relate to very early experience in our own life—whether we trust ourselves or not, whether we trust others or not. We distinguish between light stress and heavy stress. The latter is characterized by stress that really has a heavy impact on us—we "really get wet." It's stress that might have to do with

fundamental threat to our life, our existence, or our self-esteem or with the lives of our loved ones.

Level 1 to level 3

Stress patterns have different intensities. A light stress (level 1) might arise several times a day—anytime we have to do something that does not just satisfy basic needs or means fun to us. We then typically react according to a specific driver—this one linked to the specific typology we represent: "be perfect," "be nice," or "be strong" to mention some. If the stress increases to the next level, we then are submitted to attacking others, blaming others, or becoming a drooper—taking up the role of the victim.

And

It is not only such "inside-the-system" stuff that makes us different—specific types differ in choosing words, setting tones, gestures, postures, and facial expressions.

Back to start

Looking into occurrences—whether in medicine, in aviation, in business management, in crises management—in our investigations we come across stress-influenced behavior of key persons again and again.

Wouldn't it be wise to have such key persons, decision-makers, and opinion leaders to know more about their stress patterns? How they develop, how they start to pop up, how the influence their rationale behavior? How to counteract and get the stress level down again?

Wouldn't it be wise to have others know about such stress phenomena and have those being able to adequately intervene once a key player has been thrown into stress? Allow for stress-reducing intervention instead of stress increasing confrontation?

Such insight into one's own stress patterns can be achieved. The mastering of a stress-reducing intervention technique can be achieved. The knowledge and the methodology are available[1].

But

In technology-focused fields like aviation any methodology to tackle with findings of investigations is traditionally tailored along technology methodology and is less human-process-focused. And in exactly this domain—the area of the human factors—we are subjected to occurrences again and again. The time has come to do a step forward!

Proposal

- Have relevant people to know, to experience about not only their specific business area, but also about their specific mode of operation once they get under stress.
- Have such training being integrated beyond transfer of "human factors knowledge" through tutorials or CD-ROMs.
- Have teams being trained to cope with stress symptoms typical for the individuals of that team.

Conclusion

In the complex man-machine-environment interface, the machine improves constantly—heaps of money getting involved. The environment has to be accepted as a random variable. But "man" is among the most complex of the components involved. And this component gets added to the system as newcomers again and again. And it constantly shows up as a major causal factor in mishaps in any area concerned.

Do we really take adequately into consideration the ability of the "man" component to deal with his/her built-in, own variability?

Process improvement and safety enhancement should be achieved by focusing more onto the functionality of the man-component under stress. ◆

Endnotes

[1]Kahler, Taibi. *The Mastery of Management.* Kahler Communications, Inc., Little Rock, Arkansas, 1988. www.kahlercom.com.

Maintaining an Aircraft Accident Investigation Capability in a Small Military Aviation Organization

By Wing Commander Peter Wood, Directorate of Flying Safety, Australian Defense Force

Wing Commander Peter Wood joined the RAAF in 1980 and completed flying tours on C130H and Falcon 900 aircraft, accumulating 6,000 flying hours. His final flying tour was as commanding officer of 34 Squadron, a position he left on June 29, 2001, to take up his post as deputy DFS. As deputy DFS, he has completed the United States Navy Aviation Safety Officer Course and the SCSI Investigation Management Course. His duties at DFS-ADF have included supervising 16 aircraft accident and incident investigations, reviewing accident reports, and presenting to ADF aviation audiences on accident investigations.

Introduction

The Directorate of Flying Safety—Australian Defense Force (DFS-ADF) is the agency responsible for investigating all ADF aircraft accidents worldwide during both peace and war, and assisting with foreign military accidents in Australian territory. DFS-ADF is the only agency in the ADF with an aircraft accident investigation capability, and as such DFS-ADF is required to maintain the capability to, in the first instance, independently respond to aircraft accidents. This accident investigation capability must be able to respond within 6 hours (a self-imposed ADF limit to ensure minimum loss of perishable evidence) to accidents involving crewed aircraft and UAVs from the three ADF services (24 aircraft types), anywhere those platforms may be operating around the world, in both peace and conflict. ADF aircraft types include fast jet strike/fighters; jet- and piston-engined trainers; small- and medium-lift helicopters; small, medium, and large transport and tanker aircraft; and maritime patrol aircraft.

DFS-ADF is a small (depending on where you are from) organization of 21 personnel, including a director, deputy director, deputy director-education and training, 12 desk officers (air safety investigators [ASIs]), with publishing, safety product development, database, and administrative support staff. A structural diagram of DFS-ADF is at Figure 1.

Aircraft accident investigation is not the only aspect of DFS-ADF's charter. In addition, DFS-ADF is charged with aviation safety policy development, accident prevention, and aviation safety promotion, education, and training across the ADF. Our main aim is to be proactive in promoting aviation safety and assisting ADF aviators and commanders in enhancing our aviation safety culture and command commitment to aviation safety. DFS-ADF ASIs must, therefore, be available to support both accident prevention and aviation safety promotion activities as well as being prepared to investigate aircraft accidents. DFS-ADF aims to devote as much time as possible to proactive safety activities, while accepting that maintenance of an aircraft accident investigation capability is an essential requirement.

DFS-ADF is required to maintain accident investigation readiness against a recent history of very few major (fatal) aircraft accidents in ADF aviation. At the time of writing, the last fatal accident in Royal Australian Air Force (RAAF) aviation was in April 1999, the last in Australian Army aviation in June 1996, and the last in Royal Australian Navy aviation in December 1995. Despite this apparently safe record, on average DFS-ADF has conducted one accident (non-fatal) and six "serious incident" investigations for each of the past 3 years. The ADF's major aircraft accident history is depicted in Figure 2, page 160, where the dark gray columns indicate number of aircraft lost per year since 1965, and the light gray columns indicate number of personnel lost each year beginning in 1990, up until the loss of Black Hawk 216 on Feb. 12, 2004.

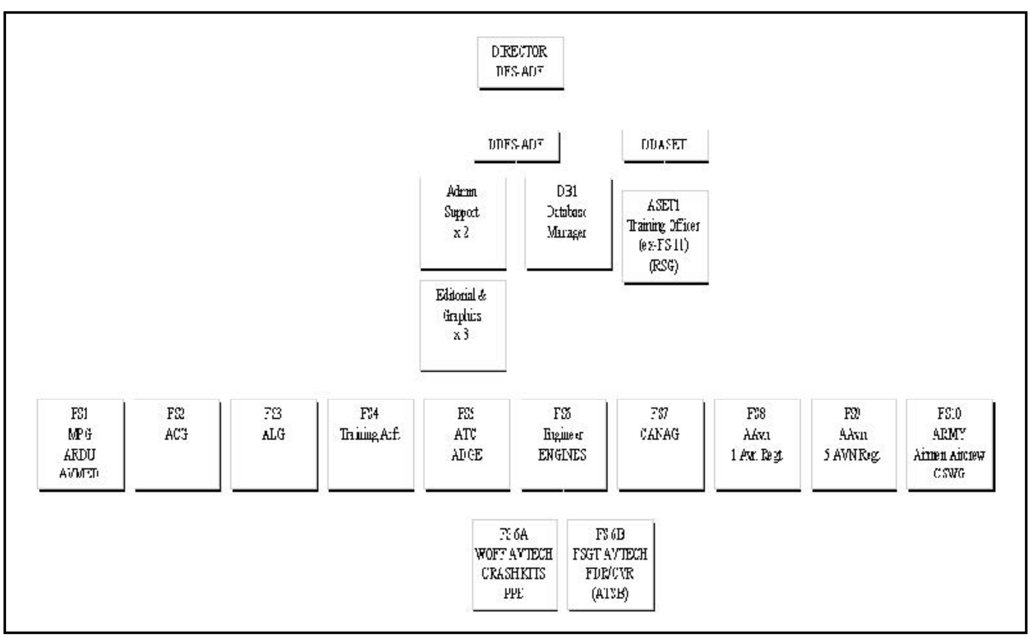


Figure 1. DFS-ADF structural organization.

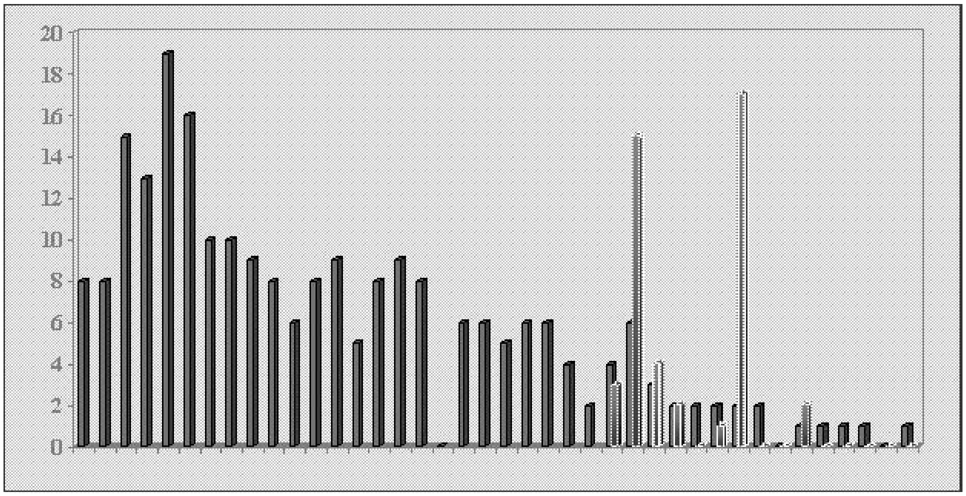


Figure 2. Australian Defense Force Aircraft accident history.

ASI training

As many readers would know, training ASIs to conduct major aircraft accident investigations takes considerable education, training, exposure and experience. With only a small number of ASIs requiring training annually, the ADF has focused on providing trained ASIs to support our aviation activities rather than developing and conducting world standard ASI training in-house. Defense ASI training is regularly available only overseas, mainly in the United States and the United Kingdom. At senior policy level, the ADF decided some time ago that maintenance of a "world class" aircraft accident investigation capability was essential, and thus all DFS-ADF ASIs were to be given the best ASI training available. This is an expensive requirement, both in terms of money and human resources, yet one that continues to be fully resourced by ADF leadership. All DFS-ADF ASIs complete a recognized ASI course, such as the United States Navy Aviation Safety Officer Course, the Cranfield Aircraft Accident Investigation Course, or the Southern California Safety Institute Aircraft Accident Investigation Certificate Course. Senior DFS staff also complete a Major Accident Investigation Management Course such as the SCSI Investigation Management Course.

Having well-trained ASIs is one thing, maintaining their skills and ensuring the ASIs are ready to rapidly respond to an accident is entirely another.

Maintaining ASI skills without recent accidents

Not having had a fatal accident in ADF aviation since 1999, and having a "posting' rotation of DFS-ADF ASIs on average every 3 years means that as of early 2004, **no DFS staff had ever attended or participated in a fatal ADF aircraft accident investigation**. While this is a wonderful problem to have (and we hope to still have this problem forever!) in terms of maintenance of ASI skill sets and experience, this is nevertheless a problem. To maintain skills and experience levels, DFS-ADF and/or the Navy's Fleet Aviation Safety Cell (FASC) investigates selected serious incidents. For example, DFS-ADF conducted a full investigation into a near mid-air collision between two training aircraft in 2001, treating the investigation and the resultant recommendations as if the aircraft had in fact collided. In early 2004, DFS-ADF completed two investigations into two serious incidents involving C130 maintenance activities. Reports for such incident investigations are completed to the same structure, standard, and depth as accident investigations, both to maintain ASI Aircraft Accident Investigation Team (AAIT) report writing skills and ensure the maximum possible organizational learning outcomes. Recommendations are made in the same manner and to the same command levels as if an accident had occurred rather than a serious incident.

In addition to investigating ADF incidents, an inclusion in the DFS-ADF/Australian Transport Safety Bureau (ATSB) MOU allows for DFS-ADF ASIs to act as observers on ATSB accident investigations. This allows DFS-ADF ASIs to observe and learn from ATSB investigation processes, and to maintain skills with using DFS-ADF accident investigation personal protective equipment (PPE) and kit. Since 2001, all DFS-ADF ASIs have participated in at least one ATSB investigation as an observer. DFS-ADF ASIs participated in the investigation into the combined East Timor government/ATSB investigation into the IL-76 acci-

Figure 3. IL-76 accident East Timor, Jan. 31, 2003.

dent at Baucau, East Timor, on Jan. 31, 2003. Participation in this investigation exposed the DFS-ADF ASIs involved to a large aircraft accident site with minimal local support and infrastructure, very demanding and austere physical conditions, international investigation liaison requirements, and major accident report writing.

Maintaining a short-notice accident response

As with most aircraft accident investigation agencies, DFS-ADF maintains a go-team. However, given DFS-ADF's small size and the cost of ASI training, in effect the entire in-uniform body of DFS-ADF is the go-team. There is no roster as such all desk officers (ASIs), once trained, are on constant 6-hour notice to move for the duration of their tenure at DFS-ADF. They are supported by in-house administrative staff who are able to support an AAIT in the field (other than in a war zone) with administration, finances, and evidence registers. When an accident occurs, all available DFS-ADF members meet as soon as possible, usually within 1 hour, in a designated AAIT room in Canberra to determine the size of the responding AAIT. Those members on deployment or travel elsewhere will be contacted ASAP and placed on immediate notice to respond in case they are attached to the AAIT. In one celebrated (at least in DFS-ADF) case, an ADF F-111 accident in Malaysia in 1999, one of the AAIT members was required to respond from Wichita Falls, U.S., where he had just arrived for jet engine mishap investigation training with the USAF.

Maintenance of such a blanket short-notice accident response requires significant planning and preparation. As DFS-ADF ASIs are also responsible for proactive aviation safety management system (ASMS) support, they spend up to 3 months of the year away from Canberra on aviation safety promotion activities. To meet the "respond from anywhere" requirement, all DFS-ADF ASIs maintain fully packed and stocked personal "crash bags" containing all personal clothing, military clothing, cool/cold weather clothing, PPE, and accident investigation equipment required to support any ADF aircraft accident **anywhere**. The personal crash bags are stocked to allow for the first 2 days of on-site investigation in any climactic conditions where ADF aircraft may operate. This includes PPE for accident sites in desert, jungle or extreme cold weather conditions. If "away base" ASIs are attached to the AAIT, their personal crash bag will be deployed for them by "at home" members of the AAIT.

