Air Safety Through Investigation

Proceedings of the 37th Annual International Seminar

‘Incidents to Accidents— Breaking the Chain’

Sept. 11–14, 2006
Cancun, Mexico

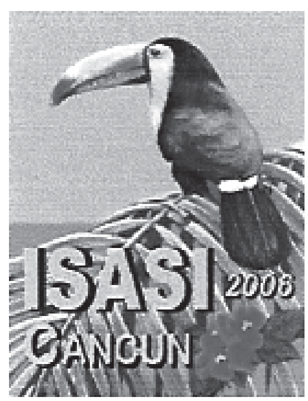

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Table of Contents

PREFACE
Welcome to ISASI and Cancun

By Frank Del Gandio, President

We are honored with the presence of our host, Capt. Gilberto Lopez Mayer, director general of the DGAC of the Republic of Mexico. A special thanks to the people of Mexico, as well as the state of Quintana Roo and the city of Cancun, for inviting ISASI to this Caribbean paradise.

The people of Mexico should be very, very proud of the rapid recovery that they have achieved here in such a short time after the devastation of Hurricane Rita. My own country has learned just how difficult it is to rebuild an entire city after a devastating hurricane. I have a deep sense of personal satisfaction that ISASI is holding its annual seminar in Mexico, reinforcing our international stature.

ISASI and I personally have long hoped to improve our presence and our representation in Latin America—and here we are. We are especially pleased with the establishment of the Latin American Society of Air Safety Investigators. ISASI also has hosted two Outreach workshops in Latin America, one in Mexico and one in Chile. Each was very well attended by regional aviation professionals.

These events speak to the future growth of the Latin American Society of Air Safety Investigators and illustrate what I have always believed to be one of the core strengths of ISASI: the breadth and wealth of knowledge that our membership brings to the table. ISASI really is proud to assist all our aviation brethren in whatever modest way we can because we in aviation accident investigation know better than most that aviation safety knows no borders. Aircraft recognize neither natural nor man-made borders—nor do they recognize awkward national fences.

We are especially pleased with the establishment of the Latin America Society of Air Safety Investigators.

The good news is that the aviation community around the world has continued to achieve higher and higher levels of safety. We have persistently eliminated more and more risk from the system. Air carrier safety has become so reliable, particularly the passenger jet system, that most of the world now finds itself trying to identify and minimize the risks of what have become very rare events.

This fact is reflected in the theme of this year's seminar, "Incidents to Accidents—Breaking the Chain." Its premise is that the aviation transport system now performs at such a level that we can no longer rely on accidents as our primary source of learning how to improve safety.

E. MARTINEZ

President Del Gandio welcomes delegates to ISASI 2006, Cancun, Mexico.

Everyone here has seen the iceberg illustration in which serious accidents are literally the tip of the iceberg, while the water depths hide a mountain of incidents that all too easily could have led to accidents. At a minimum, that mountain of incidents beneath the water may obscure persistent and serious risks that remain part of our system every day. The notion of "breaking the chain" says we must learn much more from incidents so that we can identify interventions that break the chain of events before they lead to serious accidents.

To do this right, we will need to sharpen traditional investigative and analytical skills to understand visible, high-risk incidents that come to our attention. But, similar to major accidents, even these events are only a small part of the iceberg. Breaking the chain will likely require that we target a broader range of incidents on which to use our traditional investigative and analytical resources.

Already, the aviation safety community is moving rapidly toward a system that integrates aviation knowledge with information technology and detailed statistical analysis of routine flights and routine air traffic data. What seemed to be far off in the future just a few years ago has become reality today: conceptually at least, we can now model the entire operating system.

We also are seeing the rapid growth of voluntary reporting systems in which pilots, maintenance crews, and cabin crews can report incidents to their airline without the threat of punitive action. These efforts are providing a new wealth of insight into incidents and risk.

Yet, at least two challenges remain fundamental to this shift toward incident analysis.

First, it is not easy to do well or even to do it in a meaningful way. For example, voluntary reporting systems now introduce the challenge of finding that needle in a haystack that might really be worth understanding. Even with digitally recorded data and systems modeling, we still need to know what questions to ask so that we know which data parameters to record and analyze.

The second major challenge is to make sure we don't forget lessons already learned.

We must avoid the temptation of plunging into the brave new world of incident analysis and digital data at the expense of what we already know to be critical elements in aviation safety.

For example, we had eight major catastrophic fatal jet accidents in the past year. While this is a remarkably low number compared to just a decade ago, we are reminded that risk is not zero, but we also are reminded that most major accidents are caused by very well established and well understood risks. In September last year, a Mandala Airlines B-737-200 crashed on initial climbout when the aircraft was misconfigured for takeoff (no flaps); 104 people on the airplane and 47 people on the ground were killed.

In October, Bellview Airlines lost control when one of its B-737-200 crew tried to fly around thunderstorms at night on initial climbout from Lagos; all 117 people on board were killed. In December, Solsoliso Airlines crashed on approach due to windshear associated with nearby thunderstorms; 109 people were killed. In May of this year, Armavia from Armenia crashed during a go-around in poor weather at night near Sochi, Russia;

Despite the need to retain what we already know, breaking accidents chains by improving both our understanding and our awareness of incidents is the direction that our profession must take.

all 113 on board were killed. On July 9, an A310 operated by Sibir Airlines landed long in bad weather and tailwinds at Irkutsk, then overran into a concrete wall and buildings, killing 131 of 203 occupants.

The following day, a Fokker F27 operated by Pakistani International crashed on climbout from Multan, Pakistan, after an engine failure; all 45 occupants were killed. On August 22 a Tu-154 operated by Pulkovo Airlines crashed in a thunderstorm. All 170 occupants were killed. On August 27 a CRJ operation by Comair crashed while approaching takeoff at Louisville, Ky., killing 49 of the 50 persons on board. Two other

During this seminar, several papers will be presented that outline some of the challenges and some of the successes in this transition to making better and more systematic use of incidents to break the chain. Be prepared to learn something about incidents to accidents and breaking the chain. Again, if anyone is seeking to understand more about any issue related to aviation safety, this seminar is a great place to start.

major accidents last year involved an Air France A340 that landed long in heavy rain and overran at high speed in Toronto. The aircraft caught fire, but all occupants escaped. In December last year, Southwest Airlines landed long and overran onto a city street in Chicago, killing a young boy in a passing vehicle.

None of these events involved either new or subtle risks, and none involved risks that were difficult for operators to identify before the accident scenarios began. Again, we must not forget the lessons learned.

Yet, despite the need to retain what we already know, breaking accidents chains by improving both our understanding and our awareness of incidents is the direction that our profession must take. Perhaps we could have identified something in the data before Southwest overran at Midway. Perhaps future approach-and-landing accidents can be averted by identifying an abnormal frequency of high-energy or unstable approaches on a particular approach to a particular runway. Perhaps we can identify, with real data, certain aircraft performance characteristics that invite mistakes by pilots, or identify particular portions of airspace that invite inadequate aircraft separation.

During this seminar, several papers will be presented that outline some of the challenges and some of the successes in this transition to making better and more systematic use of incidents to break the chain. Be prepared to learn something about incidents to accidents and breaking the chain. Again, if anyone is seeking to understand more about any issue related to aviation safety, this seminar is a great place to start. ◆

KEYNOTE ADDRESS
Safety Cannot Be Seen; It Must Be Felt

By Capt. Gilberto Lopez Meyer, Director General of the Mexican General Directorate of Civil Aviation

(Remarks presented by Capt. Lopez Meyer in his keynote address to ISASI 2006 delegates, on Sept. 12, 2006, in Cancun, Mexico. —Editor)

Good Morning to everyone. It is with great pleasure that I welcome you to our country and to this beautiful city of Cancun.

Aviation safety and security are behind most of the civil aviation decisions being made in Mexico and around the world. Confidence in this safety and security come from the preventive, corrective, and timely actions that are being taken. Therefore, breaking the chain of incidents that produce accidents implies a group of action projects, programs, and concrete plans to avoid a multitude of unfortunate events whose frequency or gravity may let them become major aviation risks.

Safety cannot be seen, because its purpose is precisely to avoid the appearance of incidents and accidents. But it must be felt, when periodic controls, inspections, and evaluations are made.

Prevention means looking ahead, establishing norms, correcting errors, and maintaining a set of timely inspections, so that aviation can accomplish its mission of being safe and reliable.

We have to address the issue of "Incidents to Accidents—Breaking the Chain," where we all fundamentally coincide and where each point of view and each analysis and proposal will allow us to be a bit more effective in preventing accidents.

During this seminar, we will have the privilege of listening to presentations that will be given by distinguished experts from the international aviation community. We will hear very important opinions, studies, and points of view that will increase our knowledge in the area of safety and of how to guarantee it and to perfect it. From the agenda, I can acknowledge that the different speakers will address different aspects of accident reports, accident investigation, and analysis tools to help prevent these accidents.