Being a military accident investigation agency, DFS-ADF staff members are also on call to investigate aircraft accidents that may occur in conflict. In 2003 this meant being ready to investigate accidents that may have occurred during the ADF involvement in the operations in and around Iraq. This required all DFS-ADF ASIs to be fully trained and equipped in biological and chemical warfare survival, among other requirements. Again, higher command commitment to DFS-ADF's investigative capability meant that the considerable preparations and resource costs necessary to meet this requirement were provided. Additionally, plans were initiated with the Defense Science and Technology Organization (DSTO) and the ATSB to more fully support remaining in Australia DFS-ADF staff, should DFS-ADF ASIs be investigating an accident in the combat zone when another ADF aviation accident occurred elsewhere. A similar case was experienced when DFS-ADF had three ASIs on the IL-76 accident site in East Timor and a RAAF Caribou subsequently ran off a short strip in the Papua, New Guinea, highlands in early February 2003 (Figure 3).

In addition to ASI personal equipment, DFS-ADF maintains two complete accident crash kits with all the necessary investigation equipment for a DFS-ADF AAIT to be self-sufficient in the field. Having two kits facilitates responding to an accident with an AAIT already deployed, and the benefit of having two complete crash kits was evident for the IL-76 and Caribou accidents described above. The identical kits each include satellite communications, lap tops (with evidence register databases), digital still and video cameras, laser range finders, digital interview recorders, differential GPS units, and other equipment. Once again, higher command commitment to DFS-ADF's investigative capability has meant that the funds requested to support the crash kits have always been provided.

Having the best accident investigation equipment is of no value unless ASIs know how to use it. Accordingly, when ASIs arrive at DFS-ADF, they complete a structured induction training course, which includes instruction and practical exercises using all equipment. All ASIs are trained on all equipment to enable the maximum flexibility in AAIT composition and accident response. ASIs are encouraged to maintain their skills on all equipment, and are encouraged to take the equipment home to practice with it.

DFS-ADF AAIT composition

A DFS-ADF AAIT will consist of anywhere from three to 12 members depending on the scale and severity of the accident in question. In deciding the composition of the AAIT, DFS-ADF management and staff consider the scale and severity of the accident, the aircraft type or types involved, and the areas of expertise required. As a minimum, a DFS-ADF AAIT will include the following DFS-ADF personnel:

- A senior investigator, usually the deputy director, who has completed Accident Investigation Management training, ASI training, and media awareness/liaison training. The senior investigator's role is to provide higher level liaison with local command and support agencies, the media, local service providers, next of kin, and higher command in Canberra. This higher level liaison is provided to allow the OIC of the AAIT to concentrate purely on AAIT activities.
- An OIC of the AAIT, who has completed ASI training and has been a member of at least one previous ADF AAIT.
- DFS-ADF operations (aircrew) ASIs as required to support the OIC.
- The DFS-ADF engineering ASI.
- The DFS-ADF ASI responsible for CVR/FDR download and analysis.
- The DFS-ADF ASI responsible for aircraft accident site mapping, photography, registering of evidence, security, and OH&S issues.

In addition to the DFS-ADF ASI "core," subject matter expertise from other agencies will be sought to support the AAIT as required by the accident scenario. This will generally always include human factors, aviation medicine and DSTO site mapping, and component/fluid analysis support, and may include operations and engineering subject matter experts from the wider ADF familiar with the aircraft type(s) involved in the accident.

As the ADF (in recent history) has had so few major accidents, DFS-ADF management will also consider attaching additional ASIs to the AAIT for experience and currency purposes. For example,

Figure 4. ADF Black Hawk 216 accident, Feb. 12 2004.

in the investigation into the ADF Black Hawk accident on Feb. 12, 2004 (Figure 4), the DFS-ADF Navy ASI was included in the team to provide additional rotary wing expertise to the investigation but also to gain on-site and report writing experience.

Setting up relationships with external agencies

Given DFS-ADF's size and complement, DFS-ADF lacks the resources to independently investigate major aircraft accidents. As mentioned above, assistance may be sought from other agencies, including DSTO, aviation medicine and human factors experts from the wider ADF, the ATSB, and other agencies as required. To facilitate such assistance, DFS-ADF has MOUs in place with DSTO and the ATSB on the provision of support to AAITs. The MOUs are reviewed on a regular basis as lessons are learned and the organizations evolve. DFS-ADF staff visit DSTO at least once a year to maintain the working relationship, and ATSB and DFS-ADF management and staff regularly liaise on a variety of issues.

Enabling rapid report writing

For fatal aircraft accidents, the Australian military has a "dual process" for the subsequent investigation. An AAIT conducts an air safety investigation and reports findings of fact to a subsequent Board of Inquiry, which is a legal process with the authority to assign blame and punishment. For accidents with no fatalities, usually only an AAIT is conducted. Regardless, the AAIT will be working under significant time pressure. Final reports are required within approximately 50 days of the accident if a BOI is appointed, and within 90 days if no BOI is appointed. To complete reports within this timeframe, the following processes are in place:

- all DFS AAIT reports and incident investigation reports are completed in the same structure and format (IAW ICAO standards);
- all DFS accident investigations follow the same process from commencement to completion;
- when assigned to an AAIT, this becomes the ASIs primary, and if necessarily only, duty;
- if additional report writing resources are required to facilitate on-time completion, such as secretarial and stenographic support, then these are obtained;
- time is set aside for a "peer review" of the AAIT report by non-involved DFS-ADF ASIs before management review; and
- input from senior DFS staff for report review and other requirements are preplanned and "blocked" in ahead of time.

Communicating report recommendations

In the ADF construct, if no BOI is appointed, recommendations from accident investigations are made by the AAIT accident investigation Appointing Authority (AA). In effect, the recommendations form the basis for DFS-ADF's suggested organizational response from the AA to the accident. The actual response to the accident is the responsibility of the AA: DFS-ADF's role is to ensure the AA understands the evidence, logic, and intent underpinning all the findings and recommendations. The AA has the right to accept, reject, or modify any or all of the report recommendations as he or she sees fit. To facilitate the report acceptance process, for non-fatal accidents, the following process takes place:

- the AAIT provides the AA with 2 day, 7 day, and 14 day progress reports;
- a 30-day factual report is submitted to the AA outlining all factual information obtained until that point;
- the final AAIT report is provided to the AA within 90 days;
- the AAIT OIC provides the AA and senior staff with a face-to-face brief to explain the logic, intent, and reasoning behind the report findings and recommendations;
- the report is considered by the AA and his/her staff for up to 60 days, with DFS-ADF staff providing input to the review process as required/requested by the AA;
- after due consideration, the AA will compile an implementation plan for actioning all the accepted and modified recommendations;
- all rejected recommendations are placed on file and recorded as such; and
- for major accidents, the AA will advise the relevant service chief of his/her response to the AAIT report, the reasons for modifying or rejecting recommendations, and the details of the implementation plan.

For accidents where a BOI is appointed, the AAIT will follow the same process until submission of a report within 50 days. The report will contain no recommendations, and after the AAIT has tabled its report and given evidence to the BOI, DFS-ADF will take no further part in the process until the BOI recommendations are accepted, rejected, or modified by the AA. While not pertinent to the actual investigation, once the BOI has been accepted by the AA and agreed by the relevant chief of service, DFS-ADF assists in the development of a Ministerial Submission for release on information to the next of kin and the public.

Closing out recommendations

Completion of the implementation plan and actioning all recommendations following an accident is a command responsibility. To ensure all recommendations are completed, DFS-ADF plays a monitoring and reviewing role, receiving regular updates, usually quarterly, on the status of recommendation completion. All recommendations are entered into a DFS-ADF database and their current status updated as information is received by the relevant AAs. In this way, all recommendations are tracked to completion to ensure the report recommendation process is closed-loop, and no recommendations "slip through the cracks." In addition, through the database, a permanent record of the recommendations and their closure is maintained.

Using accident reports for aviation safety education

Accident investigations and their resultant report and recommendations are of no value unless they result in the prevention of future accidents and organizational learning. To facilitate these aims, as well as a closed-loop recommendation tracking process, there must be a process of communicating the details of accidents, the actions taken, and the lessons learned to the entire aviation community. To this end, after an accident investigation has been completed and the implementation plan formulated, a deidentified copy of the report is circulated to the relevant areas. In addition, an Accident Review, which is a short (usually up to eight pages) document containing the basic accident factual information, findings, and recommendations, is produced and distributed to all ADF aviation units.

After the accident investigation report is completed, DFS-ADF will prepare a PowerPoint presentation containing the accident factual information, findings, and recommendations, and relevant and releasable imagery, and deliver the presentation to relevant areas of ADF aviation as soon as practicable. When available, the presentation will be delivered to the general ADF aviation community through such forums as safety days, commander's conferences, and flying supervisor's courses.

Learning accident investigation lessons

Given the infrequency of DFS-ADF major accident investigations, it is essential to ensure that lessons learned on individual accident investigations are captured and maintained as corporate knowledge. To this end, after an accident investigation is completed, a "lessons learned" workshop is conducted to review the lessons and develop concomitant actions to ensure the lessons are captured. This may require amendments to policy, processes and/or DFS-ADF instructions, or the acquisition of new/improved accident investigation support equipment.

Summary

DFS-ADF is a small organization charged with maintaining the capability to respond within six hours to investigate any accidents involving any ADF aviation platform anywhere in the world. DFS-ADF is required to maintain this capability against a background of no fatal ADF aviation accidents since 1999 and on average one non-fatal accident per year. To maintain this capability, DFS-ADF processes are built on the following tenets:

- All DFS-ADF ASIs are given the best ASI training available.
- To maintain ASI skills given the paucity of major ADF aviation accidents, DFS-ADF:

—investigates selected ADF aviation serious incidents, making findings, and formulating recommendations as if an accident has occurred;

—in agreement with the ATSB, provides DFS-ADF ASIs as observers on civil aircraft accidents; and

—where available, attaches additional ASIs to actual ADF aircraft accident investigations for experience and currency purposes.

- A short-notice accident response is maintained by keeping up-to-date personal and duplicated equipment crash kits supplied with up-to-date investigative tools and equipment. All DFS-ADF ASIs are trained on all equipment and encouraged to maintain personal currency.
- Proactive relationships are established and maintained with internal Defense and external agencies to facilitate support for accident investigations.
- Processes and resources are in place to support rapid AAIT report writing.
- Recommendations from accident investigation reports are formally tracked to completion to ensure organizational learning.
- Briefings, PowerPoint presentations, and Accident Reviews are used to educate the ADF aviation community regarding ADF aircraft accidents to ensure organizational learning.

A lessons learned workshop is conducted after all accident investigations to review the lessons and develop concomitant actions to ensure the lessons are captured.

DFS-ADF's main aim is to be proactive in promoting and assisting Defense aviators and commanders in enhancing the ADF's aviation safety culture and commitment to aviation safety. However, through these tenets, despite our recent excellent safety record, we are permanently ready to conduct a professional military aircraft accident investigation, which can stand NOK, Ministerial, public, media, and peer scrutiny, and result in the best organizational learning and safety outcomes. ◆

The Use of Full Flight Simulators For Accident Investigation

By Robin Tydeman, Air Accidents Investigation Branch, U.K.

Robin Tydeman *spent 20 years as a pilot in the RAF, primarily as a flying instructor on large aircraft. After attending the Empire Test Pilot School in 1985, he spent his final 3 years in the RAF evaluating large aircraft in the air-to-air refueling role. He then flew as a commercial pilot on Boeing 737 aircraft before moving to Cranfield University where he instructed on flight test techniques. In 1994, he moved into flight simulation and was involved in the development of the first Boeing 777 simulators. He joined the AAIB in 1996 and has since been involved in more than 50 investigations. He maintains his ATPL and is current on both the Boeing 757 and 767.*

Abstract

Flight simulation has become an indispensable tool for training within aviation. In little more than 50 years, it has established a reputation for high levels of fidelity and the ability to provide an environment in which the effective training of aircrew can be conducted economically and safely. Flight simulation has also proven itself to be invaluable to the aircraft accident investigator. However, with the onset of digitally controlled simulators and compelling visual systems, it is easy to become beguiled by the supposed "fidelity." Any dependency on simulation will invite legitimate questions about the validity of any subsequent conclusions, and may cast doubts on the technical veracity of the investigation as a whole. This paper suggests that the use of flight simulation in accident investigation should be approached with care, acknowledging the fact that simulators have limitations.

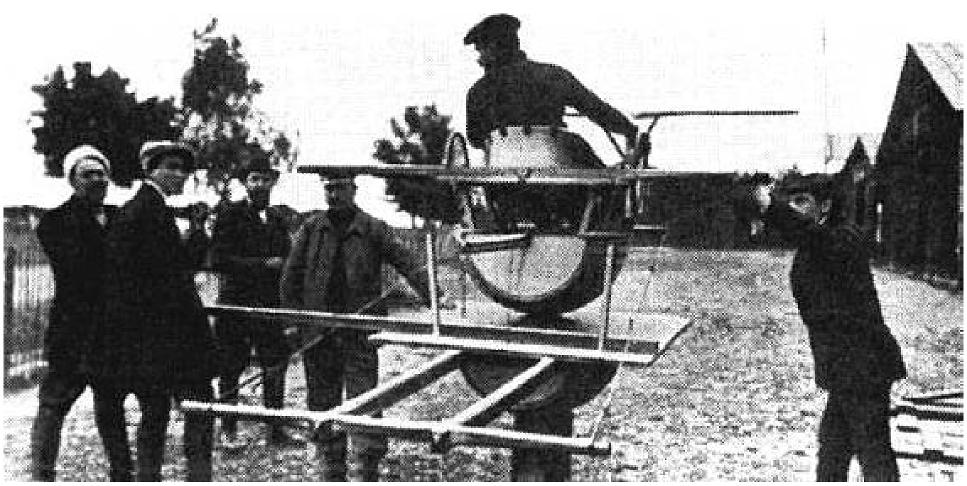
The traditional use of flight simulators in accident investigation is to use the digital data from the flight data recorder (FDR) to program the simulator, usually a fixed-base engineering simulator, which will then replicate the flight of the aircraft. Data from the air traffic control radar, TCAS units, and the cockpit voice recorder can also be incorporated. Then, surely, the investigator has the complete picture! But how accurately does the simulator represent the aircraft and the ground and air environment in which it operates? While many flight simulators have a debrief facility that allows simulator data to be replayed for training purposes, a full flight simulator was simply not designed to accept data from the FDR; errors, particularly with systems integration, will occur. A malfunction of an aircraft system is often the precursor to an accident investigation; but how accurately are these malfunctions presented in the flight simulator? Furthermore, since pilots involved in accidents usually exhibit the symptoms of a high workload, how can the simulator affect our understanding of the workload experienced by the pilot dealing with a problem?

In order to answer these questions, I will start by considering the development of full-flight simulators in order to identify those areas where the simulation can be expected to represent accurately the aircraft in flight and on the ground. The regulatory framework within which flight simulators operate will be outlined and will include the problems of data acquisition for malfunctions. The basic concepts of simulator modeling and its limitations will then be explained. Throughout the paper, examples will be given of the potential for the misuse of flight simulators in accident investigation.

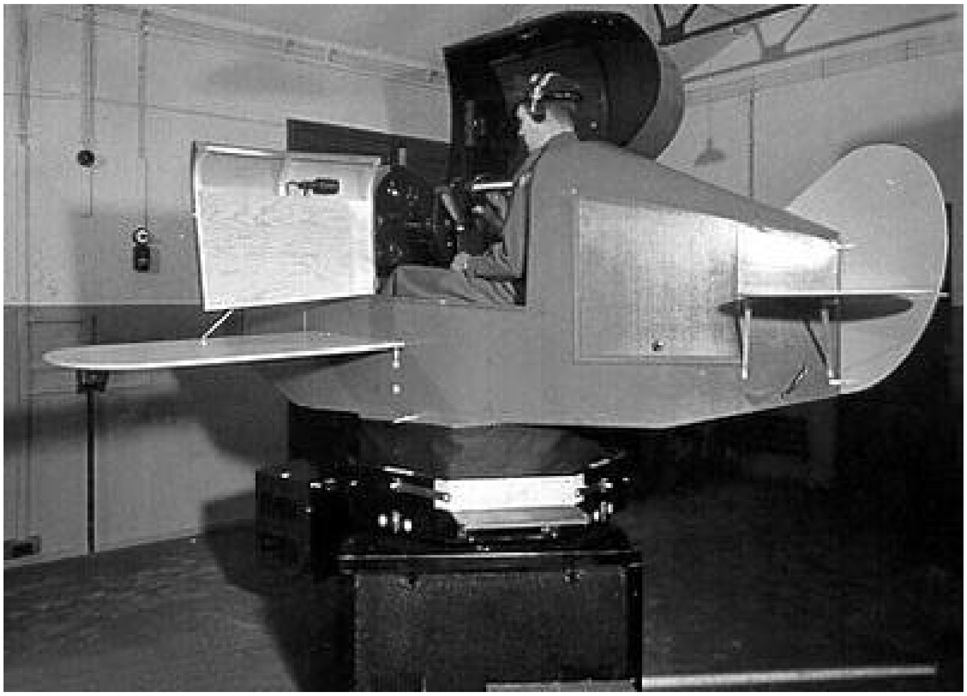
The development of full flight simulators

In 1928, Edwin C. Link left his father's organ building business to begin work on a "pilot trainer." He envisioned a device that would allow pilots to take their preliminary flight instruction while remaining safely on the ground. With his background in organ building, he utilized air pump valves and bellows to make his trainer move in response to its controls. Introduced in 1934, it was later used for instrument flight training for virtually all North American pilots during World War II, and was still in widespread use in the mid 60s. With a rudimentary motion system and no visuals, it certainly had no pretensions to replicate any known aircraft; its sole purpose was to allow the pilot to learn to fly, and then practice, instrument procedures.

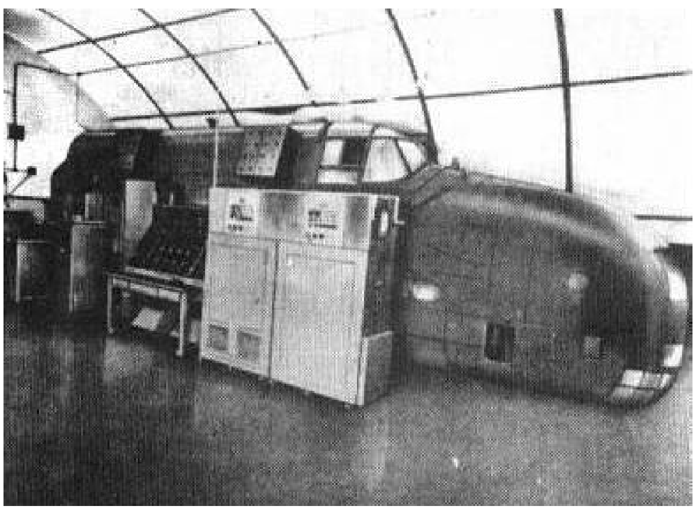
In the early 50s, with the advent of more complicated aircraft, the actual cockpit itself was used as a simulator. Taken from the production line and placed in the training center, it was clearly an accurate representation of the cockpit. The aerodynamic model was rudimentary, driving little more than the flight instruments in response to flight control inputs, and there was no motion or visual system; however, it



Early flight simulator circa 1910.



Link flight trainer.



Silloth trainer, 1945.

provided valuable training and laid the foundations for further simulator developments. At this stage the training conducted in the simulator also expanded to include normal and emergency procedures.

Motion system

In an attempt to increase the realism of simulator training, motion was introduced. There has subsequently been a great deal of debate within the flight simulator industry on the need for motion, and many accident investigations have utilized engineering simulators that invariably have no motion systems. Is motion necessary in either case? To attempt to answer this question, the RAND Corporation conducted a study in 1986 which evaluated U.S. pilots flying the C17 flight simulator and showed that their performance was greatly enhanced through the use of a motion system. This should not be surprising; in the real world acceleration precedes displacement and, since our motion sensors detect acceleration very quickly, cues of motion precede visual displacement. Research has indicated that the brain senses acceleration first (sec/100) whereas visual displacement cues follow (sec/10). When flying an aircraft, the pilot has three main input sources of information

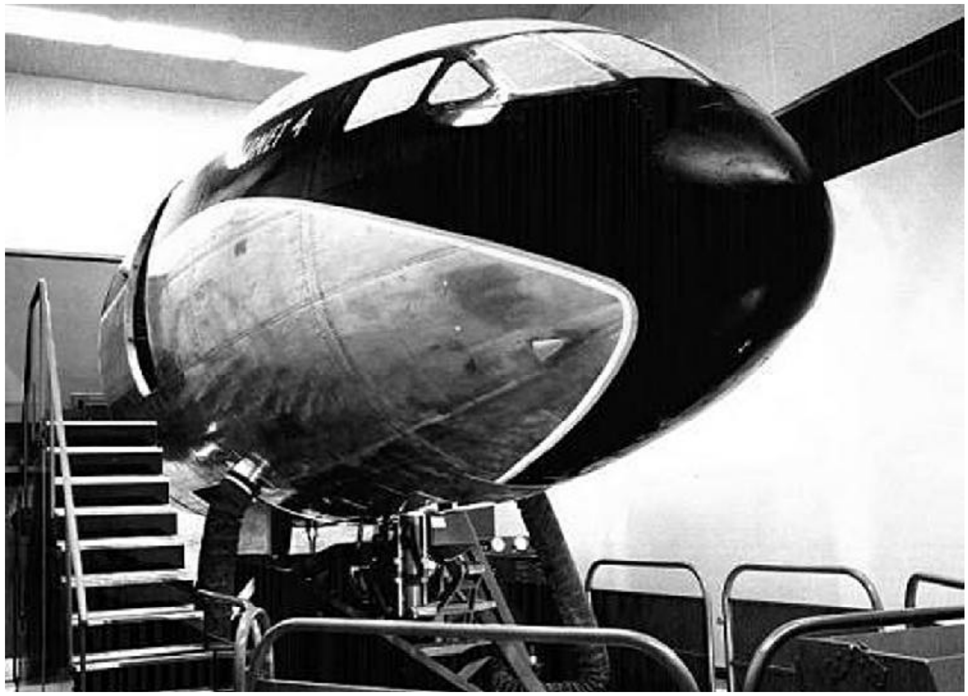
a. The eyes—these provide his main input. The information from the instruments tells him his attitude, position in a space, and, to a lesser extent, the rate of change of these variables.

b. The limbs, which tell him the position of the aircraft controls together with the force that he is exerting on them.

c. The vestibular system, which tells him when he is subjected to acceleration and, importantly, also stabilizes his eyes.

Let us now consider the pilot in a flight simulator equipped with a good quality, low-latency motion platform and consider a sudden disturbance in flight. The pilot's vestibular system immediately alerts him to the disturbance, because it responds rapidly to the acceleration cues; and although this information may not tell him the exact nature of the disturbance, he is warned to monitor the instruments to detect a change. Since the instruments generally indicate the attitude or position of the simulator, the second integral of acceleration, there will be a delay following the acceleration before the instruments show the result of the disturbance. However, the pilot will now be primed to notice this change in indication as soon as it is discernible and can apply an immediate correction by means of the aircraft controls. This brings another feedback loop into operation that tells the pilot how much he has moved the controls together with the force resisting the movement. The acceleration generated by these controls is again sensed by the pilot's vestibular system, and he is aware that the correction is taking effect even though the instrument may still be indicating the results from the initial disturbance. The pilot is thus able to predict what is going to happen to the simulator by means of these feedback loops and thereby utilize identical strategies to those used in the aircraft. It should, therefore, be clear that any meaningful assessment of pilot behavior in an investigation should *only* be conducted on a simulator with a high-fidelity motion system. The civil regulations have recognized the importance of motion, and only a device with a motion platform is called a full-flight simulator. Current regulations require a maximum time of 150 milliseconds from the initial input to the last effect (normally visual), but this maximum time may well be reduced in the future to reflect the increasing capability of motion systems.

Modern motion platforms are usually driven by six hydraulic actuators; by sending appropriate commands to all six actuators simultaneously, motion in any of the aircraft six degrees of freedom can be obtained. But even the best motion systems have their limitations. This is not surprising when we consider that we are asking these six actuators, each about 5 feet in length, to provide all of the typical motion and vibrations cues experienced throughout the flight envelope of the aircraft, but while remaining firmly anchored to the ground. It has not been possible, so far, to generate prolonged "g" and thus prolonged feedback cues to crew; this means, for instance, that during a tightening turn onto a final approach there will be no increase in stick force, an important cue to the pilot. Some simulators have attempted to introduce this cue but with varying degrees of success. Rejected takeoffs are an obvious area where there is simply not enough motion available to generate the correct cues. However, perhaps one of the most significant problems is that motion is not an exact science and is still correctly regarded as a "black art." There are always compromises to be made. One operator may decide that he requires a strong motion cue to simulate heavy braking and is prepared to accept the subsequent false cue provided by the high level of washout; another operator may prefer weaker motion cues but with no false cues. The only way to prevent any false cues being generated is to tune the system down until you cannot really feel anything. In addition, special effects are often exaggerated in order to conceal the lack of motion. How is the accident investigator to make sense of this?



Comet IV flight simulator with pitch motion system, 1958.

Visual system

The next step toward increased realism was to incorporate a visual system. Early systems used a model board, but computer-generated displays soon became available. Initially these were only capable of providing night/dusk scenes through a monitor display system with a limited field of view. Modern systems provide night/dusk/daylight scenes with realistic weather simulations and a horizontal field of view of 240° and 60° in the vertical. Of all the elements that comprise the modern flight simulator, perhaps the most immediately impressive is the visual system. With the increased capability and availability of satellite imaging, together with the dramatic increase in economically priced computing power, the visual image is seductively authentic. Earlier visual scenes had a somewhat sterile appearance. Thus an airport would consist of a runway, with its attendant lighting, surrounded by grass and some stereotypical buildings. With little "depth" in the scene and little to no textural feedback, there were poor visual cues for the pilot during precise events such as the landing flare. Modern visual systems incorporate high levels of detail in areas such as the airport, but the dilemma facing the visual modeler is that the volume of data representing this scene is almost infinite, yet the image generator will only accept a finite number of polygons (shapes) and textures. Texture is used like digital wallpaper and brings a lifelike quality to otherwise sterile scenes without increasing the polygon count. It is typically used on flat surfaces such as grass, buildings, etc., but is also the technique used to display airport signs, people, and vehicles. Importantly, it is also used on runway surfaces and, while it may appear to be realistic from a distance, the texture surface produces an indefinite landing surface with little detail apparent during the final 30 feet prior to touchdown. Once again the pilot is deprived of realistic visual cues during the landing. There are other facets of current visual systems that do not assist the pilot during the flare maneuver, such as restricted peripheral field of view on the older simulators, the importance of which, I suspect, is not really understood. Exactly what sensory inputs does the pilot process during the landing flare, and what is their relative importance? Until we honestly understand this process, the simulator manufacturer does not know, with certainty, what he should provide in the simulation and the accident investigator is groping in the dark.

One of the practical problems associated with the visual database is keeping pace with the real world. For example, I recently conducted training in all-weather operations in a modern flight simulator. The airfield in use was Manchester, U.K., which has had a second runway for 4 years, but this was still missing from our simulator visual database. It was decided that this did not affect the training needs, but would this be satisfactory in an accident investigation where the rapid assessment of the visual scene is an important element of the pilot's decision-making process and thus workload?

Conclusions

Having considered the development of the flight simulator, it would be expected that modern examples would be able to replicate accurately the spatial layout of the cockpit. However, it may be pertinent to note that the cockpit is only simulated back to a defined line, usually around the back of the pilot's seat; the locked cockpit door, with its attendant distractions is not simulated. It would also be expected that the cockpit controls, together with their force feedback, accurately represented those in the aircraft, as did all displays. However, both the motion and the visual systems have their limitations. Most crucially, the weakest area for these important subsystems is that of integration, both with each other and the simulator as a whole. Any failure in integration will affect the performance of the pilot, albeit at a subconscious level. However, if an understanding of pilot behavior is part of your quest, and it is difficult to accept that the investigator would not be seeking answers here, then you will have to be sure that all of the variables have been taken into account.

The regulatory framework

Flight simulators are used as a means to acquire, maintain, and assess flightcrew proficiency, and those operating within the civil sphere are designed to meet international regulatory requirements. The current definitive standard is a Level D simulator which allows for zero-flight-time training. The basic premise for the qualification of a full-flight simulator was, and still is, that since the training and testing of the aircrew would normally be conducted in a real aircraft, any alternative to this must possess exactly the same characteristics and level of realism as the aircraft. Thus, once the regulators have evaluated the simulator to prove that it adequately represented the aircraft, they will grant a **QUALIFICATION,** which implies a certain level of realism in comparison to the aircraft. Other factors are then involved in deciding the training tasks that may be carried out in the simulator, a process that is known as **APPROVAL**.