Mexico, Canada, and the United States have been part of the North American Free Trade Agreement since 1994. This Agreement contains a special charter for aviation, called the North American Aviation Trinational, that brings together three important organizations: Transport Canada, the Federal Aviation Administration, and the Mexican General Directorate of Civil Aviation.

During these more than 10 years of work, our three countries together have been developing various programs—those related to accident prevention being some of the most important. A very important tool was developed: a computerized database containing, in detail, the various elements of accidents reports from the three countries. The database contains a description of each accident. And after a detailed analysis, the root cause and secondary or contributing factors that led to the accident were established.

Our work during the next few hours and days will be to break these [accident] chains, to analyze, to establish proposals, and to agree on control and preventive measures to try to eliminate those incidents. Aviation safety concerns us all—aviation companies, government authorities, airports, specialists, and technicians—all those that in some way or another participate in aviation indus-try decisions or in verifying compliance with domestic and international regulations.

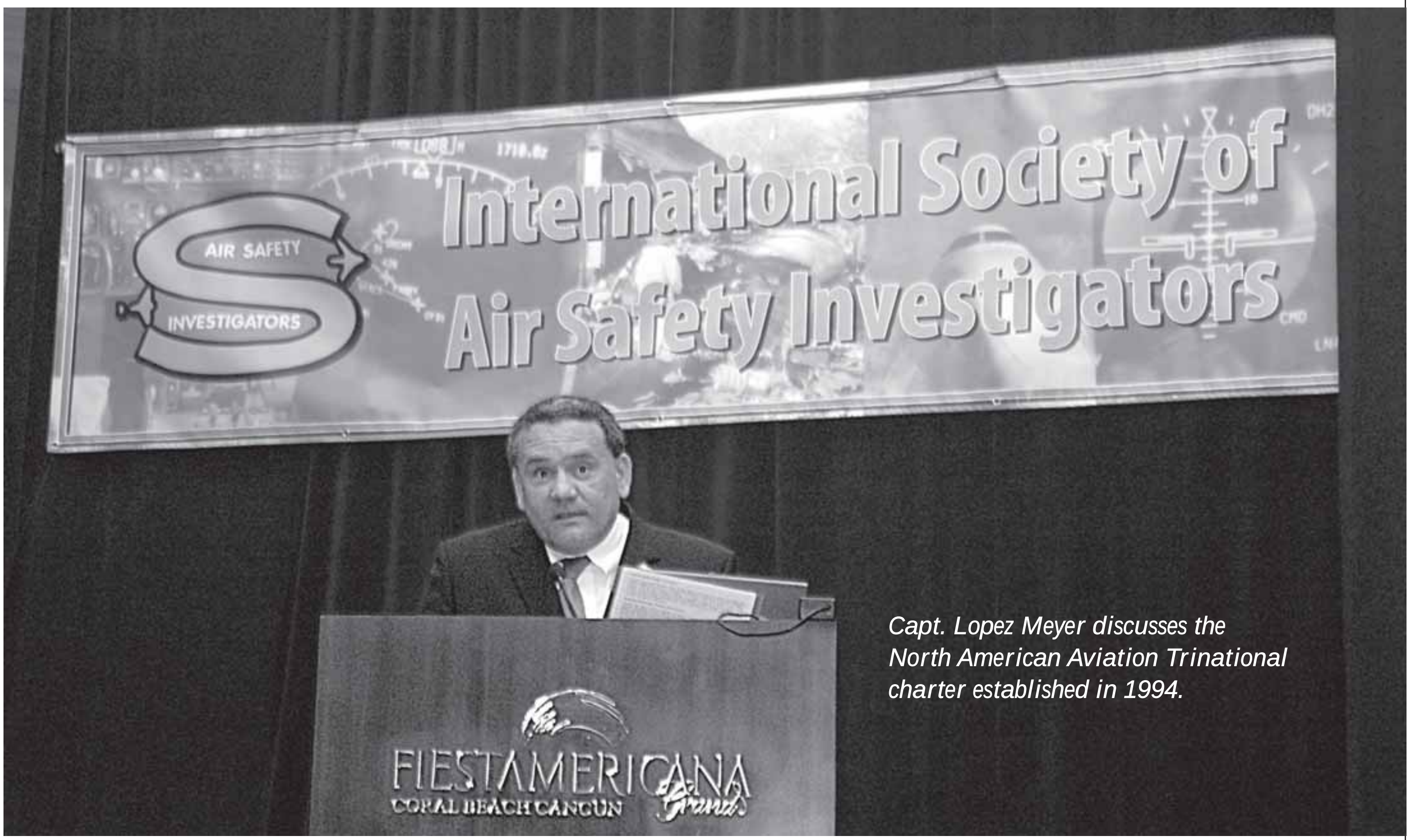
The database, thus, allowed us to work out statistics so that intervention strategies for each of the root causes could be developed. For example, approximately 500 air transport accidents that occurred in the three countries were analyzed. Eight main root causes were established, and intervention strategies to address them were developed. Those eight root causes were

1. not following proper procedures by operations.
2. equipment or component failure.
3. poor judgment by operations.
4. aircraft handling.
5. lack of crew coordination.
6. not following proper procedures by maintenance.
7. diminished situational awareness.
8. lack of communications clarity.

Do these sound familiar?

From the analysis of these eight root causes, the following preventive strategies were established:

- Pilot reexamination.



E. MARTINEZ

Capt. Lopez Meyer discusses the North American Aviation Trinational charter established in 1994.

- Confidential safety reporting programs for airlines and employees.
- ISO evaluation process (or equivalent internal quality assurance system such as ISO 9001-2000).
- Quality assurance programs.
- CRM courses.
- Line-oriented safety audits.

The same procedure was used for general aviation airplanes and for helicopter operations.

In Mexico, accident investigation is done in accordance with ICAO Annex 13, Mexican civil aviation law, and its regulations. It is interesting to note that aviation accidents are investigated by the General Directorate of Civil Aviation itself.

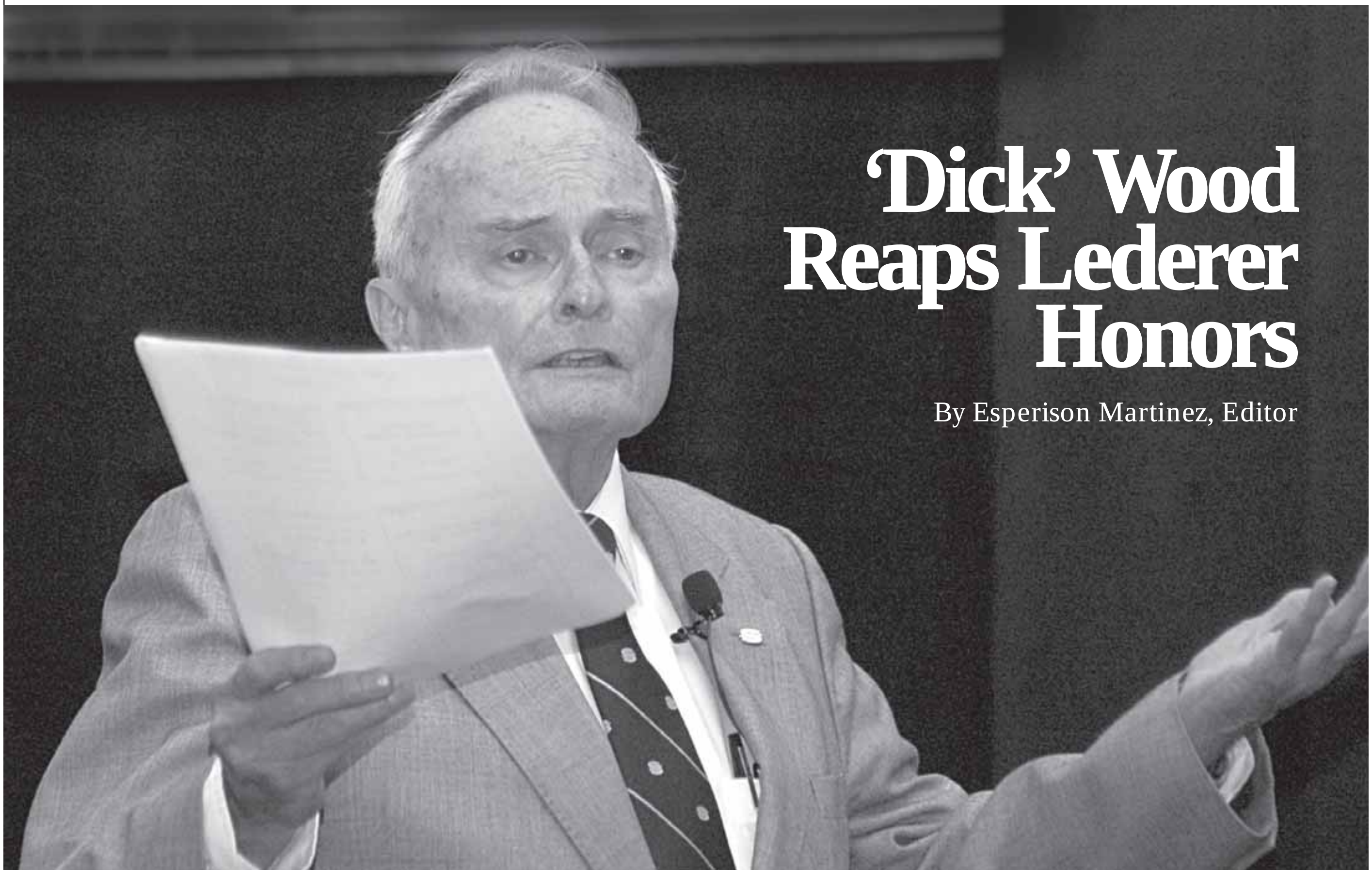
I may say that in Mexico we are actually in the middle of a discussion, trying to decide if the authority responsible for accident investigations should not be part of the civil aviation authority. It has been very interesting to me to find that there is not a simple and unanimous answer for this question—not even in countries that took the decision to separate both responsibilities many years ago. Maybe we will be able to learn some valuable experiences from the lectures that will be presented at this seminar during the next days.