The simulator is constructed using "design data," which originate from the aircraft manufacturer, supplemented by data from the vendors of any equipment fitted to that aircraft that can affect the realism of the simulation, e.g., engines, autopilot, flight management systems, etc. The simulator performance is then compared against the "check-out data." The data should have been collected from inflight recordings on a particular aircraft of the type being simulated. Once the simulator demonstrates that it matches the check-out data, and when other objective and subjective tests have been completed, it receives its qualification.

Malfunctions

Most malfunctions on modern aircraft types are part of, or supported by, the data pack and reflect correctly the procedures in the aircraft operating manual. Modeling component failures in these types invariable provides a correct simulation for the subsequent effects. The more reputable aircraft manufacturers now also provide simulation models that can be incorporated directly. Other malfunctions are the result of discussions between the simulator manufacturer and the operator who agree between them the cause and effect. But during the acceptance phase, it is common for the operator's pilots, who are often senior training captains, to insist upon altering elements of the malfunction. One example that is repeatedly seen relates to engine failures after takeoff. Since this is one of the mandatory elements of training required during the pilot's routine simulator checks, it is quite understandable that the acceptance pilots should wish to ensure its fidelity, and they will often demand more or less roll or yaw accompanied by higher or lower rates of motion. When I asked one senior training captain what he was using as his comparison, he explained that he had suffered just such a failure in a Boeing 737-200, but he was accepting a Boeing 777! It is also common for acceptance pilots to base such judgments on the performance of other simulators that they have flown. However, as long as the acceptance pilot does not deviate too far from the baseline malfunction, whatever that is, who is to say that he is wrong? The simulator will be approved for training, but is the engine failure that is modeled in the simulator the same as that which you are investigation? Engine failures in the simulator generally have muted responses in both motion and sound, but when reading reports of pilots suffering engine failures or surges in aircraft, they will often use phrases such as "It was like hitting a brick wall."

Two issues fall from this. Firstly, if the pilot has been trained in a simulator that provides a different response to the aircraft during an engine failure, or any other malfunction, then has he been taught inappropriate behavior? If so, and he then makes a mistake in his initial reaction to the failure, is it pilot error or a systemic error? Secondly, during the subsequent investigation, how does the investigator evaluate what cues the pilot used to identify the failure? I have suffered one engine failure and two engine surges in my career, and in all instances it was a combination of the sound and motion cues that warned me of the malfunction. We have not even discussed the importance of sound to the pilot—for both normal and non-normal operations. It should be easy to obtain during routine operations even if we cannot capture the sound of an engine surge. But was that recording of normal operations completed with the flightdeck door open? If that is the case, the background sounds of air conditioning and engines are unrepresentative, as is the sound associated with the engine failure, or do we just pretend that sound is not important?

We have already accepted that modern flight simulators accurately represent the spatial orientation of the cockpit, but what happens with "combo" simulators, i.e., those that represent more than one aircraft type? For example, there are many simulators that represent both the Boeing 757 and the 767, and pilots will often have a rating that covers both types. However, to reduce costs and to ensure that the "down time" between simulator slots is kept to a minimum it is accepted practice that much of the overhead panel and control stand is left in place for both aircraft types, even though some of the controls are different. For example, on these aircraft types, the hydraulic control panel, stabilizer trim indicator, and stabilizer trim cut out switches are different, as are others systems to a lesser degree. Where is the fidelity here, and how can the accident investigator make valid judgments, unless he has carefully considered the consequences? Similar problems also occur with the Airbus A330 and A340.

Within the simulator industry, it has long been recognized that extraneous activity that can affect a pilot's workload is often not incorporated into the flight simulator. In an attempt to more accurately reflect the distractions encountered when flying into a busy airport, modern flight simulators now have the capability to introduce extraneous air traffic transmissions, and the more capable visual systems have much more traffic around, both on the ground and in the air. But there are other facets of simulation that more immediately affect the pilot. For example, ADF needles in simulators are invariably deadbeat whereas this is rarely seen in an airplane, and it has a real impact on the mental workload. Smoke, together with the need to fly with oxygen masks donned, creates a very difficult cockpit environment, and although smoke has been available on simulators for many years it is not frequently used. In the U.K., for example, it is a requirement to inform the local fire brigade because prior to the use of smoke the fire alarms have to be disabled—otherwise they will operate and may also initiate the sprinkler system!

Modeling and its limitations

To further appreciate why I voice this note of caution, it is necessary to understand what is involved in the process of simulation. Simulations are essentially dynamic processes that attempt to represent the behavior of some aspect of the real world. Flight simulation sets out to represent the behavior of a specific aircraft. However, in the flight simulator, apart from the physical representation of the cockpit interior, the aircraft simply does not exist. It is represented by a series of interrelated mathematical models that attempt to mimic the handling characteristics of the aircraft and its various systems. Moreover, the ground and the air environments in which it appears to perform are also only mathematical models. Thus the basis of the simulation is a family of models responding to each other in such a manner that their outputs, if channeled through a suitable device (the simulator), will give those in the cockpit the impression of being in control of an aircraft operating in the real world. Therefore, most modeling in the simulator, and particularly aerodynamic modeling, can only provide an estimate. Once you move from the data point there is no longer any defined precision. It is accepted practice to interpolation between data points within the cleared flight envelope since this will probably not lead to erroneous responses; however, how should the modeling be extrapolated outside of this flight envelope? This does become important when considering, for example, the use of flight simulators in upset recovery programs with their attendant excursions in both pitch and sideslip. Thus, while the collection of models may give the illusion of an aircraft in flight, they do not constitute an aircraft, even when flown aircraft data are used for the design and validation of the simulation. This produces limitations for the accident investigation that must be recognized.

MD-11 flight simulator.

The models on which a simulation is based are unlikely to fully represent the real world because of their range, complexity, and variability. For instance, flutter is not modeled in any flight simulator that I am aware of. Moreover, some elements may be absent because of a lack of understanding of their influence or even of their existence. Even when the models are fully understood, the designer of the simulation is often forced to simplify the representation of the real world in order to produce useable models. In addition, the operator or the manufacturer of the simulator may also restrict the level of detail contained in the simulation models. Knowing that modeling is an expensive process, neither will want to include more complexity than is thought necessary to achieve the training objectives. This clearly has ramifications for the accident investigation where there are differences between the questions to be answered during the investigation and the training needs for which the simulator was designed.

Furthermore, the fidelity of the flight simulator is based upon the quality of the data package and while many of these are excellent, some are not very good. In addition, the individual aircraft systems are developed separately from within this package, and if they do not integrate seamlessly, then the overall fidelity of the simulator will suffer. Moreover, system engineers, whilst excellent software engineers and very knowledgeable, may have had little or no experience of actually operating an operational system, e.g., an aircraft braking system.

Implementing the model

The full-flight simulator is a ground-based training aid, and, despite the use of advanced computational techniques, sophisticated visual systems, and cockpit motion systems employing acceleration-onset cueing, it will have physical limitations to the extent to which it can represent the aircraft. It is important to remember that the simulator is successful because it does not conform to behaving like an aircraft. The aircraft cannot freeze its position in space, translate from one position to another in any direction, land without taking off, repeat a maneuver precisely, and operate safely outside of its normal performance envelope.

In commercial aviation, the aircraft that the simulator is attempting to represent is rarely stable as various fleet modifications are introduced. Sometimes these arise across the whole fleet, and on others the variation may exist only on recently introduced versions of the aircraft. In an ideal world these changes would be immediately reflected in the simulator, but if the simulator does not retain an absolute resemblance to the aircraft how valid are any of the conclusions made by the accident investigator? Some may argue that absolute compatibility with the aircraft is unnecessary if it only involves the positioning or standard of an avionics unit, e.g., the TCAS display or a radio control box. But how then can you accurately assess the pilot's workload and the effect this may have had on his performance? This problem has increased in recent years because of the number of different variants of a particular aircraft being offered by the aircraft manufacturer and has been compounded by the emergence of flight training centers that cater to a number of different customers with dissimilar aircraft. For example, each different engine fit results not only in different performance characteristics but also potential aerodynamic variables due to the engine cowling/pod design. Additionally, modern "fly-by-wire" aircraft employ sophisticated avionic units in their control systems. These units are populated with both "firmware" and "software" that can be and frequently are modified, both during aircraft development and while in service. To ensure that the concept of the use of flown data for simulator validation remains inviolate would require that the aircraft manufacturer retains an instrumented test aircraft, in each configuration, available at all times. This would clearly be financially unacceptable. Therefore, the aircraft and simulator manufacturers have proposed that, so long as one set of original data is based upon aircraft tests, it is possible to substitute alternative data for the variant models. The most commonly accepted substitute is the use of engineering simulator data. The problem is that these same regulatory bodies that are supposed to approve the use of the substituted data are often not staffed with personnel capable of monitoring the validity of this computer-generated data. But even more fundamental problems can occur during the lifetime of an aircraft. For example, the Jetstream 31 aircraft was originally designed and entered service with a four-bladed propeller driven by a 900 shp Garret engine and the associated simulators used the appropriate data for both qualification and approval. However, the same aircraft finished its life with an engine producing 1,020 shp, but this has never been incorporated into the simulator. Any investigation into an accident involving engine malfunctions or any handling qualities assessment would clearly be affected by this change.

Summary

Flight simulation has become an indispensable tool for training within aviation and has established a reputation for high levels of fidelity. Flight simulation has also proven itself to be an invaluable tool for the accident investigator, but the seductive level of "fidelity" might lead the unwary investigator to draw invalid conclusions. In order to reduce the possibility of this occurring, the investigator needs to follow a simple plan.

Consider carefully what is required from the simulator assessment. Flight simulators are good if you need to understand the sequence of a systems malfunction, or the manner and rate at which information is provided to the pilot, although this may not be true of an older flight simulator. They are also excellent for evaluating the time frames at which events occur; at least we can then begin to appreciate the problems facing the pilot. However, weaknesses exist relating to both the motion and visual cues, and particularly their integration. The detailed modeling on which a simulation is based may also be imperfect, and it would be wise to develop a clear understanding of the precise nature of the physical differences between the particular aircraft and the chosen simulator. Any excursion from the cleared flight envelope should be considered a "best guess," because that is all that it is, and be very careful with any workload assessment.

Having considered what is required, it is then necessary to discuss the detail of the assessment with both the simulator manufacturer and the aircraft operator. The manufacturer will understand the simulation issues and, when prompted with the correct questions, will be able to explain their limitations. The operator will be able to explain the standard operating procedures and how their training is conducted. For example, how were their pilots taught that a certain system worked? How does this correlate to the simulation of that system? How were their pilots taught to respond to a particular malfunction? With answers to these questions, it is probable that valid conclusions can be drawn from the simulator assessment and the best use will have been made of this unique investigative tool. ◆

Air Safety Investigation in The Information Age

By Dr. Robert Crispin, Embraer, Brazil

***Dr. Crispin** is a senior air safety investigator with Embraer. He previously worked as an investigator with the National Transportation Safety Board (1994-2001) and has previously worked as an investigator, researcher, and/or as an instructor in aeronautical science with a variety of different organizations. He has a Ph.D. in education, as well as ratings as a pilot and instructor on rotary-wing and fixed-wing aircraft.*

Introduction

Most of us have heard the belief expressed that we are living in the Information Age, due in large part to the proliferation of computers and the world wide web, through which many of them are linked. As a result, the amount of information available in virtually all fields of endeavor has increased exponentially over the past two decades. This information continues to have the potential to increase with no end in sight.

As investigators, we first learned to investigate by first gathering all the relevant facts, circumstances, and physical evidence surrounding an accident or incident in a thorough, accurate and precise manner. In the past, the majority of the information gathered was based on physical evidence (wreckage) or circumstantial evidence (weather, witnesses, maintenance records). This information then formed the foundation and, often, the limits of our investigation.

Under our traditional methods of collecting information on accidents and reported incidents, we, as investigators, have to wait until an accident or incident has occurred and then wait for it to be *reported* before we initiate an investigation. At the same time, information surrounding hundreds of similar events remains unrecognized and unreported. The potential data remain uncollected and unscrutinized.

As the commercial airline fleet has evolved both in total numbers as well as in technical sophistication, we have found ourselves more and more often being unable to obtain key bits of transient information that is crucial to a complete and accurate determination of probable cause but have been lost in the aftermath of a crash.

According to the Federal Aviation Administration (FAA), after declining steadily since the 1950s, the worldwide commercial aviation fatality accident rate plateaued in the early 1980s. Given the projected increase in volume in international aviation traffic, studies by Boeing have forecast that unless the current accident rate resumes its decline, there will be a major hull loss every 7 to 10 days, somewhere in the world, by the year 2015. For the commercial aircraft industry, this projection is unacceptable, and even more importantly the flying public is not likely to accept an increase in occurrences of that magnitude.

We, as air safety professionals, have been challenged by aviation safety organizations to counter these rising numbers by reducing the current fatal accident rate over the next 10 years by at least 50%.

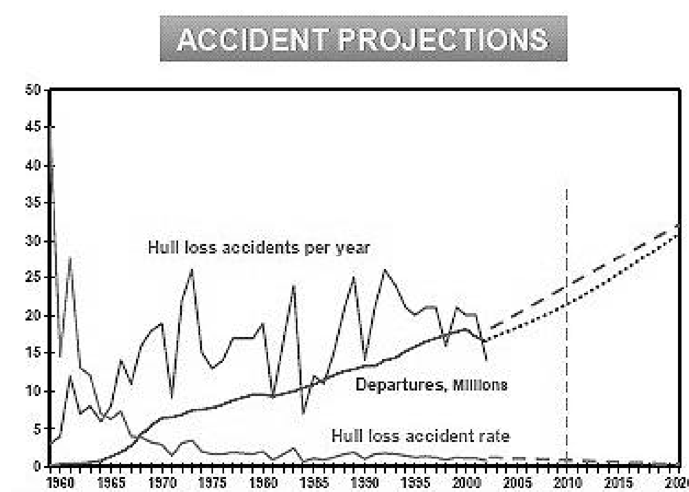
On reflection, the value of past investigative practices, while fundamentally sound, appear to have reached the point of diminishing returns in the face of evolving technological changes. Consequently, we are now faced with the task of raising air safety investigation to a level commensurate with the technology found in modern aircraft. In the future, we will no longer be able to wait for an event to be reported before taking action. Waiting will only compound the problem.