Traditionally, the focus has been on accident prevention and avoidance and on establishing the necessary trinational prevention strategies. Today, we are looking at something less dramatic, but just as important: incidents. And we must realize that when they often occur, they can lead to what we really want to prevent: accidents.

Our work during the next few hours and days will be to break these chains, to analyze, to establish proposals, and to agree on control and preventive measures to try to eliminate those incidents. Aviation safety concerns us all—aviation companies, government authorities, airports, specialists, and technicians—all those that in some way or another participate in aviation industry decisions or in verifying compliance with domestic and international regulations.

Thus, the audit and follow-up inspection and control programs and projects are fundamental within the framework of our safety plans. Mexico's civil aviation authorities look with great interest to this international seminar, which we feel will greatly enhance our future decision, and we appreciate the effort that has gone into putting it together.

On behalf of the Mexican federal government, thank you very much for coming to Cancun. ◆



'Dick' Wood Reaps Lederer Honors

By Esperison Martinez, Editor

ISASI Life Member Richard H. Wood stood on the stage and fidgeted slightly as he listened to President Frank Del Gandio's lauding comments about the accident investigation and accident prevention contributions Dick has made over a lengthy career. It was those contributions that accounted for his standing before the crowd of 300 persons to be recognized as the recipient of the Society's prestigious Jerome F. Lederer Award for 2006.

At the lectern, President Del Gandio said: "Dick Wood truly fits ISASI's demanding criteria for the Lederer Award, standing tall among his peers for more than 50 years. Through his teaching, writing, and service to our profession, he has made significant contributions to aircraft accident investigation and aviation safety. His professional lifetime has been punctuated with countless contributions—both to ISASI and the industry—and those contributions continue to this day.

"A pilot with 6,000 hours of transport, general aviation, and military combat aircraft, Dick began his life's work in the U.S. Air Force rising through the ranks as he focused on a career in aviation safety. When he retired from the Air Force in 1978, Colonel Wood was chief of the Safety Policy and Programs Division in the Directorate of Aerospace Safety office; while there, he replaced "the primary cause" concept of accident analysis with the "multi-cause" system in use to this day.

"He then joined the University of Southern California as a professor of safety science, developing and teaching courses in aviation safety program management, investigation, maintenance, photography, and other related subjects. He was also an active consultant in aviation safety and aircraft accident investigation. Later, he became director of USC's aviation safety programs, specializing in development and teaching of many programs, until he left to help form the Southern California Safety Institute (SCSI). There, he is a member of SCSI's boards of directors and advisors, and is a 23-year Executive Committee member of SCSI's Cabin Safety Symposium.

"Currently, Dick is a writer, lecturer, and consultant, specializing in aviation safety and aircraft accident investigation. He has participated in the investigation of more than 125 civil and military accidents, and has served as a technical consultant in countless others. He is truly a person who gives back to his profession through publications and hands-on teaching, with eight books and manuals to his credit, as well as 24 magazine articles. He recently released the second edition of the definitive textbook used throughout the world, *Aircraft Accident Investigation,* coauthored with the late Robert Sweginnis.

"Dick's service to ISASI has been outstanding. A member since 1972, he has held various offices and committee positions, including president of the Los Angeles Regional Chapter, twice. He has authored nearly 30 professional papers since 1978, most of which have been presented at ISASI seminars. Indeed, his latest paper, presented on Tuesday [see page 32], is another excellent example of his dedication. Dick's back-

"I have an office in which the walls are filled with all the awards, decorations, and citations of 26 years in the military and 13 years in academia at USC. But this Lederer Award is going out in the front hall, close to the front door, because I want people who come to visit me to look at it and say: 'What's that?'"

ABOVE: Dick Wood, right, accepts the Jerome F. Lederer Award from President Frank Del Gandio during ceremonies at the ISASI 2006 awards banquet held in Cancun, Mexico. FACING PAGE: Dick Wood displays his lively style of delivery during the presentation of his technical paper "Defining and Investigating Incidents" to the ISASI 2006 audience.

ground, training, skill, and experience more than qualify him for the prestigious Jerry Lederer Award."

Then, turning to the now-calm figure next to him, Frank announced, "Dick, congratulations." As thunderous applause filled the room, the highly polished Lederer plaque set in deep mahogany wood, exchanged hands. The Jerome F. Lederer Award is conferred for outstanding lifetime contributions in the field of aircraft accident investigation and prevention. It was created by the Society to honor its namesake for his leadership role in the world of aviation safety since it infancy. Jerry Lederer "flew west" on Feb. 6, 2004, at age 101.

Somewhere in the "hereafter" Jerry probably smiled gleefully when Dick accepted the Award and said to himself: "I told you so!"

Why? Here is a story Dick, whose personal friendship with Jerry dates back to 1973, recounted in his acceptance remarks to the audience.

"In 1990 I was asked to become the chairman of the ISASI Awards Committee and held that job for seven years. In 1996 I received a letter in the mail. It was from Jerry Lederer. It was typewritten and it was formatted precisely the way called for by the Award nomination rules: typed, one page, one side only. I looked at it and recalled that Jerry Lederer did not own a typewriter; everything he wrote was pen and ink, so if he wanted something typed, he had to pay to get it done. Well, the letter looked like a nomination. I read it and discovered that Jerry was nominating *me* for the Lederer Award. I thought, 'Jeez, what am I going to do with this.'

"I picked up the phone and called Jerry, we talked often anyway. I said, 'Jerry, I'm chairman of the Awards Committee, I cannot accept this nomination!' He says, 'I know that, but I had to try.' Now here I am 10 years later, accepting this Award."

Is it any wonder Jerry may have been smiling?

Dick regaled the audience with other stories involving himself and Jerry, evoking feminine peals of delight and hardy male laughter. He then turned to the topic of the presentation.

In a crisp voice he thanked all of the persons who played a role in his selection: the person who nominated him, the Awards Committee members who are scattered throughout the world in a fashion that attempts to duplicate the distribution of the ISASI membership as closely as possible, and ISASI itself for having established such an award.

"I am very, very proud to receive this Award. But what am I going to do with it?" he asked rhetorically. "Well, in my condominium in Bellingham, Wash., I have an office in which the walls are filled with all the awards, decorations, and citations of 26 years in the military and 13 years in academia at USC. But this Lederer Award is going out in the front hall, close to the front door, because I want people who come to visit me to look at it and say: 'What's that?'"

With that, the audience burst into loud applause, over which Dick exclaimed: "That question will get them a free 10-minute lecture on what ISASI is and what it stands for and who Jerry Lederer was!" By now, the audience was on its feet making noise with shouts of glee, in appreciation for the expressed gratitude and implied veneration he holds for the meaning of the Award.

Then, a much more demure Award recipient whispered into the mike with a breaking voice, "I'm profoundly grateful to ISASI for giving me this reward; thank you," and the applause just got louder. ◆

Remarks to ISASI 2006

By Stuart Matthews, Kt.O.N., C.Eng., F.R.Ae.S., F.C.I.T., A.F.A.I.A.A.,
President and CEO, Flight Safety Foundation

Good morning. As you probably all know, the main aim of the Flight Safety Foundation (FSF), and my own personal priority for a long time, has been to put all of you in the accident investigation community out of business. It is very demanding task, and I have to admit that since you are a very dedicated and determined group, we are not likely to succeed completely for quite some time. However, we will not stop trying, and this morning I want to take this opportunity to tell you about a few of the things that we in the accident prevention world have been doing recently.

I don't have to remind you that commercial aviation is very safe. In fact air transport is probably the safest form of mass transportation that the world has ever known. And it is constantly becoming safer as more advanced aircraft come into service, facilities are upgraded, and improved procedures are adopted. Worldwide, based on a 10 year average, the hull loss accident rate is now about 0.7 per million departures and since things have been improving constantly during those 10 years, the rate at this very moment can only be much lower. Of course, the accident rate varies considerably from one region of the world to another. In North America and Europe, the current rate is about 0.2 per million departures, which means that if you took a flight every day for the rest of your life, some 14,000 years would elapse before you were ever involved in a fatal accident and even then, there is only about a 10% chance that you would be one of the fatalities. On the other hand, we do continue to have aviation accidents that keep you folks busy enough, and it is no secret that most of commercial airline accidents occur to older aircraft in more primitive parts of the world.

Let me tell you about some of the things that FSF has been up recently to help further improve aviation safety.

Stuart Matthews was born in London, England, and from a very early age has been passionately keen on aviation. He obtained a pilot's license before he could drive a car and built his own aircraft at age 19. He began his aviation career with the De Havilland Aircraft Company upon leaving school, and today he has more than 53 years continuous experience in both the aircraft manufacturing and air transport industries in Europe and North America. In the manufacturing industry, he was a project design engineer and, among other projects, worked on the Comet, the world's first jet airliner. Later he was involved in the Concorde SST program as a senior sales engineer. In the air transport industry, he was responsible for all corporate planning at the former British Caledonian Airways. In 1974 he was invited by Fokker Aircraft in the Netherlands to set up its subsidiary company in North America. He ran this for the next 20 years, selling several hundred aircraft in the process. Upon his retirement from Fokker in 1994, he was elected to be the president and CEO of the Flight Safety Foundation, a major international non-profit organization devoted to the continuous improvement of aviation safety. He is a chartered engineer with a degree in aeronautical and mechanical engineering. He is a Fellow of the Royal Aeronautical Society, a Fellow of the Chartered Institute of Transport, and an Associate Fellow of the Institute of Aeronautics and Astronautics. He has served on various select committees in both the USA and Europe and has received numerous industry awards. In 1994, he was knighted by the queen of the Netherlands in the Order of Orange Nassau for his services to aviation. In 2005 he was decorated by the Russian Federation for his assistance in helping make Russian aviation safer. Other awards that he has received include GAPAN's Cumberbatch Trophy and NBAA's Meritorious Service Award.

ALAR implementation

Back in 1992, the Flight Safety Foundation's International Advisory Committee identified the fact that half of all aviation accidents occurred during approach and landing, while over half of all fatalities were the result of CFIT accidents. Furthermore, virtually all CFIT accidents happened during approach and landing. As you will probably recall, we set up a task force, eventually numbering more than 300 aviation experts from all over the world, to address these major concerns. Out of all this effort came our approach and landing accident reduction (ALAR) toolkit, which sets out everything one would ever want to know about avoiding an approach and landing or CFIT accident. The recommendations and best practices contained in the toolkit have been accepted by FAA and JAA (now EASA).

However, it is one thing to have developed the best ways and means to avoid this type of accident; but unless the information is being used by those who need it the most, predominantly line pilots, air traffic controllers, and operational personnel, it is not of much use. A CD containing the ALAR toolkit has been distributed widely throughout the world—well over 35,000 so far—and FSF is now engaged in implementing it on a regional basis. In recent times we have held nearly 25 1- and 2-day workshops around the world training local aviation representatives in the toolkit's use so that they, in turn, can pass the information on in their own organizations. We do these workshops free of charge and, to date, some 3,000 people have had such training. It's a slow process, but it would appear that we might be winning since the statistical trend in CFIT accidents indicates a 30% reduction since we started. This means, of course, fewer accidents and less work for you.

Corporate FOQA

FSF has long championed the use and benefits of flight data monitoring, also known as FOQA, in commercial airline operations. Flight data monitoring on a regular basis can identify incipient problems in the operation of an aircraft or its systems that can be corrected before they become serious. They have been shown to prevent accidents, to save costs, to prevent injuries, and to save lives. In short, they work! We have now developed a demonstration program for corporate operations that is being tested with good results and, in due course, we hope to have FOQA in widespread use in business and corporate aircraft. We anticipate that this will make corporate aviation that much safer and, hopefully, will lead to a quieter life for those of you in the accident investigation community.

Commercial Aviation Safety Team (CAST)

Another activity in which FSF has been very much involved is CAST. As you might recall, CAST was established in the USA in 1997 as a result of the recommendations of the review commissions set up after two major aircraft accidents (ValuJet and TWA 800). It was recommended that, rather than working independently, industry and government should work together to achieve a national goal of reducing the then prevailing U.S. fatal accident rate by 80% over the next 10 years. FSF has been a member of the CAST Steering Committee and an active participant since its inception. Nine years on, without going into a full review of all the safety recommendations and best practices that have now been developed within CAST, when fully implemented, we expect that they will lead to a 73% reduction in the accident rate. That is very close to the 10-year national goal set in 1997, and the results already appear to be manifesting themselves, since there has now been no major commercial jet aircraft accident in the USA for the past four years. It's not for the want of trying, but regrettably we have still had two turboprop accidents during that period that have kept the NTSB busy.

There has been a similar organization to CAST in Europe, the Joint Safety Strategy Initiative (JSSI), set up independently by the JAA. It also had similar objectives to those of CAST and the two organizations have worked closely together. Now that JAA is running down, the JSSI has been taken over by the new European Aviation Safety Agency (EASA) and has become the ESSI. FSF is a participating member of this group also.

Smoke, fire, and fumes (SFF)

Following the tragic Swissair 111 accident off Nova Scotia it was recognized that the accepted best practices and procedures following the discovery of smoke, fire, or fumes while in flight needed to be reassessed. Assembling under FSF's neutral umbrella, representatives of the major stakeholders—including the major manufacturers (Airbus, Boeing, Bombardier, and Embraer), major airlines, IATA, ALPA, and IFALPA—worked together to develop consensus on new guidelines and procedures to be followed in the event of a smoke, fire, or fumes situation being encountered on board an aircraft in flight. These procedures have now been accepted, and the flight manuals of all aircraft are now being changed to reflect them. Hopefully, we can say that following implementation of the revised procedures there will be no more such disasters for you to investigate.

ICAO Global Safety Roadmap

Although air transport enjoys an incredibly low accident rate in North America, Western Europe, and other parts of the developed world, FSF has long pointed out the need to address the significantly higher accident rates prevailing in less developed areas, particularly Africa and South America. As a result, FSF has played a major role in the development of the recently published Global Aviation Safety Roadmap, which has been developed for ICAO by the international industry. Others who have also been involved in this initiative include ACI, Airbus, Boeing, CANSO, IATA, and IFALPA. The Safety Roadmap sets out the framework of actions necessary to systematically improve aviation safety in those areas of the world having the highest accident rate.

Nigeria

Over the years, west Africa has consistently had one of the highest accident rates of any area of the world. Of all the west African countries, Nigeria had a particularly poor record in 2005 with four major accidents with 225 fatalities. The government announced a major shakeup in the civil aviation organization and appointed Dr. Harold Demuren as the new Director General of Civil Aviation. Dr. Demuren has been a long-time member of the FSF's Board of Governors, and he turned to FSF for assistance. That is now being provided and FSF has a team of experienced aviation personnel in Nigeria at this time.

Well, that's what FSF has been doing to try and put ISASI members out of work. Now I'd like to conclude by telling you some things that we have been doing to make your work easier and, possibly, to keep you out of trouble.

Protection of aviation safety data

For some time we, like you, have been increasingly concerned about the tendency for judicial authorities to interfere with aviation accident investigations. You are all probably familiar with situations that have occurred in the past when hard evidence was sequestered and witnesses intimidated to the detriment of the investigation itself. Our position has long been that it is more important to establish the causes of an accident so that corrective action can be taken to prevent a reoccurrence—with, possibly, yet more lives needlessly lost—than it is to find someone to blame in the hope that punishment will eliminate any safety concerns.

With this in mind and following a couple of instances whereby, in our opinion, the accident investigation had been hindered by judicial interference, we approached ICAO through the President of the Council, Dr. Kotaite, and proposed that action should be taken to amend ICAO Annex 13 (which deals with accident investigation) to give priority and immunity to the investigation. Dr Kotaite was very supportive of this proposal and subsequently members of our ICARUS (think tank) Committee worked with ICAO staff to develop appropriate language. However, changing Annex 13 itself seemed to be an insurmountable hurdle so it was decided to offer the proposed changes in the form of a resolution that would be adopted by the ICAO Assembly. This resolution called upon States to show how they would change their laws or regulations to give priority to accident investigations. As part of the resolution, ICAO would provide assistance to States in providing appropriate guidance, and this resolution was agreed by the ICAO Assembly at its meeting in October 2004.

However, once the resolution had been adopted, things appeared to go on the back burner for a while with no apparent action by ICAO on the development of any of the guidance that had been agreed. Consequently, in mid 2005, we again approached Dr. Kotaite, who took immediate action to get things back on track. Within a very short while, it was established that the only effective way to deal with the matter was to amend Annex 13, as had been proposed originally. The proposed changes were developed as Amendment 11 to Annex 13 and I am very pleased to tell you that they were adopted by the ICAO Council on March 3 earlier this year and that they will become effective on next November 23.