As we have learned over the years, accidents, incidents, and other unreported events of a similar nature, have a rather unique numerical distribution. On *average,* as illustrated by the Heinrich pyramid, for every one to three fatal accidents there may be another seven to 10 resulting in serious injury, another 30 with substantial damage, 600 with minor damage, and *up to 1,000* more unreported events. The common thread that runs through these events is the *random* chance of occurrence and the *similarity* of their underlying facts and circumstances. It is obvious then that the largest body of potentially *useful* information can be found within the base of the pyramid.

The stated goal of an investigation still remains to learn as much as possible about the factors that caused or contributed to an accident in order to prevent similar occurrences in the future. To make a significant difference in the future, we must focus much more investigative effort on those events that are currently unknown and/or unreported.

The most critical task in achieving investigative success in this segment hinges on the ability to collect useful information on heretofore-unreported events. Currently, the expansion of the information collection "net" is providing investigators with a much wider and more detailed array of event information, encompassing virtually all phases of commercial operations.

As current technological advances have made traditional investigation techniques inadequate, those same technological advances have created opportunities for new techniques that will



provide a greatly increased scope and accuracy in the collection of event information. In no area is this more evident than in the rapidly evolving onboard electronic systems. We are fast approaching the realm of the *virtual* accident in which events that were previously unknown will now be reviewed in a depth and detail not previously attainable.

The barriers to a successful investigation remain the same. The solution is access to *accurate*, *timely*, and *complete* information across the broad spectrum of in-flight operations. The old nemesis from the past, "*limited time and resources,*" will continue to attempt to restrict our efforts, but this is also an opportunity in which we now have the ability to do *more* with *less*.

Accuracy of information

First, to be useful, all event information should be accurate. This accuracy needs to be reliable and verifiable. It should be collected and handled in a way that minimizes the possibility of inadvertent loss or corruption of critical information. Subjective decisions and selective judgments can be made before an event in determining which information and sources are deemed applicable to this end, such as trends, exceedances, fluctuations or any other anomaly that departs from the expected norm.

Completeness of information

Second, for information to provide the "big picture," more than the specific event needs to be captured. Additional parameters must be included and along a significantly greater time line so that a more insightful history of the event can be shown. Completeness involves the collection of information over a series of cycles, encompassing a significant portion of the fleet for a given model. This will provide substantially more information than we had traditionally been able to obtain from flight data recorders (FDRs) alone.

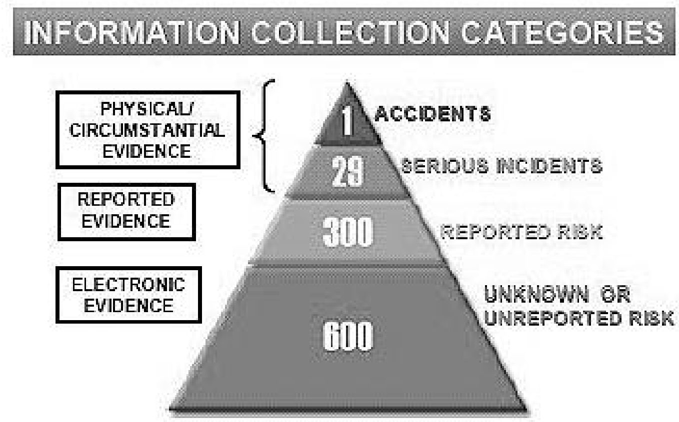
In the past, investigators have wished for access to information that was not being collected due to a limitation on the number of parameters. Digitalization has drastically changed that aspect, making collection of hundreds or even thousands of additional parameters an attainable reality.

Timeliness of information

Third, the information should be timely. Unnecessary or avoidable delays in obtaining information can needlessly extend the period of risk. Real-time access to information is critical in order to ensure that related information of a time-sensitive nature is also collected and preserved. We can no longer be totally dependent on the "after-the-fact" reporting of an event by a flight crew or a mechanic in order to be brought into the investigative loop. Expanded electronic overall system monitoring will provide our first real-time information concerning a potentially hazardous result of a previously unknown event.

Development of automated information collection

In the late 1950s, the increasing complexity of commercial airliners had already begun to overwhelm traditional investigation methods employed at the time. As the number of unresolved issues surrounding high-visibility crashes began to multiply, pressure from safety organizations mounted to find more reliable ways of collecting the information necessary to fill in those blanks. This led to the development of first commercial FDR in 1958 and later to the cockpit voice recorder (CVR). These additional



requirements were initially resisted, however, based on additional cost, labor, and potential loss of privacy.

Although, the first FDRs recorded only about six parameters, the early successes of FDR information providing critical information, along with continued advances in electronics, resulted in the number of recorded parameters to be steadily increased. Corresponding to these enhancements, the sophistication of sampling and recording of the information occurred simultaneously. On this basis, the concept of the routine collection of what had previously been at best transient information began to be noticed by other areas of commercial aviation, most notably by maintenance.

The concept of having access to a wide range of flight information for every flight, every day, proved to be of great interest to operators and maintainers in terms of the potential for reduced operating and maintenance costs as well as limiting down time. From these initiatives grew formal programs such as the first FDR-based flight operations quality analysis (FOQA) program initiated by an European airline. The greater acceptance of flight data management (FDM) has led to several variants of the FOQA program, all providing access to an ever-expanding range of information.

Accessing real-time inflight information

To obtain and utilize this information for safety purposes, some FOQA programs currently incorporate a quick access recorder (QAR) to download information from about 100 to 2,000 discrete parameters in modern aircraft. Once downloaded, this information can be readily analyzed and displayed by specially designed software programs.

By downloading every 3 to 20 days, depending on the type of analysis program employed, information related to a wide range of anomalies can be identified and analyzed in a contextual manner. Already, some aircraft communications and addressing system (ACARS)/datalink systems now have an integrated airborne printer that allows flight crews to receive flight data information while still enroute.

The QAR and the central maintenance computer (CMC), which also have the capability to capture data for analytical purposes, are now providing insights into flight operations and systems performance that had been previously unavailable. As benefits were gained through this new ability, operators soon realized the cost benefit effect on their bottom line, and they pressed to have the ability to monitor additional parameters.

Unlike the FDR, with QAR, operators have the advantage of being able to reconfigure the data frames to include or exclude specific parameters and/or increase or reduce the sampling rate. In addition, depending on the system architecture (an integrated QAR versus a stand-alone version), the QAR can be linked with ACARS, providing operators the capability of a real-time data flow.

The impetus behind the development and utilization of the CMC is based on efforts to improve the dispatch rate and to provide a means to perform troubleshooting complex and integrated systems. The early versions of the CMC recorded only about 100 data messages. However, current CMC capability now affords the ability to record 7,000 messages in its non-volatile memory.

Within the CMC, the aircraft condition monitoring system (ACMS) has the ability to provide data through ACARS to a ground-based receiver. To add to its flexibility, the operator can reconfigure ACMS at any time. This allows the system the versatility to provide whatever data are needed at the time, without the need for system re-certification.

Although not part of the current automated QAR and CMC systems, the following components on many Embraer aircraft also contain potentially useful, retrievable component condition information as a function of their nonvolatile memory chips. These include

- ground proximity warning system
- enhanced ground proximity warning system
- attitude and heading reference unit (two per aircraft)
- micro air data computer (two per aircraft)
- weather radar
- radio management unit (two per aircraft)
- integrated navigation radio (two per aircraft)
- integrated communications radio (two per aircraft)
- TCAS computer unit
- flight management computer (optional equipment)
- display unit (five per aircraft)
- lighting sensor processor (optional equipment)
- global positioning satellite system (optional equipment)
- data acquisition (two per aircraft)
- integrated avionics computer

The evolution of automated information collection

The ACARS/datalink was designed to provide a real-time method of transmitting information. The system provides great flexibility in that it can be user programmed to accomplish a variety of air/ground and ground/air data transmission reports. When this capability is combined with accelerated analysis and display programs, the time between information acquisition and the completion of formal analysis is significantly shortened.

The obvious benefit of incorporating an ACARS function with ACMS is that this combination allows engineering and maintenance personnel to have real-time knowledge of *current* inflight problems. This in turn allows flight crews to receive a more in-depth and accurate insight into actual or potential system malfunctions, which can then identify the most viable options.

A final advantage of ground-linked data systems is that real-time transfers mitigate the vulnerability of the information hardware loss due to the result of impact forces.

Analysis and use of automated information for investigative purposes

Once the data are collected and in order for the data to have value, the information must be analyzed, and the results must clearly and completely be understood. Action(s) should be taken based on what has been discovered without any undue delay. The recent tragedy with the space shuttle *Columbia* highlights this fact beyond all doubt. There must be a clear realization among all involved as to the specific level of risk the recognition of an explicit hazard may present to the safe operation of an aircraft.

This ability to collect and analyze a large amount of information is also valuable from a variety of macro perspectives. Trends that were once indistinguishable with only the information available from a few events may now appear evident when viewed from the standpoint of the fleet. This is particularly important to smaller operators whose relative fleet density precludes in-house macro analysis. Consequently, the goal of information collection should be aimed at data sharing with all operators on a worldwide basis.

The result from this approach will not only identify potential hazards without the need of a reportable accident or incident but will also have the added benefit of identifying hazards in systems in which problems had not previously been suspected. Consequently, corrective actions can be based on faults that were identified through the analysis of the facts and circumstances surrounding *potential* accidents and incidents rather than requiring investigators to wait for an actual accident or serious incident to occur.

Current datalink restrictions

Information is transmitted by ACARS by means of a worldwide communications system operated by ARINC or SITA, which combines both satellite-based and ground-based VHF relay antennas.

Currently, the cost of using the system does not economically justify continuous flight data transmission. However, ACARS can be configured to automatically transmit abnormal condition reports for events such as in-flight shut downs, electrical malfunctions, and loss of pressurization or hydraulic power. Since these events are relatively infrequent, the transmission costs will not likely have a serious financial impact on the operator.

Of course, the main advantage of real-time information is the ability it provides operators in terms of strategic planning and fleet management. Current cost transmission levels, however, are not justified at this time in relation to the prospective cost reduction that could be obtained.

On-site accident information collection

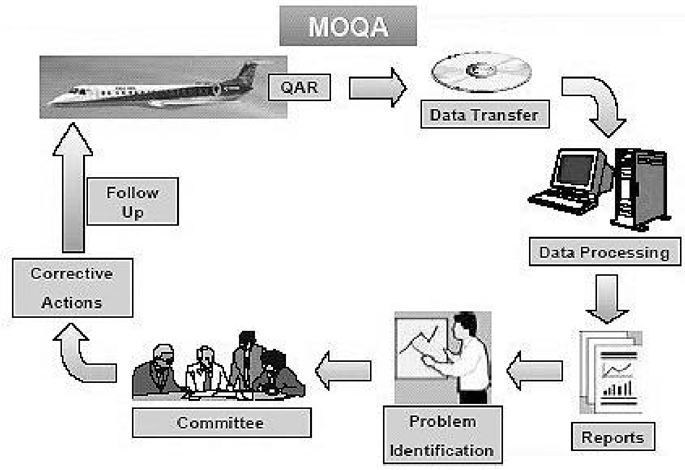
Regardless of how broadly and thoroughly we collect automated information, the importance of documenting on-site physical evidence should not be overlooked. The physical evidence will become even more relevant since it is now possible to compare and correlate that evidence with a much wider range of electronic information than had been available in the past. Here too, though, there are new tools currently available to improve the speed and accuracy of on-site documentation.

In debris fields, in which the terrain is expansive or difficult to transverse, hand-held, global positioning units can establish the location of critical points in a wreckage distribution that are now accurate to within a few feet.

Optical or laser range finders allow investigators to more accurately measure moderate distances over what might be inaccessible terrain.

Metal detectors help detect buried components that might otherwise not be located during an on-site investigation.

Many investigators now routinely use video recorders to add



in the post-crash documentation process. The photographic quality and low-light capabilities of these recorders adds another dimension to wreckage documentation. Video recorders with five or more mega pixels are also a source of additional photographs that retain excellent resolution in up to 8 × 10 enlargements.

However, the most dramatic advance is in the area of wreckage description, which involves laser scanning and digitizing an entire crash site. This provides the investigator with a perfectly scaled, three-dimensional depiction of any wreckage distribution with the ability to rotate and zoom in and out while seamlessly providing the ability to move from point to point thus viewing the wreckage from virtually any perspective with photographic resolution. Measurements between any points obtained through this process have been shown to be accurate up to 1/8 inch. The equipment, while still bulky, is portable and the scanning speed is increasing at the same rate that computer processor capability is increasing. With this aid, an investigator will be able to "*revisit*" any aspect of the accident site, obtaining additional details, measurements or photographs at any time and from any position just by opening a computer file.

Follow-up information collection

If a suspected component has been identified and located, routinely, a photographer will be present to pictorially record the "before" and "after" of each step of the inspection process. An overall digital video recording of the event, while not intended to replace photographs, will add a dimension of context and continuity to the entire process, while also enabling the investigator to simultaneously add a narrative description. As we have learned with witness interviewing, a much more detailed description will result from an oral narrative as opposed to written statement.

Follow-up research and analysis information

If a component shop finding does not satisfactorily disclose the precipitating cause of the discrepancy, a more scientific examination, such as a metallurgical examination, may be warranted, but the detail precludes the use of a hand-held camera or video recorder. Many times a scanning electron microscope (SEM) is frequently employed to examine suspect surfaces on an extreme microscopic level. Most SEMs have the ability to have their findings downloaded directly to a personal computer (PC) so that cathode ray tube (CRT) images and spectrographic material analysis plots can be directly saved for storage and later reference.

Displays of circumstantial information

From an investigative perspective, real-time reenactments and animation allow investigators the added insight sometimes needed to more fully appreciate the interaction of crucial factors from a simulated real-world perspective. The added dimensions of an aircraft inflight, control movements, instrument displays, and environmental factors combined with the added dimensions of sound and time now allow investigators to obtain a contextual sense of what the pilot and the aircraft were experiencing as the event progressed.

During collecting flight data and FDR information collection, advances in computer simulation and full-motion simulators can be combined with radar data, weather satellite imagery, terrain mapping, and air-ground communication information. In addition, the ever-more sophisticated software programs now provide the ability to replay the data. This real-time format allows the investigator to access real-time audio, topographical views, weather restrictions, aircraft movement, and systems performance in an animated format or to review the event in a flight simulator.

When radar data are combined with information from the FDR and are displayed in conjunction with a topographical database, programs can accurately depict a recreation of the aircraft in flight. The viewer's point of reference can be shifted to various vantage points, inside and outside the aircraft, while concurrently displaying real-time flight instrument readings and flight control movements.

Recordings from air traffic control (ATC) and CVR audio often contain information beyond the value of mere words. A greater insight into procedures, crew resource management (CRM), and cockpit sounds can have added significance when put into context with simultaneously occurring events.

For several years, proposals have been made for the inclusion of a cockpit video recorder. It is unfortunate but with the occurrence of 9/11, and the changes in security that have been implemented, the advent of onboard cockpit video recorders may yet come to pass. With the advances in recording digital images, this may allow us the see *what the pilot saw and did* correlated with *what the pilot heard or said*.

Flight simulators can present a degree of realism that from a pilot's standpoint is evermore approaching the reality of an actual aircraft. The expanded capabilities of today's simulators allow the programming of accident data so as to recreate an accident or incident based on the electronic information obtained from the FDR and/or FOQA while utilizing ATC and CVR audio as an additional reference. The visual displays can incorporate the actual runway in use for takeoff or landing events.

Organizational information collection

All the advances in information collection have not been limited to automation. The approach to human factors has also evolved significantly during the past 30 years. Advances in theories of accident causation were also occurring and providing insights into the roles that organizational management play in an accident scenario. We have made significant reductions in environment and hardware-related events, but in the area of human factors and the expanded area of human factors in the organization there is still significantly more that can and should be accomplished.

The Reason Model of accident causation that is now most prevalently used by air safety managers has significantly expanded the view of accident causation bringing us into the age of the *organizational* accident. This is significant because the model identifies not only proximate factors and active failures but also allows us to identify latent failures introduced into the system as a *result* of faulty or inadequate organizational processes as well. While faulty or inadequate organizational processes do not directly cause accidents, they do, however, significantly increase the *probability* of an accident by introducing unrecognized latent failures.

In the past, the collection of organizational information has been one of the less undeveloped areas of an investigation for several reasons. First, the organization often seems quite far removed from the actual event, and senior management is often immersed in an agenda that views a wide variety of processes from a macro perspective. Second, the information is often difficult to access objectively since reliable and valid methods for collection and analysis of this information were often not available. Often times the investigator receives scant encouragement or support even from his organization.

Until relatively recently, it has been difficult to quantify organizational information with any degree of validity and reliability. Researchers realized that in spite of the difficulty in collecting and analyzing organizational information, the difficulties did not preclude its importance in fully understanding what caused and *contributed* to the event.

In a successful investigation, after identifying the proximate events in the accident sequence, the next question is likely to be "Why did this happen?" or "Who or what allowed or caused this to happen?" Virtually every aspect of any accident can eventually be traced back to an error, omission, or violation committed by someone far removed in place and time from the final event.

Given that any organization is designed and operated by people, it follows then that human factor problems also exist in an organizational or management process. By examining the concepts and models of contemporary safety researchers in accident causation and organizational error, it has now been shown, through human based research, that it is possible to arrive at a quantitatively based conclusion regarding the role the organization played in the overall accident sequence.

The researchers (J. Reason, J. Rasmussen, D. Maurino, J. Williams) and others have all contributed to the continuing refinement of the accident causation model. With that development has come the ability for investigators to identify and quantify the faulty or inadequate organizational processes that worked to defeat defensive safeguards and increase the probability of the occurrence of an unplanned, adverse event. Some training and practice is required since many investigators have not yet been sufficiently exposed to this process.

The importance of conducting a thorough organizational investigation cannot be overemphasized due to the negative and pervasive effects of organizational errors have on a safety culture. While these errors do not directly result in accidents or incidents, they do, however, result in *conditions* that are conducive to the creation of latent errors that can be identified as cause factors.

Potential loss of information collection opportunities

Chronic problems still remain in the area of information collection. The loss of potentially useful information may result from delays or inaction during the investigative process in the same way that shortcuts or abbreviated procedures can also impair an investigation. Consequently, it is important for an investigator to know both the sources of information as well as the windows of opportunity for the collection perishable information.

With these two factors, for example, the investigator for a manufacturer may be concerned with obtaining a part that had been removed before the operator discards or submits the part for overhaul. The inability to acquire an unserviceable part may impair or setback the investigative process, sometimes requiring the investigator to wait for a comparable event to occur in the future in order to make further progress.

Similar problems with lost information can occur when troubleshooting intermittent faults is not properly performed and parts are replaced based on the recollection of what seemed to have corrected a similar problem in the past. In this instance, the "remove and replace" approach to troubleshooting may result in the removal of a part that had nothing to do with the problem. Since the fault is intermittent, a satisfactory operational check may not reveal the uncorrected problem. Consequently, an examination of the part will be productive only in terms of ruling it out as causing or contributing to the problem.

Delays in obtaining FDR information for past events, which have significance to the manufacturer but have not raised the same degree of interest with the operator, are common sources of lost information.

The collection of CVR information has a much more limited retrieval window. The looped CVR information is subject to inadvertent loss through a failure to power down the recorder after an event has occurred. This results in an information loss as the CVR records over and thus erases the desired information.

The physical distance from the maintenance facility, which prevents the investigator from establishing a professional working relationship with the operator through frequent visits, reduces the investigator to a voice on the phone or a name on a business card. This lack of a personal relationship may result in a potentially serious problem remaining unknown or unresolved by the manufacturer for an extended period of time. Lost or delayed information retrieval resulting from poor communications allows the opportunity for the same event to reoccur. ◆

Using Physical Evidence from More Complex Mid-air Collisions

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The views expressed in this paper are those of the authors and not necessarily the views of the NTSB.

Introduction

Mid-air collision investigations are one of the most interesting investigations faced by the professional air safety investigator. While increasing technology has reduced the number of mid-air collisions, they continue to happen and present the investigator with some unique challenges. This paper is a review of the principles used in the investigation of basic mid-air collisions and how those same principles can be applied to even more complex investigations. The basic principles of a mid-air collision investigation have been examined in several sources but the discussion here will be limited to the ICAO *Manual of Aircraft Accident Investigation*[1] and the simplified approach to using the ICAO procedures previously outlined in the *ISASI Forum* by one of the authors titled *Using Physical Evidence From a Mid-Air Collision*.[2]

The investigator may be able to use flight recorder information, radar data, and even witness statements to assist in the investigation. However, these sources of information may not be available on all accidents and in some cases are not as accurate as the physical evidence. The physical evidence left from a mid-air collision can tell you precisely the relative headings of the two aircraft involved at the time of the collision. Combined with other data like radar, you will end up with a more complete picture of the collision sequence. Of course there will also be situations where the physical evidence is the only data available. In that case, the analysis of the scratch marks will be the only basis for determining the collision angle.

A review of the ICAO manual approach to using physical evidence

The techniques developed in this paper and the previous paper

Beech Bonanza PG BWC aircraft 1. The main wreckage vertically impacted the ground.

Aircraft 2 was found in a meadow. From the track in the meadow, it could be determined that a rather smooth gear-up landing was executed. The cockpit roof was heavily damaged and scratched, and the left upper wing was dented.

on the subject by one of the authors varies somewhat from Appendix 11 of the fourth edition of the ICAO *Manual of Aircraft Accident Investigation*. The ICAO manual, for example, refers to 19 "rules of thumb" that provide guidance for analyzing scratch marks. While these rules of thumb are valuable, this paper uses a simpler approach to the analysis of scratch marks that is easier for the investigator to remember and use while at an accident scene. By adding the concept of convergence angles onto the ICAO approach, the investigator is able to more quickly determine what the visibility was from each cockpit. (See Attachment A, page 176.) If we have a scratch mark on an aircraft that is going from the leading edge to the trailing edge of the wing forming a 20-degree angle with the longitudinal axis, we know that the convergence angle of the second aircraft was also 20 degrees from the 12 o'clock position at the moment of impact.

Convergence angles have to be based on heading rather than track in order to establish a valid visual perspective for each pilot. Once these angles are established, you can replicate the visibility from a cockpit with fairly good accuracy. A visibility study can be done with a computer to provide a graphical plot of what the pilot(s) could have seen from the cockpit. The pilot's visibility can also be assessed manually by reconstructing the pilot's seated height and seat location in a similar aircraft and then determining what is at the convergence angle.

Using scratch marks to determine the collision angle always gives a relative angle between the two aircraft headings rather than the actual compass headings of the aircraft. This is actually a very helpful result in that we need the relative headings of the two aircraft to determine each crew's visibility of the other aircraft. However, while the scratch marks can tell you the relative attitude of one aircraft compared to the other, they will not give you the absolute heading of either aircraft. Likewise, the scratch marks may tell you the relative attitudes of the aircraft to each other, but you will not know what the attitude of either aircraft is in reference to the horizon.

The techniques discussed in this paper have been limited to determining horizontal angles of convergence and collision. However, the same techniques will work to establish the vertical angles of convergence by using scratch marks from vertical surfaces rather than the horizontal surfaces. The ICAO manual uses eight pages to explain how to calculate the collision angle when there is both horizontal and vertical motion involved. While this material is excellent, there is an alternative approach that is less time consuming. Simply solving for the horizontal angle and the vertical angle separately and then combining the results at the end will give the same result as the ICAO approach.

Basic ways to calculate a collision angle using scratch marks

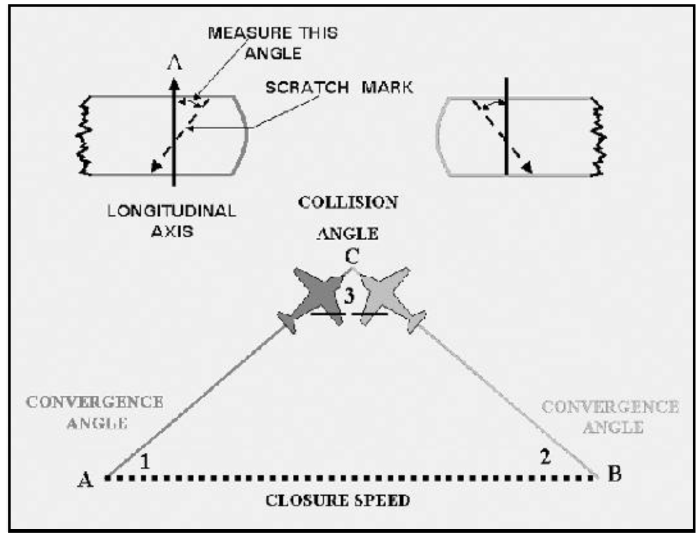
It is important to note at this point that a common mistake made in evaluating a mid-air collision is for the new investigator to assume that the scratch mark (or structure deformation) is synonymous with the track of the other aircraft. Investigators will sometimes find themselves sighting down the scratch mark as though that represents the flightpath of the other aircraft. Occasionally, even experienced investigators can be seen placing a part of an aircraft wreckage into a matching damage on the second aircraft as though that was the way the two aircraft collided. In reality, a scratch mark is a combination of the movement of two different bodies in motion. (See Attachment B.) Only when one of the aircraft is not moving or the second aircraft is approaching from the 12 o'clock or 6 o'clock positions will the scratch marks show the direction of travel for that aircraft.

When both aircraft have good scratch marks

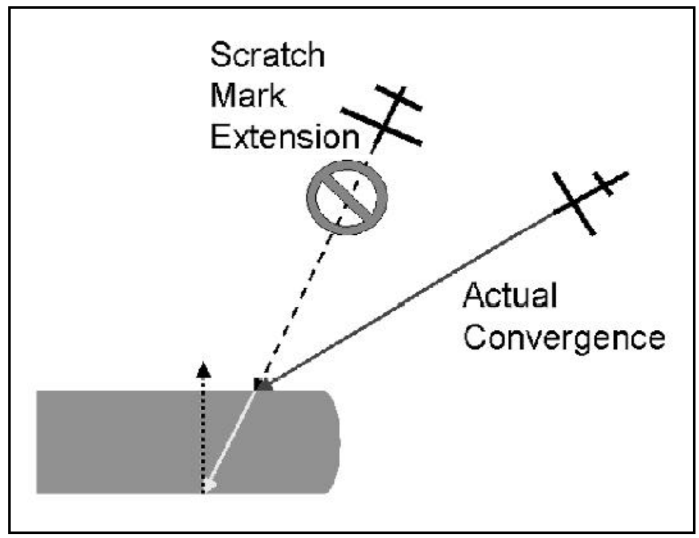
When both aircraft have reliable scratch marks, solving for the collision angle is a fairly simple process. Since the scratch marks are the same as the respective convergence angles, it is simply a matter of subtracting the two scratch mark angles from 180^0 to get the collision angle.

When only one aircraft has a good scratch mark but the speeds of the two aircraft can be determined or estimated

When only one aircraft has a reliable scratch mark, it is necessary to have the speeds of the two aircraft in order to solve for the



Attachment A



Attachment B

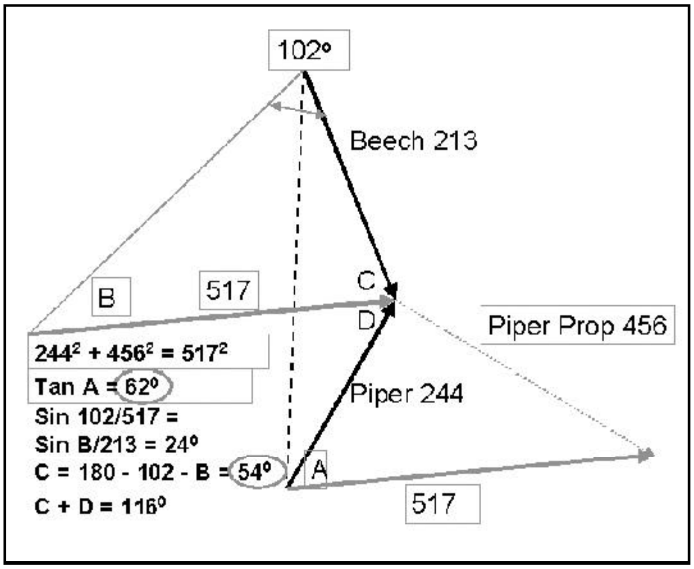
collision angle. While any estimate introduces some error into the final results, a range of probable speeds can be used and the resulting range of probable collision angles will provide useful information to the investigation. The variation in one general aviation accident was only about four degrees. While it's desirable to have more precise calculations, this range can still be very useful for a visibility study.