Under the new amendment, States agree and are given guidance on how their laws or regulations should be changed to ensure that evidence and information provided voluntarily by witnesses, or information collected from data recording and processing systems as part of an accident investigation whose purpose is to improve aviation safety, should not be released or used in any inappropriate way other than to assist in the accident investigation. While these changes are not intended to prevent the normal administration of justice, inappropriate use refers to, and I quote, “the use of safety information for purposes different from the purpose for which it was collected, namely, use of the information for disciplinary, civil, administrative, and criminal proceedings against operational personnel and/or disclosure of the information to the public.” Of course, as might be expected, there are some caveats that talk about overriding considerations where it might be considered necessary to release certain information in extreme circumstances. However any decision to release the information must now be weighed against the adverse consequences that such release might have on the ability to collect safety information in the future.

As a result of all this, accident investigators should now be able to go about their work collecting information from witnesses who are secure in the knowledge that their evidence will not be used against them. Similarly, the investigators themselves will not be required to be part of any subsequent judicial inquiry.

We consider all this to be a major step forward and are proud that FSF has been in the forefront of making it happen. I hope that you also think so and that it will be yet another way in which, collectively, we are constantly striving to further improve aviation safety.

Of course, none of this relieves me of my self-proclaimed responsibility to eliminate the need for accident investigators, but that is likely to be a never-ending task.

Thank you very much. ◆

Accident and Incident Investigation In Argentina—One View About a Maintenance-Related Case

By Eng. Horacio A. Larrosa (MO4131), Chief of Technical Investigation and Support Department, Junta de Investigaciones de Accidentes de Aviación Civil, Argentina

The present paper is related to a 2004 non-fatal accident investigation of an airliner that occurred in Argentina, starting with a technician maintenance error, involving a lack of warning inscriptions in parts and documentation, ineffective exchange of information between different levels in the maintenance organization, and resulting in a worldwide alert issued by the airplane manufacturer.

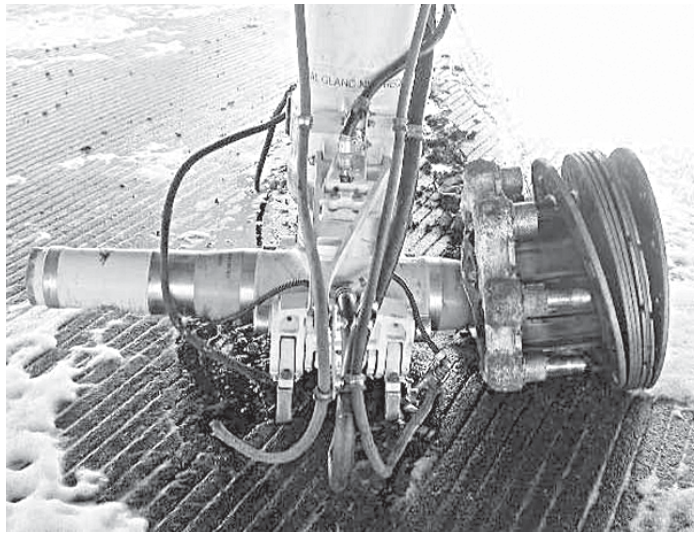


Photo 1. Damage of left main landing gear after landing.

Information about the events

Flight description

On Feb. 20, 2004, at 16:15 UTC, the aircraft pilot in command of a scheduled flight, with a Mc Donnell Douglas aircraft, model MD-81, registration mark LV-WPY, serial number 48024, took off from Jorge Newbery Airport (AER) heading for Iguazú International Airport.

During the takeoff run, when rotating, the internal wheel of the left main landing gear became detached from the axle and went straight onto the runway. First, it hit the localizer antenna (LLZ) of the AER instrument landing system (ILS), then it went through the airport perimeter fence, crossed a public avenue, and continued running until it stopped in the vicinity of some facilities located outside the airport. The flight crew did not notice what was happening and was informed by the personnel of the Air Traffic Services. The pilot in command interrupted the ascent and asked for a sector in order to hold and consume fuel so that weight could be reduced and the maximum landing weight reached.

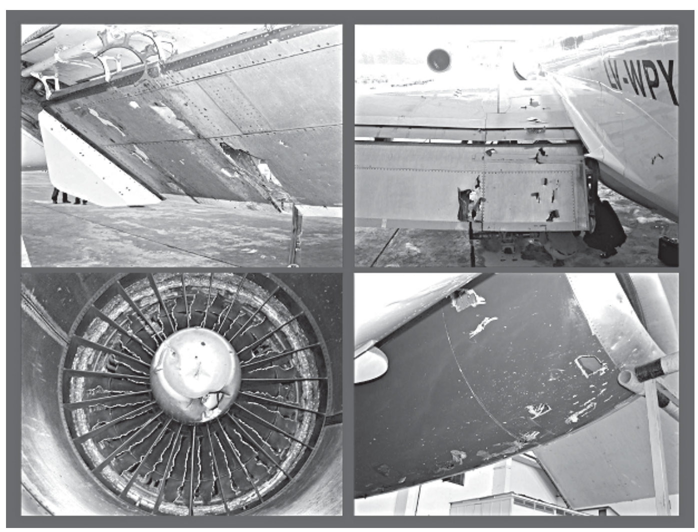


Photo 2. Aircraft damage in left flaps and engine.

When the aircraft touched the runway, everything was under normal conditions until the other wheel of the left main landing gear, after a short run, also became detached from the axle. The aircraft continued its landing run putting all its weight on the wheels of the right main landing gear, the nose, and brake assembly components of both wheels of the left main

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landing gear; finally it stopped 1,690 meters from the runway threshold.

Aircraft damage

Left wing and fuselage damage was produced by the metallic parts thrown out of the brake assemblies during the landing run.

The left engine (No. 1) showed signs of severe ingestion.

Investigations and trials

Technical nature

For the purposes of the technical investigation, the following material corresponding to the left main landing gear was sent to the Material Science and Technique Department of the Armed Forces Scientific and Technical Research Institute (CITEFA): the piston (P/No. SR09320081-9, S/No. CPT0181), the wheels, the brake assemblies, and the axles protecting jackets (or sleeves).

The piston looks like an inverted "T," and is the element that withstands weight and dynamic forces during takeoffs and landings. At the ends of the piston axle, the brake assemblies and wheels are installed. The wheels are inserted and placed not directly on the piston ends, but on the jackets that are put to them in order to avoid wear and damage during the change of wheels or under normal operation.

Both wheels detached presented similar characteristics: Inside the protective cap, fastening and anti-rotating elements were found, almost with no damage and with the corresponding safety wire intact. From what was observed, it was deduced that the axle nut (gray color) that fitted the wheel to the axle had slipped from its housing without rotating and without suffering damage that would indicate great contact strain between the threads.

Material trials at CITEFA laboratory

Three main verifications were carried out: metrology, thermal expansion, and torque.

Metrology and dimensions control

The dimensions of the following elements were verified, and these are the results obtained—

a) Axles ends inner threads: The values correspond to the item indicated in the components maintenance manual (CMM) as "2nd Reworked."

b) External threads of the retaining nuts: The values correspond to the item indicated in the CMM as "Original" (or standard).

c) External threads of the retaining adaptors of the wheel speed transducer ("Adapters"): Internal position (yellow color) and external position (gray color). According to the CMM, the yellow adaptor corresponds to the dimensions of the "2nd Reworked" and the gray adaptor to "Standard" values.

Torque Test

The manual establishes that when mounting the wheel, a pre-torque of 200 foot-pounds should be applied, then it will be loosen and the definite of 90 foot-pounds will be provided. A complete wheel was mounted over the damaged piston, and the torque tests were carried out with both damaged retaining nuts and one that had not been used for comparison purposes. In all cases, the reference torque values were reached.

This test showed that, although the threads clearance is noticeable when threading the nut, it is not possible to determine that the nut is not the one established by the manual, through torque. When checking the nuts after the trial, it was found that they were in perfect condition.

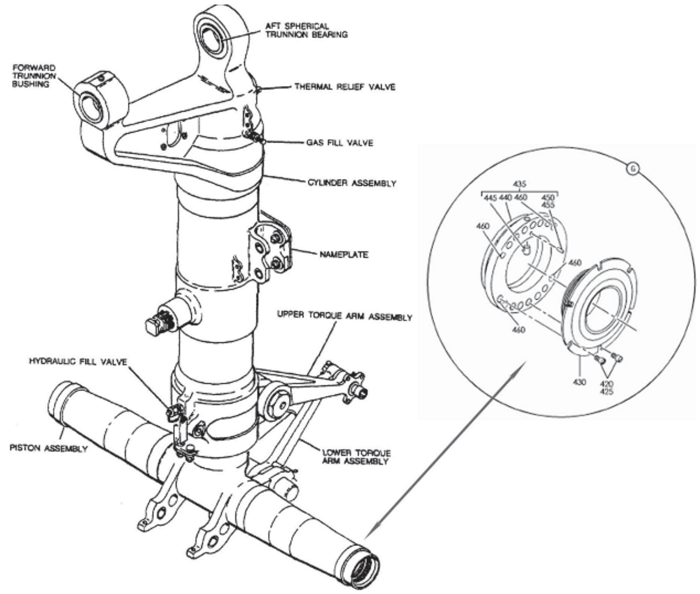

Photo 3. Piston assembly and wheel attachment system.

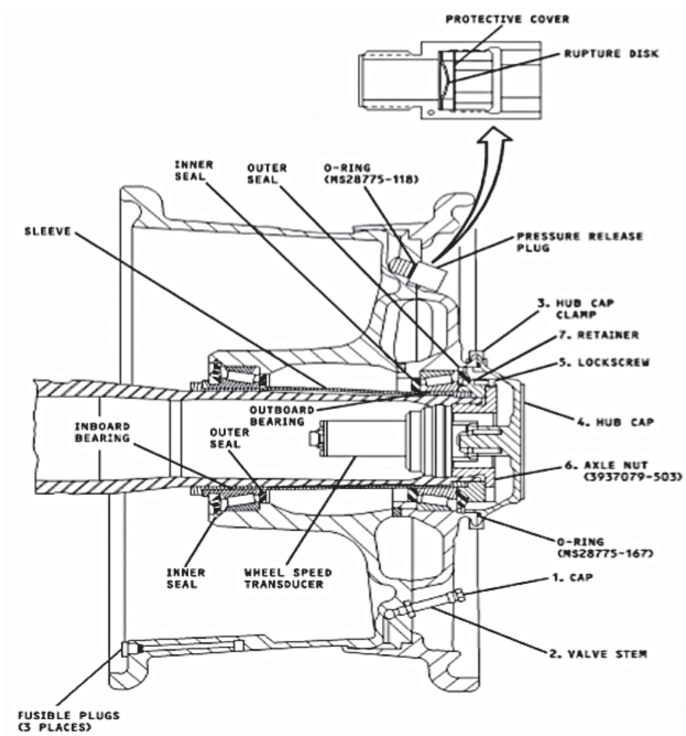

Photo 4. Detailed drawing of wheel attachment assembly.

Thermal trials

In order to explain the way in which the retaining nuts were expelled with no deformation or rotation, a test that consisted of inserting the nut into the piston, with a difference of temperature between both pieces that produced a differential expansion, was carried out.

When the retaining nut is matched up with the piston, the transmission of the piston heat to the nut is carried out through

Photo 5. Detail of axle, spacer. and adapter (internal side).

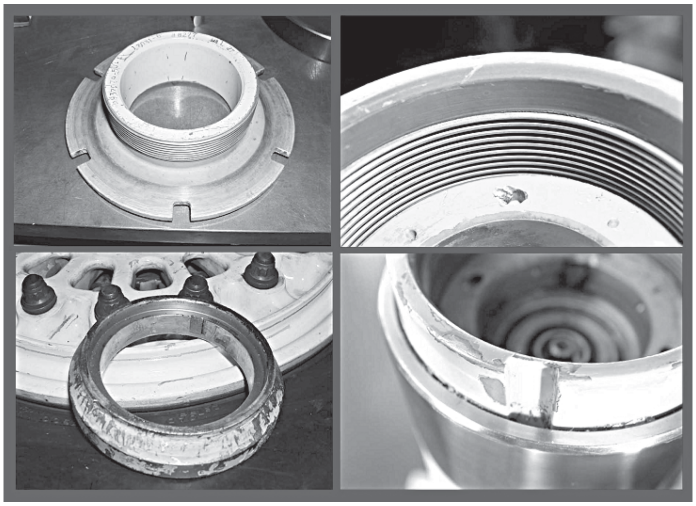

Photo 6. Detail of axle thread, nut, and anti-rotating devices (no damage).

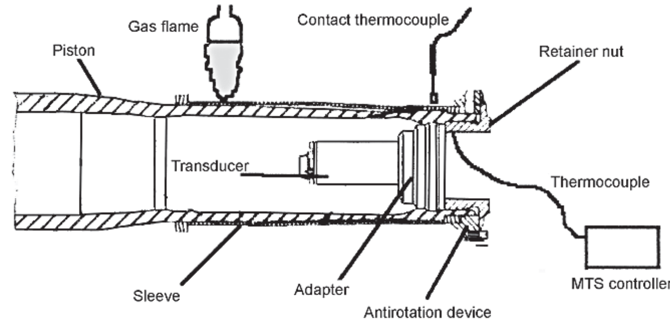

Photo 7. Thermal test: thermocouple system in axle assembly.

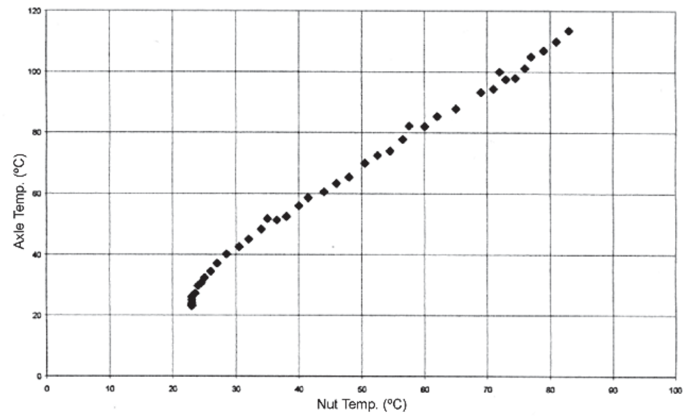

Photo 8. Thermal test: curve "Nut Temp. vs. Axle Temp."

all the contact surfaces of the threads. When the nut used is smaller, the heat flow is restricted since the contact surface between threads is reduced. Nevertheless, it was not possible to determine the exact conditions of the heat flow during the accident; however, in order to quantify the phenomenon characteristics, a test that consisted of inserting the nut into the piston end maintaining a difference of temperature between the pieces was carried out. With this purpose, the axle was heated, and it was confirmed that the nut could be placed by being hit slightly with the hand (without rotation) if there was a difference of temperature of about 55º C and higher.

In order to better simulate the operating conditions and be able to assess the thermal effects that could be generated as a result of using the brakes, another trial was made and it consisted of heating the axle with the standard axle nut installed with its anti-rotation elements to verify if these pieces had a noticeable differential heating by conduction.

The temperatures were measured through a thermocouple system for both elements.

At the beginning of the trial, the temperature of both parts was 23º C. After about 80 minutes (there was no equipment available for a quicker heating), the axle temperature reading reached 113.6º C, while the nut record was 83º C (difference: 30.6º C). All the intermediate values were also registered, and the curve "Nut Temperature vs. Axle Temperature" was traced.

If the temperatures increase was even, the graphics should have one pending value, but in this case the value is higher. It was also observed that, at the beginning, when the heating stationary regime had not been entered, the slope was even higher. This supports the hypothesis about the amplification of the quicker heating phenomenon. According to what was verified in the trial, it could be believed that when the axle heats quickly because of the braking effect, the difference of temperature to be reached between the axle and the nut could approach the 55 ºC.

Summary of the results

From the way the parts were found and the measurements carried out, it is deduced that the key part is the **wheel retaining nut** ("axle nut").

After the eye observation and the inspection with stereoscopic glass, it was revealed that the threads were almost intact. Likewise, it was proved that the clearance with which the nut threaded with the piston was too much—although, the nominal torque values were reached during the tests.

Because of their dimensions, it was confirmed that the nuts were original (**standard**), while the piston had threads corresponding to a **second reworking,** which should have matched up retaining nuts of second oversize according to the manual.

All the same, at room temperature, it was impossible to extract them without rotation movements. It was confirmed that the nuts could not have rotated since they were connected to the anti-rotation rings; these were also checked, and they were in perfect conditions, as well as the piston insertion slot.

The aircraft manufacturer's information indicates that, under normal operating conditions, temperatures of about 150º C are reached, at approximately 28 cm from the axle end. Such temperatures could be deemed enough to consider the differential expansion as a mechanism highly contributing to the expelling of the nuts (not matched up), added to the important lateral loads that the landing gear withstands during the taxiing procedures, especially when turning the aircraft.

Background and chronology

After having detected that standard nuts had been used for fastening the wheel, instead of the appropriate oversize nuts, specially matched up for the reworked piston, the traceability of the assembly from its manufacture process was followed, studied mainly the following documentation: FAA Form 8130-3, packing list, supplier invoice, and planning of workshop process ("Shop Traveler").

During the assembling process on another aircraft, the piston Serial No. CPT0181 was damaged in the chrome plating, thus it was removed to be sent to repair at external workshops.

Once removed from the aircraft, it was placed back on its transportation case, in order to be sent to the dispatch sector (parts control). The mechanic executing this task did not put the yellow nuts back in their place, which had been removed and placed on one side before assembling the piston on the aircraft. The inspector intervening on that occasion also failed to detect the omission.

It is worth mentioning that said nuts were painted yellow and serialized with the piston serial number, since both the piston axle and the nuts were reworked at its origin country and, therefore, they were matched up and were not interchangeable.