Extending the techniques to more complex accidents

Using propeller slashes to calculate a collision angle

Using the exact same physics as in the basic approach, we can extend the techniques to more complex accidents. For example, when there are propeller slashes left on an aircraft, we can calculate the "collision angle" between the propeller blade and the aircraft with the slash marks. Working backwards, we can then calculate the collision angle between the two aircraft.

A propeller tip moving through space is the combination of the propeller blade motion and the aircraft motion. Since propeller blades are a fixed dimension and rotate within certain expected RPM ranges, we can calculate the speed of a prop tip for any given RPM. Obviously, constant-speed propellers and air-



Attachment C

craft with known power settings will give more accurate results, but a range can be used to calculate a collision angle range much like we do when only the speed of one aircraft is known.

By using the diameter of the propeller, direction of rotation for the propeller and the RPM of the propeller, a calculation for the prop tip speed can be established using standard trigonometric functions. (See Attachment C.) Since the prop is always providing thrust at a 90^0 angle with the longitudinal axis of the aircraft, we can use the square of the prop vector and the square of the aircraft vector to get the square of the combined vector, which represents the prop tip moving through space. Combining this prop tip moving through space with the movement of the second aircraft allows us to solve for the collision angle between the prop tip and the second aircraft. Then, using basic geometry, we can determine the collision angle between the two aircraft.

Case study #1 Beech King Air/Piper Navajo collision with only one prop slash

A Beech King Air collided with a Piper Navajo near a VOR while both airplanes were in cruise flight in VFR conditions. Both aircraft were substantially damaged but landed safely. Interviews with the crews revealed that they were not aware of the other aircraft until just before the collision. The only reliable scratch mark was a prop slash on the underside of the right wing of the King Air. The angle between the prop slash and the longitudinal axis of the Beech was 102 degrees.

The Piper prop tip speed was calculated at 456 knots using the diameter of the propeller and the RPM of the propeller. This was then combined with the 244 knot speed of the Piper aircraft to produce a resultant 517 knot vector. Since this is the vector that actually produced the slash on the Beech, we can combine the prop tip vector with the Beech vector to calculate a collision angle of 54 degrees between the Piper prop tip and the Beech. (Angle C in Attachment C.) While interesting, this number in itself is only part of the collision angle between the two aircraft and useless to the investigator by itself since we really aren't interested in the collision angle between the prop tip and the aircraft. What we need to ultimately determine is the collision angle between the two aircraft themselves.

To determine the second part of the collision angle, we first need to use basic trig functions to calculate the angle between the final prop tip vector and Piper aircraft vector. While this number once again isn't a particularly useful number, it does allow us to then calculate the remaining angle in our drawing (Angle D in Attachment C) to find the collision angle between the two aircraft. From basic geometry we know that when a straight line intersects two parallel lines, the opposite interior angles are equal. This allows us to substitute the angle between the resultant prop tip vector and the Piper (Angle A in attachment C) for the remaining part of our collision angle (Angle D in attachment C) with a resulting collision angle of 116 degrees.

For many of the calculations in the mid-air collision diagram, the law of sines is the best equation to use. However there is one significant exception when it comes to solving for the closure speed when using only a single prop slash. In this case it is necessary to use the Law of Cosines.

Case study #2 mid-air collision between two Beech Bonanzas

In the afternoon of June 8, 2000, an accident with a Beech Bonanza of the KLM flight academy (KFA) was reported. The aircraft (registered PH-BWC, aircraft 1) had crashed in a field. The instructor and two students who were on board were fatally injured.

On my way to the accident site, I was informed that another aircraft was involved. It was from the same school and also a Beech Bonanza. (PH-BWD, aircraft 2) The instructor had made a successful emergency landing and was uninjured. The two students that were on board this aircraft suffered back injuries.

The accident happened during a sunny day in uncontrolled airspace south of Groningen Airport Eelde CTR, the home base of the KLM flight academy. The KFA uses this area frequently for training flights.

The wreckages of the two aircraft were found approximately 1.7 nautical miles from each other.

Aircraft 1 was found with the nose section (engine, propeller, and nose gear) separated from the aircraft. The distance between the main wreckage and the nose section was approximately 50 meters. The main wreckage (wing leading edge) showed traces of an almost vertical impact. The tail section was undamaged.

Aircraft 2 was found in a meadow. From the track in the meadow it could be determined that a rather smooth gear-up landing was executed. The cockpit roof was heavily damaged and scratched.

A closer look into the damage of Aircraft 2 revealed the following:

- Tail section undamaged.
- Right upper wing undamaged.
- Left upper wing: dented and partly covered with a black greasy substance.
- Left aileron: heavily damaged, partly disappeared, and pushed in neutral position to the outer side of the wing.
- Left lower wing:

1. Slash marks in wing and aileron corresponding with a propeller that turns to the right and passes underneath the wing (roughly speaking) from front to rear.
2. A hole, just outside the wheel doors, that appears to have been made by a soft body. Inside there are traces of a black material, probably rubber.

Analyses

The heavily damaged and scratched roof of Aircraft 2 showed clearly that there was a collision with something above the aircraft. The propeller slashes in the left lower wing pointed to a collision with an aircraft from below.

How was it possible that Aircraft 2 was heavily damaged both at the top and at the bottom?

Was a third aircraft involved?

Where did the big hole in the left lower wing come from?

We think the sequence of events was as follows:

- Both aircraft were flying in the same direction.
- The bottom of aircraft 1 came in contact with the roof of Aircraft 2, probably during a pull up of Aircraft 2.
- Aircraft 1 "slid" to the left over Aircraft 2.
- The left inner wing and leading edge "supported" Aircraft 1 just behind the engine section.
- The engine and nose gear separated from aircraft 1 due to acceleration forces during the collision, leaving dents and oil on the left upper wing of Aircraft 2.
- The nose section with the engine still running turned upside down and passed underneath the left wing of Aircraft 2.
- The propeller, still turning clockwise, made the prop slashes, damaged the left aileron, and pushed it outwards.
- Because the clockwise-turning propeller was cutting the wing, the engine itself tended to turn anti-clockwise (action = reaction)
- During this process, the nose gear came out of the bay and was slammed against the bottom of the wing, causing the hole.

Later when the radar data and witness statements were available, we found out the following:

- The two aircraft were flying in formation
- Both instructors had come up with the idea to use their instruction slots for a birthday greeting for another KFA instructor, who was the father of the instructor who survived the accident. Aircraft 1 crashed a few hundred meters from his home.
- The aircraft passed the house two times at low altitude (below 300 ft). During the second pass, the collision occurred.
- During the second flyby, there is no transponder signal from Aircraft 1.

Beside the investigation into the direct cause of the accident, the Dutch Transport Safety Board performed an investigation into the safety culture of the academy, which was state owned until 1990. Also the role of KLM as owner of the flying school and the CAA-NL as former "owner" and as organization responsible for the oversight was investigated.

Outline of the findings and causal factors related to the root causes of the accident

Findings:

- Neither one of the instructors was trained in formation flying.
- The formation flight was not authorized and not reported to operations or ATC.
- Because of their position, the two instructors should have set the example and should not have even considered this flight, especially not with students on board.
- At the time of the accident, the KFA did not have a head of training nor a flight safety officer.
- The KFA board did not take "adequate measures" to keep the quality of the group of instructors on the recommended level.
- The KFA board did not implement and maintain a good working safety management system and did not create the conditions for the proper safety culture. This was one of the reasons that important positions were vacant.
- KLM, as the owner of the academy, developed less activities to enhance safety, the safety management system, and the safety culture than can be expected from an owner of a flying school (especially when the owner is an airline and has the necessary knowledge to enhance a safe operation).
- The oversight of CAA-NL was insufficient.

Causal factors:

- Absence of a just safety culture as a result of a lack of adequate measures by KFA management.
- The absence of adequate activities of the owner of the academy.
- The insufficient overview by CAA-NL.

Recommendations:

To the KLM flight academy:

- Develop an adequate safety management system and incorporate a non-punitive safety reporting system with feedback to all participants and encourage instructors and students to report occurrences

To KLM:

- As owner of the KFA, set requirements in relation to the safety, the safety management system and the safety culture. Keep oversight by requiring reports and performing audits.

To CAA-NL:

- As civil aviation inspectorate of the KFA, set requirements in relation to the safety, the safety management system, and the safety culture. Keep oversight over the implementation and execution by requiring reports and performing audits.
- Investigate the possibility of requiring limited registration of flight data for aircraft operated by approved flying schools, for example, by flight data recording.

Remark: Shortly after the accident, a number of safety actions were taken by the KLM flight academy.

Summary

The aircraft wreckage from a mid-air collision can provide valuable information to the investigation process. The techniques in this paper provide a framework for expanding the basic mid-air collision investigation principles to more complex accidents. By properly documenting the scratch marks created from a mid-air collision, the collision and convergence angles can be mathematically derived even in some of the more complex cases. ◆

Notes

[1] *Manual of Aircraft Accident Investigation*, fourth edition, 1970 Doc. 6920-AN/855/4.

[2] "Investigating Mid-Air Collision Accidents," Keith McGuire, *ISASI Forum* January-March 2002, Vol. 35, Number 1.

Reinventing (With Wheels, Wings, and Sails)—A New Look at Transport Accident Investigator Training

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Abstract

Since 1977, Cranfield University has run air accident investigator training in collaboration with the Air Accidents Investigation Branch. In 2003, following an approach by the Marine Accident Investigation Branch and with the imminent establishment of the Rail Accident Investigation Branch, an opportunity arose to redefine accident investigation training. Recognizing that training investigators from different modes was a significant change to an established program, the fundamentals of investigation were researched and a syllabus put together that drew upon the key strengths and experiences of the three domains.

Investigators were challenged to go beyond their comfort zone and consider the science of investigation from a number of different perspectives. Strong consideration was given to how investigator competencies could be assessed, and a research program was initiated to verify this. This was particularly important, as the Rail Accident Investigation Branch was to go from zero to full capacity without the opportunity for on-the-job training that other established agencies enjoy.

This paper describes the process of syllabus development and training design, along with the lessons learned in running the first program in May 2004. It considers the advantages and disadvantages of training investigators from different modes together.

Introduction

Cranfield University first ran an accident investigation course in 1977 and since then has trained hundreds of investigators from around the world. Its founding course director, Frank Taylor, was awarded the Jerome Lederer Award for his contribution to aviation safety in 1998.

With Frank's retirement and the appointment of the author in 2003, Cranfield was presented with an opportunity to take a fresh look at its accident investigation activities. This paper outlines the new developments and the lessons learned in training accident investigators.

Sharing the lessons

Popular wisdom suggests that we learn from our mistakes, yet the wisest among us learn from other people's mistakes. As safety professionals, we have become increasingly made aware of the lessons that can be learned from other industries or modes of transport. The work of system safety gurus such as Perrow (1984) and Reason (1990, 1996, etc.) have highlighted the common failures to be found across a range of complex sociotechnical systems, including power generation, rail, marine, air and space transport, medicine, and even banking. As improvements in safety move industries increasingly toward what Amalberti (2001) refers to as "ultra-safe systems," the need to learn lessons across modes is heightened in transport accident investigation, which has led to the formation of multimodal investigation agencies such as the U.S. National Transportation Safety Board (NTSB), the Transportation Safety Board of Canada (TSB), and the Australian Transport Safety Bureau (ATSB). Such models have not been without criticism, but have brought a number of advances in the sharing of resources.

In the U.K., the Air Accidents Investigation Branch (AAIB) provided a framework for the formation of the Marine Accident Investigation Branch (MAIB) in 1989. Both branches have operated successfully since with a limited amount of collaboration. Following a number of high-profile rail accidents and in particular the recommendations of Lord Cullen after the 1999 Ladbroke Grove accident, the U.K. government announced the formation of the Rail Accident Investigation Branch (RAIB). The choice of title was no coincidence reflecting the successes achieved by the MAIB and AAIB.

In discussing the formation of a new investigation agency, Cullen (2000) noted "the evidence before the Inquiry plainly supported the view that inquiries by and under the RAIB should concentrate on the search for root causes rather than to ascribe fault, and the investigation process should not be distorted by questions of civil liability or criminal responsibility. This is, of course, the general approach taken by the AAIB [Air Accidents Investigation Branch] and the MAIB [Marine Accident Investigation Branch]. Regulation 4 of The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996 states: *The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It will not be the purpose of such investigation to apportion blame or liability.*"

It was logical then that the RAIB's chief inspector, Carolyn Griffiths (2003), described the Branch's purpose as being to "undertake investigations into accident and incidents with the aim of enabling lessons to be learned and making recommendations to improve safety on railways and preventing railway accidents and railway incidents. Its task is to try to determine what caused an accident, not to consider or determine blame or liability in the context of either criminal or civil proceedings."

The decision to create three parallel organizations, rather than a single agency, was not taken lightly. The Branches were careful to preserve their mode specialty, but noted several key areas for potential resource sharing (Smart, 2004). Some are very practical, such as the sharing of publishing and website functions. Others more technical, such as developments in data recorder analysis, legal services and investigator training.

RAIB faces a specific challenge that, having reached a stage of maturity, the AAIB and the MAIB do not. That is, of "going live" on a particular day. In other words, railway accidents that occur between now and the end of February 2005 will be investigated by the Health and Safety Executive or Formal Inquiry. From March 1, 2005, the RAIB will become the designated agency with a staff of some 25 investigators. There is no opportunity for new investigators to shadow existing ones, so how can they be sure that investigators are competent?

A partial answer lay in sharing some of the selection and training methods successfully employed by the other two branches. This is an area in which Cranfield recognized the opportunity to share some of the experience it had in the training of aircraft accident investigation. Hence, in 2003, the University commenced a project to examine the possible benefits of offering training for investigators from the air, marine, and rail domains.

From the ivory tower…

Although Cranfield has always enjoyed a close relationship with industry, it was felt that we could do more to ensure our courses and research remained relevant and up-to-date. An Industry Advisory Board was formed in September 2003, chaired by Ken Smart—head of the U.K. Air Accidents Investigation Branch and president of the European Chapter of ISASI. In keeping with our main area of expertise, membership was drawn predominantly from the aviation industry. However, in anticipation of future growth, two key representatives from the U.K. rail and marine investigation agencies were invited to join. The full membership of the Board in June 2004 was

Ken Smart—Chief Inspector, U.K. Air Accidents Investigation Branch
Carolyn Griffiths—Chief Inspector, U.K. Rail Accident Investigation Branch
Stuart Withington—Principal Inspector, U.K. Marine Accident Investigation Branch
Peter Wigens—Head of Safety, Cathay Pacific Airways
Roger Whitefield—Head of Safety, British Airways
Mick Quinn—Senior Vice-President—Safety, Emirates
Kwok Chan—Head of Safety and Accident Investigations, Airbus
David Burgess—Senior Advisor, Royal Navy Flight Safety and Accident Investigation Center

The aim of the Advisory Board is to provide guidance on the strategic direction for the Center in its teaching, research, and other development areas. Its first meeting was held in October 2003 and made a significant contribution to the progress that has been made over the last year. Two key areas were the subject of prolonged discussion: The first was that of whether it was possible to include a multimodal element of investigator training without diluting the existing aircraft accident investigation course. The second was on the subject of assessment and accreditation of investigator training.