The operator dispatch sector received the piston with the origin documentation already mentioned attached, but the latter did not include documentary data indicating the existence of those nuts.

The landing gear installation on the LV-WPY, carried out at the operator's major maintenance hangar, was performed in 2 days. Tasks began on February 16, and the installation was completed—including brakes, wheels, and the subsequent final functional test—on Feb. 17, 2004. The aircraft resumed commercial service on February 18th of that same year. The accident took place during the aircraft third operation cycle, after the wheels installation.

Considerations on the organizational factor

From the interviews of the technical area staff, at all levels, a general task satisfaction, work appreciation, and commitment, as well as enough experience were observed. Nevertheless, when consulted if they were aware of the existence of reworked components in the fleet, mechanics from all levels said they did not know about it. It is worth clarifying that the company only has two reworked main landing gear pistons.

Repetitive case for the landing gear repairing workshop

The operator contacted JIAAC, during the present investigation, in order to request JIAAC technical personnel to be present to verify the conditions under which another piston was received in the warehouse, coming from the same provider, after being overhauled.

The piston came with two axle nuts for the wheels and two adaptors for the tachogenerator fastening. All these parts were vibro engraved with the piston serial number, marked as oversize ("O/S") and were painted yellow.

A mistake was verified in the part identification; moreover, task No. 100.0 from the "Shop Traveler" indicated the painting of quarter-of-an-inch black letters on a one-inch yellow band: "1ST RWK OVERSIZE THREADS," which was not carried out. As it was considered that the lack of a clear identification on the part about the existence of oversize threads, which warns about the need to use "matched up" nuts was one of the accident contributing factors, the JIAAC decided to inform the manufacturing country about this situation through a "Safety Alert."

Information exchange with the NTSB and the airplane manufacturer

From the beginning of the investigation carried out by the Civil Aviation Accident Investigation Board (JIAAC), close contact was maintained with the Airworthiness National Administration (DNA), the National Transportation Safety Board (NTSB), the manufacturer, and the operator.

Many consultations were carried out, especially about similar background information, obtaining data from the manufacturer about various cases of wheels losses in which their axle nuts rotated and gradually became loose until free or the anti-rotation cramp was missing. Only one case was recorded of a DC-9 with a reworked axle and an unsuitable nut, which caused a wheel to be lost, leaving the nut with significant damage to the thread.

Manufacturer asserts that a theoretical simulation of the nut expulsion process would not be completely truthful, due to the great number of variables to be considered and which are unknown for this case.

As a precautionary measure, the manufacturer included the case of LV-WPY (without its identification) in its website in order to inform all operators of similar aircraft.

Issuance of a "Safety Alert" to the NTSB (USA)

The JIAAC issued a Safety Alert to the NTSB Office of International Affairs, with a copy to the DNA, stating the mistakes found in the documentation and in the markings, both in the piston involved in the accident. These outcomes could also be present in other elements processed by the same company in other parts of the world. Immediately, the NTSB distributed the document to the related Federal Aviation Administration (FAA) offices and to the aircraft manufacturer so that they take measures about this.

Operative analysis

Flight recorders were in service and data were obtained. According to the interpretation, landing was carried out in the right way for the present circumstance.

Passengers were duly informed about the situation by the pilot in command himself, and, even though some of them were nervous, the situation was controlled by cabin crew in a correct manner.

Technical analysis

The factor triggering the accident was identified as the fact that the wheels axle nuts were original (standard) while the piston had second reworked threads, which should go with matched up second oversize axle nuts.

The reason to use reworked elements is basically technical-economical, since they are parts that have suffered wear and tear in their threads and thus they fall outside standard tolerance; that is why they are reworked. This procedure is approved by the manufacturer in its CMM and it is allowed up to a third rework, in the case of the pistons.

The installation error of these standard nuts was mainly due

Photo 9. Axle tip vibro engraved inscription, covered by painting (view after painting removal).

to the following factors:

1. Separation of the piston and its matched up and serialized fastening elements during its removal 8 months before the accident. This action could be understood due to the fact that the staff was not aware of the existence of reworked elements.
2. Inadequate communication was discovered here regarding the information available for lower level personnel and the lack of consultation of the latter to their supervisors about the existence of an unusual element in the task (a yellow nut).
3. During the installation of the wheel with standard nuts on the reworked piston, the personnel did not count on any marks warning about this situation, thus duly carrying out the task and with the usual elements. The markings mentioned—the vibro engraving on the axles tips was covered by painting, and the yellow band with the relevant inscription was not present.

The maintenance manual did not warn against this situation. Even though the nut clearance was evident when installing it manually, the threaded joint absorbed the established torque without any problems.

Cause

During the takeoff phase of a scheduled air transport flight, the inner wheel came off the left main landing gear, which caused an emergency landing, during which the external wheel of the same landing gear came off, due to the installation of standard fastening elements for the wheel, on a reworked assembly.

Contributing factors

- Lack of warning inscriptions of it being a non-standard element, on the landing gear leg, by the repair workshop that had carried out the piston overhaul.
- Lack of warning about the existence of reworked elements in the aircraft maintenance manual.
- Ignorance of the operator's mechanics about the installation of reworked parts.

Safety recommendations

To the operator

Consider the convenience to establish procedures aiming at improving communication among mechanics, supervisors, inspectors, and higher levels, such as the implementation of working groups in classrooms, the utilization of suitable techniques that enable the strengthening and improvement of interpersonal relationships, and the development of maintenance resource management (MRM) programs.

Consider—in order to improve safety levels in the maintenance activity—including the facts leading to the present accident in the technical training program developed by the company to avoid a similar condition in the future.

Consider the improvement of their established procedures for receiving parts not listed in the landing gears documentation, regarding all not interchangeable, not storable, serialized/matched up parts, that form an indivisible part with their corresponding component.

Consider the improvement of communications and of information flow between technical managements and the logistics chain common in the business group, when there are supplies policies changes, such as the admission of reworked elements into the fleet.

To the National Transportation Safety Board (NTSB, USA)

Consider the convenience to submit a recommendation to the Federal Aviation Administration (FAA) so that in Form FAA 8130-3, in the "Remarks" box, indication is given in the necessary cases of the condition of the element as reworked and/or having matched up or easily removed parts.

Consider the convenience to submit a recommendation to the aircraft manufacturer with the following:

- Include in the MD model aircraft maintenance manual (AMM), in the chapter corresponding to wheels installation, a clear warning about the utilization of special elements necessary to mount assemblies with oversize elements. These inscriptions are present in other AMMs. **(Accomplished by the manufacturer Feb. 25, 2005: A warning will be added in the upcoming revisions of the AMM affected airplanes).**
- A possible change in the design of matched-up parts, such as a variation in the threads pitch of oversize elements, that do not allow the interchangeability with standard ones.
- Consider the convenience to submit a recommendation to the landing gear repair workshop with the following:
- Carry out the corresponding warning markings, in a perfectly visible way, on the reworked parts. ◆

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A CFIT Accident: Lessons Learnt

By Capt. Carlos Limón, IFALPA Deputy President

On July 8, 2000, a British Aerospace Jetstream 31 had a CFIT accident when operating the route Tuxtla Gutierrez (Chiapas) to Villahermosa (Tabasco) in southeast Mexico. All 19 people on board perished as a result of the accident.

You will probably question the importance of reviewing an accident that happened 6 years ago. However, during the presentation we will analyze, based on Reason's Model, the chain of errors that led the crew to this CFIT accident. Indeed, we will discover several lessons of what should not be done. Moreover, the most important lesson can be found in the actions taken by the airline and the Mexican government to avoid having other accidents like this one.

This could be an example to be followed by other countries similar to Mexico, with limited resources to invest in infrastructure, for instance, in navaids, precision approach systems, and so on.

Tuxtla Gutierrez Airport has an elevation higher than 2,000 feet. It is located in a plateau in the middle of a mountain chain. Because of this location and the weather conditions around the area, it is very common to find low visibility at the airport due to fog and clouds. We must remember that the three main ingredients for a CFIT accident are low visibility, mountainous terrain, and non-precision approaches.

Even though the airport has an ILS, there are a lot of mountains in the surrounding areas, making Tuxtla Gutierrez a very complicated airport to operate. Since the airport was closed for long periods because of low visibility, the decision to stop its operation was finally taken. A military base was used while a new airport was being built in a better location.

The day of the accident, the visibility was reduced as a result of the fog. The air traffic controller "was estimating" that the weather conditions were above minimum for operations. Consequently, the airport was operating normally.

Because of the low visibility, most of the regular flights had been delayed. This was the case of our J31 that was operating the flight Aerocaribe 7831. The originally route was from Tuxtla Gutierrez to Veracruz. Owing to all these delays, the crew was instructed to stop in Villahermosa for passengers going to that destination.

The total length of the flight was less than 30 minutes. This allowed us to analyze the CVR from the moment that the crew was taxing to the runway in use to the moment of the accident. From this analysis, we observed that several mistakes had been made starting from the very first moment of the takeoff clearance—errors that resulted in the CFIT accident.