Similarities

In developing a possible multimodal course, it was decided to start by highlighting the fundamental skills that are required of a transport accident investigator. While it was always acknowledged that there was to be a lot of specific content for each mode of transport, the criteria for what was considered as "fundamentals" was always to be those things that would be needed of any accident investigator. The length of the course was to be driven by the content and not the other way around.

Thankfully, major transport accidents are relatively rare events. Within aircraft accident investigation, this can mean that certain States have little hands-on experience in dealing with large accidents. Cooperation between agencies has often provided the opportunity for States to second investigators to major investigations in order to gain experience. It is this transmission of best practice that can be enhanced by opening up the boundaries between modes.

For example, it is the railways in the U.K. that have seemed to have attracted the most attention in recent years following a string of fatal accidents at Southall, Ladbroke Grove, Hatfield, Potters Bar, and Great Heck. The public and political interest in these accidents has been intense and, therefore, these accidents provide some of the best case studies to draw on. One example relates to the role and demands of the news media. The BBC was kind enough to facilitate a visit to its news headquarters in London. While all of those involved in investigation would be well aware of "horror stories" involving the news media, it was felt that one way of understanding what the media would be likely to do was to see exactly what they were trying to achieve. Even in the last 5 years, the way in which the media work has changed beyond recognition. Major news providers such as the BBC no longer work to the timetable of two or three major broadcasts per day, or even hourly bulletins, but rather are delivering content via 24-hour streams on TV, radio, and the world wide web. The case study of the news media response to the 2002 Potters Bar rail crash in which seven died illustrated the point clearly. Posed with the news editor's dilemma of whether to move the only satellite truck within the cordon to a better shot than the rival network, investigators were asked to consider what they would do. The aim is not to create apologists for the media, but at least an understanding of what the different motives are.

Other experiences are of particular value to at least one other mode. For example, marine salvage is an important area for marine and aircraft accident investigators, but it is rare (though not unheard of) for railway vehicles to need recovery from water. In the case of surveying land-based accident sites, the main techniques are less relevant to the marine investigators, but the basics of how to approach an evidence collection have relevance.

The first run-through of the fundamentals course commenced in mid-May 2004. At the start of the course, delegates were asked to define what makes a good investigator:

Open-minded
Able to focus on the big picture
Starts at the beginning
Asks for help when needed
Curious
Logical
Cooperative
Thorough
Looks beyond the obvious
Good observational/analytical skills
An eye for detail
Empathetic
Trustworthy/ethical
Unbiased
Plans ahead
Good communicator
Flexible
Confident in decisions
Able to "switch off"
Care about welfare (self/others)
Doesn't miss the obvious
Resilient

The answers are very similar to those presented in Frank Taylor's paper "The Ideal Air Safety Investigator?' in *ISASI Forum* in July 1996 and were agreed upon by delegates from air, marine, and rail transport. Upon completion of the 3-week course, there was very positive feedback on the way in which the course had drawn upon the experiences of other modes. Having said that, there were some areas of clear difference too.

Differences

Perhaps one of the most valuable outcomes of bringing investigators from different modes together has been in revealing differences in approach. Some of these differences are entirely logical and are a function of the operating environments. However, some of the others do suggest an opportunity to question whether "the way we have always done it" is necessarily still valid. A good example arose during the working group phase of the new course, while visiting the data recorder facility at the MAIB. Presented with a near collision involving two ferries off the coast of Britain, the aviators were puzzled at being able to listen to the full audio from the voyage data recorder. The marine investigators were happy to point out that there was no problem at all in being able to share such information. Indeed, the unions positively supported it as a way of helping clear members who had genuinely done nothing wrong. The philosophical difference may be for some valid historical reasons, but there is considerable value in asking why we do certain things the way we do.

One of the biggest challenges for training is in deciding what sorts of exercises can be used to practice skills when delegates are drawn from a range of modes. One of the major components of Cranfield's success to date has been the inclusion of field exercises involving crashed aircraft on the university's own airport. The logistics and organization of these exercises is complicated enough, but imagine what would be involved in putting together a rail accident. Tabletop exercises provide a good substitute for some of the elements, but also an opportunity to allow trainee investigators to push outside their comfort zone and surprise themselves. This year, four investigation teams looked at the early phases of a major rail accident site investigation. One of the teams was purposely made up exclusively of marine and air accident investigators while the others included rail specialists. The fact that it was all but impossible to pick out which team had no rail investigators acted as a powerful reminder that the key principles of investigation remain the same.

Getting the balance right in the first run through was always to be a tall order. Feedback at the end of the course suggested that where individuals had wanted something different from a particular session, this was not a view that was necessarily shared with others from the same mode. The fact that the rail investigators petitioned their chief inspector to be able to stay on through the "air only" weeks 4-6 of the course was perhaps the best recommendation.

Establishing competencies

Returning to the issue of competencies, Cranfield have taken the opportunity to review both the objectives and assessment of the course and commence research to look deeper into the subject if investigator competencies. Within the air, rail, and marine transport communities, there has been an increasing interest in recent years in the issue of establishing and measuring competencies in accident investigation.

The International Society of Air Safety Investigators is a well-recognized and respected body of professionals. Its Code of Ethics provides clear guidance as to the expect behavior of its members, but does it have a role to play in defining competencies? Full membership of the Society requires an investigator to have completed 10 investigations, but does such a criteria define a level of competence? In simple terms, it may be argued that the completion of 10 investigations equates to a certain level of experience and, indeed, the fact that an individual is still working in the field may suggest a certain level of competency. However, just as accident types can be very different, then so can the levels of experience gained.

It would be deeply challenging, if not impossible, for ISASI to attempt to set measurable competencies for membership. Defining competencies would be a difficult enough task, but actually measuring them is a mammoth one. This does not mean that ISASI does not have a role here—quite the opposite in fact. By using the experience of its membership and the organizations that are involved in training and employing investigators, there is a major opportunity to move the agenda forward. The continued professional development of the discipline is an important one.

Accreditation

What qualifies someone to be an aircraft accident investigator? In practical terms we may know that investigators are multiskilled individuals who bring a wealth of experience and qualifications. However, experience and qualifications are generally earned in roles such as engineer, pilot, or air traffic controller leading a persistent lawyer or coroner to press "but what is your qualification to be an accident investigator?" There can be few professions requiring as much skill as accident investigation without a formal qualification to recognize this. In the past it seems to have been enough to have a *de facto* qualification of having attended a course at Cranfield, USC, SCSI, and so on, but what does "attendance" at a course really qualify someone to do—unless they are assessed? Increasingly, there has been a move toward assessed and certificated courses. For example, both SCSI and George Washington University offer certificate programs.

In Australia, the ATSB launched its own diploma program in transport safety investigation with the Canberra Institute of Technology. The first staff completed the diploma in 2002. The structure of the diploma was the culmination of 2 years of development that included deciding between a University degree-style program and a more vocational path. The diploma allowed greater flexibility to assess the full range of investigator competencies from basic office and work skills through to more complex investigation techniques. It also allowed the ATSB to establish its own competency measures, which could be assessed by its own staff as new investigators built up their experience levels.

Faced with increasing scrutiny from the legal and coronial processes, the U.K. investigation branches are faced with deciding on whether an academic or more vocational path is the right one to follow. The reality is that a combination of both is probably the sensible way forward. While the industry would benefit from standards that are accessible to many agencies, e.g., through a degree program, each individual investigation agency must satisfy itself that its own staff are competent to do the task.

At Cranfield, we are well aware that 6 weeks of accident investigator training was a long time to work without recognition toward a qualification. However, it was also clear that an appropriate level and style of assessment was required in order to make it accreditable. Having said that, Cranfield did not have a fixed view that the only accreditation path was through a formal degree program. After long discussions with industry partners, it was agreed that we would establish a degree program in safety and accident investigation that would provide one element of an investigator's qualification path.

As many investigators join the profession with a first degree or equivalent vocational training, it was clear that a degree program would need to be at the postgraduate level. In the U.K., a masters degree generally requires the equivalent of a minimum of 45 weeks of full-time study. (Masters degrees recognize that attendance at short courses is supplemented by a considerable amount of self-study time so a student would not be expected to attend campus for 45 weeks!)

From September 2004, Cranfield will offer the new part-time program in safety and accident investigation with streams for air transport and, subsequently, marine and rail transport. It will be offered at three levels: postgraduate certificate, postgraduate diploma, and masters (MSc). The structure is as follows:

Postgraduate certificate
- Fundamentals of Accident Investigation (3 weeks)
- Advanced Aircraft Accident Investigation Techniques (3 weeks)

Postgraduate diploma
The two modules from the postgraduate certificate course, a small research project, plus any four 1-week short courses from
- introduction to human factors
- human performance and error
- research methods and statistics
- safety culture and risk management
- forensic science—investigation and evidence collection
- fire and explosion investigations
- engineering failures and accidents
- analytical techniques in forensic science
- courtroom skills and the legal responsibilities of the forensic scientist
- forensic aspects of the effects of explosions on materials
- underwater vehicles and their application
- corrosion in the offshore environment
- design for operation and aircraft crashworthiness

Masters (MSc)
As postgraduate diploma except the small research project is replaced with a major research thesis equivalent to 22.5 weeks of full-time study.

Does the program cover everything an investigator needs to know? Of course not, but it does offer a wide choice of specialist subjects for an investigator to pursue their specialism. Additional modules will be added as Cranfield expands its offerings through its new Institute for Safety, Risk, and Reliability. The critical question is what such a program can add to the discipline of aircraft accident investigation?

Investigation is a discipline in evolution, and as technologies and techniques become more advanced, so, too, the demands on the investigator will increase. A structured qualification program is one way of developing and recognizing the role of the investigator and in clearly demonstrating this for external scrutiny. It is certainly not the complete solution, which is why Cranfield has embarked upon a research project in collaboration with the U.K. Marine, Rail, and Air Accident Investigation Branches to explore how investigator competencies can be assessed through recruitment and training.

The recruitment of new investigators has provided a challenge for many years and certain developments have only made that more difficult. Well-intentioned policies designed to prevent stereotyping and discrimination can make recruitment processes rigid in their structure. Anecdotal evidence suggests that good potential candidates may be missed out if their profile does not match that which was predicted at the start of recruitment. With investigators being drawn from a pool of people with many talents and skills, it is difficult to avoid being caught out in this way. With investigator training having been largely unassessed until now, the opportunity to be able to demonstrate that an individual is competent to work in a particular role has been limited.

The research project aims to establish the competencies required of a transport accident investigator and evaluate what sorts of assessment techniques may be used to measure them. It may sound a relatively simple task, but previous attempts have demonstrated that it is not. We would welcome the participation of ISASI members in the research study and look forward to sharing results over the next few years.

Summary

The training of accident investigators is an important function and one that needs to keep developing if it is to continue to meet the industry's needs. Cranfield University, an important experience in the careers of many aircraft accident investigators working around the world, has recognized the need to facilitate the sharing of investigator experience, not just within the aviation community, but also with those in rail and marine transport. It has also recognized the need for structured assessment and, therefore, accreditation of investigator training and is working hard toward the development of objective measures of competency. The future of accident investigation is exciting, and we look forward to continuing to play our role. ◆

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ISASI 2004 Pictorial Review

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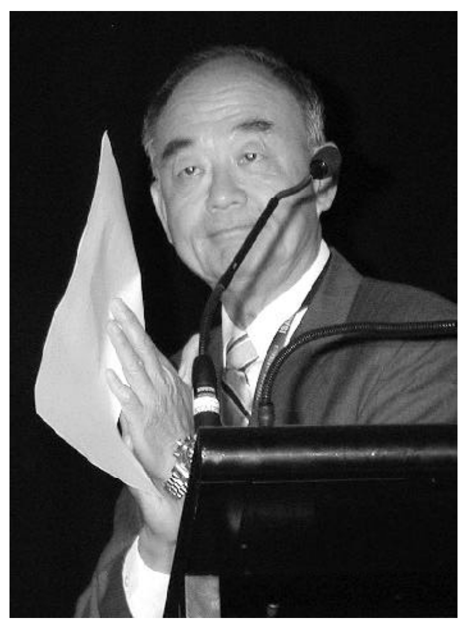
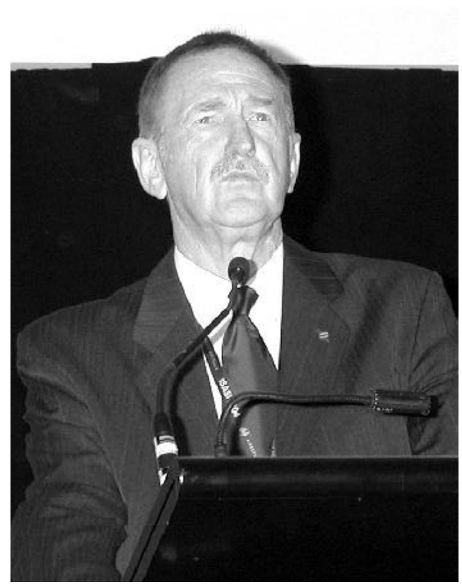
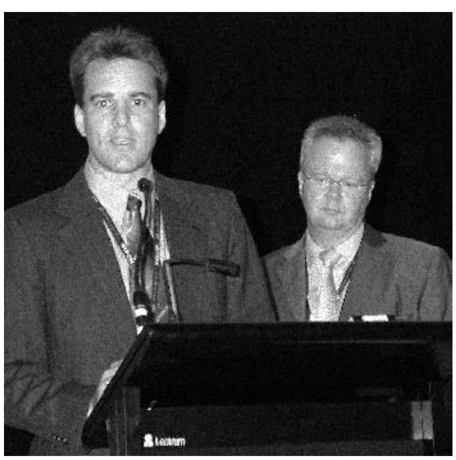



Landing Accidents
BEECH 1900D
Emirates




Lectrum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