It is unbelievable to witness the amount of errors made in a very short period of time. Throughout the presentation, we will discuss most of them, including loss of situational awareness, communications, deficient SOPs, complacency, weather, ATC, and so forth.

In addition to the performance of the key players involved in this accident, we will review Reason's Model, where the failures and latent failures prevailed over all possible defenses. We will also discuss the recommendations and actions taken by the airline and the Mexican DGAC in order to prevent similar future accidents.

It is important to note that at the moment of the accident, Mexico was the only country that had established mandatory CFIT training, based on the material developed by Flight Safety Foundation and translated into Spanish by Colegio de Pilotos Aviadores de Mexico (the professional pilots organization recognized as an authority advisor). As a consequence of the CFIT training, in Mexico we have not had a CFIT accident since July 2000 in airplanes for 13 or more passengers doing commercial operations.

In order to reinforce the CFIT training, almost 2 years ago, the DGAC mandated that all the pilots must present the ALAR (Approach and Landing Accident Reduction) training certificate adapted from the Flight Safety Foundation ALAR toolkit.

On the other hand, Aerocaribe improved its SOPs and training manuals. It was also the first airline in Latin America to implement Robert Sumwalt's concept of pilot flying and pilot monitoring.

Conclusions

This presentation and the analysis of the accident could help countries like Mexico with limited resources to invest in infrastructure and to develop training programs with the solely goal to reduce accidents and have safer operations. ◆

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The Advanced Qualification Program (AQP) as a Tool to Break The Chain of Accidents

By Claudio Pandolfi (AO4028), Safety Manager, DGAC–Chile

Introduction

Since the first flight of the Wright Brothers in Kitty Hawk in 1903, until the early days of the present century, "*the human factors have been responsible for air accidents,*" i.e., more than three out of four accidents (80%) are due to problems related with human factors (ICAO Doc. 9683 An-950).

According to Dr. A. Kotaite, from the International Civil Aviation Organization, 2004 was the safest year in the world aeronautical system. Nevertheless, 2005 stands as a contradiction against the trends shown by the history of flight safety. In the present study we will try to demonstrate that the advanced qualification program (AQP) breaks the present tendencies related to aviation accidents and promotes the use of 21st century technology in aeronautical operations in a safer and more efficient way. We will start by defining the basic concept of AQP as Dr. Thomas Longridge (1998) describes it: *"The systemic methodology in the development of instruction, training, and evaluation programs for crews and air dispatchers, including skills in CRM."*

Starting from this hypothesis, we will analyze historical background, to eventually check some national and international statistic data, as well as the techniques we are using to face the human factors dynamics as a proposed strategy. We will also look at the conceptual way to achieve quality training along the context of this complex operational dynamics and how high-technology systems admit a real air safety solution according to 21st century trends. Thus, these guidelines will allow us to reduce the present tendencies that generate accidents with catastrophic consequences.

Following the above, we will expose how we are facing these new challenges through the application and adaptation of the AQP program, according to a platform that was defined and transferred by the United States aeronautical authority, with the support of Dr. Douglas Farrow and Chris McWhorter from the FAA. Within this theoretical frame, we will show the tools used to aim through adapted models in human factors training, under the Shell Model concept (Edwards/Hawking 1975), together with using the opportunity windows described by Reason (1990), and the model developed by Novis and Bendito in 2000, which allows us to consider the skills and behaviors of the sixth generation CRM, the last being based on the TEM Model (Helmreich 1998), of error management.

In the same order of ideas, we will show how we are managing operational risks (MAROP) and the way to integrate all these concepts under one common system related to the air Safety Management System (SMS), based on the application of ALARMA type programs (CFIT/ALAR toolkit), LOSA and FOQA, and once this information has been processed, updating the AQP program.

Through these options, we have defined for short and mid term the targets for its implementation, for which we are applying the technological innovation that will lead to the optimization of *instruction, training, and supervision* factors for the air crews in their interaction with the different kinds of technological contraptions, which allow the adaptation to our operational cultures and regional and socioeconomic realities.

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Genesis and development

The application of human factors in commercial aviation has been a tool that led to various ways of implementing safety flights, but its verifications in real operations had yet remained more as a recommendation than a true way of theoretical and practical training.

We can show that the advanced qualification program, or AQP, is based on the operational form of the human factor training, and on the so-called management skills of the crew resource management. Concerning the AQP program, we will talk of an ACRM (advanced crew resource management), or advanced CRM, which is directly related to the behaviors evaluated in today's operating commercial aviation

What is the AQP program and what is it for? Will AQP break the current accident barriers? Is this model a vanguard system? The answer to all these questions is undoubtedly YES, as a systemic way to face the instruction, based on the technology available in the 21st century, and using for this CRM skills and tools. Another open question would be: Is the AQP model based on human factors? Here too the answer is positive; in order to apply and develop this program, it is essential that the companies apply the systemization of the different human factors concepts that are based on the models published by Shell (Hawkins 1975) and TEM (Helmreich and ICAO).

This program has been applied since the early nineties and reveals itself as a proposal for the U.S. air industry, under the supervision of the Federal Aviation Authority (FAA). Its main lines have been led by Longridge and Farrow, from the FAA, which certainly allowed to create the most efficient way of operational training at a global level, and in my opinion, has permitted to break barriers and trends in accident rates, thus generating a more efficient and secure system.

What is the AQP? What makes it distinct from the traditional programs? When we analyze and check the distinct models applied at a global level, be it by Europe or the United States, we can acknowledge important differences, through which the AQP system demonstrates a more systemic and efficient application to the real world of operations. A comparison lets us see that the JAR 1978 regulations only includes tendencies and general application requirements of an AQP style model, while a detailed analysis of the standards defined by the FAA's AC 120-54 allows us to appreciate a complete and systemic application of this model to the commercial air operations.

First, let us analyze the AQP origins and genesis. This program results as a natural expression of the companies in the North American system, where the multitask groups needed a deep and auto-critical study of the various failures and accident trend labelled according to the phenomenon called "operator error." Moreover, this study was oriented to the research of operational trends that might bring systemic improvements into the air industry. This resulted in the constitution of several multi-task work groups under the leadership of the aeronautical industry, the FAA, NASA, and the commercial companies, in order to optimize air safety factors and achieve scale economies that allowed the latter to be the safest and most efficient transport means in the eyes of the public. It is this voluntary work that generates an advanced knowledge around 1988, that grows in 1989 in such a way that may appear the first training profiles in environments that are typical or adapted to the real world of operations, or typical evaluations (LOFT/LOS) for the air business. The instruction theory was defined by Bloom's taxonomy, the latter being the basis of this descriptive study, which described in detail every move to be performed or expected to be used in operational training.

In 1990, the start is given under the FAA's supervision, and the AC-120/54 is created, together with the SFAR 58 special regulation, which is presently obsolete. This program is based upon a voluntary application by the different companies and aims to obtain validated and free access data from the FAA, under a defined chronogram of events that considers five stages in order to achieve the final qualification of the complete application and chose the AQP program.

After analyzing the statistics at a worldwide level, the ICAO signals then in its document C-302-AN/175 that the USA and Canada maintain at global level a rate of 0.5 accidents per million flights, taking into account that over half the world's air traffic takes place in the area included between Mexico, Canada, and the United States. Under this perspective, we may thus say that the operations in this area undoubtedly show a definite leadership, as this region is the only one that uses this innovative program, and is based on the systemic application of human factor as an essential component of the theoretical and practical training. This is where the AQP program plays a vital role in air business, as this program has allowed an indirect control and compelled the operators to apply the human factors tools together with an objective assessment of the behaviors and skills of the crew resource management (CRM), which are an integral part of the instruction and continuous evaluation programs for air crews.

During the late IATA meeting held in Santiago, Chile, at the FIDAE 2006 aerospace fair, the phenomenon generated by the low-cost companies was pointed out, as the latter have to respect two variables that the public is not ready to give up: the cost of the ticket and air safety factors. "Who does not understand this will fail." With this statement, the ICAO President Bisignani clearly expresses the new model that the air business has to face.

The goals of the AQP program

The operational purpose of this innovative program consists in seeking excellence in the instruction processes, which have to be clearly defined at all stages, and clearly describe each one of the events to be assessed by using the technology available in our century. Since the beginning of the process, it is compulsory to define the formula and the way to use the technological level at hand, where basic training computers or CBT are the perfect tool for the initial stage, when used in conjunction with the syllabus concept or E-learning. A second stage is defined by the use of more advanced programs in flight training machines, of FTD, which allow to perform hundreds of maneuvers, and activate systems such as hydraulics, FMS, or typical failures (Dismukes), and leave the third stage for the application of theoretical as well as practical knowledge in full level, or Category D simulators: these are called full-flying simulators (FFS) and allow to integrally qualify the pupil and operate an aircraft without actually having to fly it. This is where the AQP program plays a vital role, as this gives quality training to even the less experienced pupils and balance the errors, thanks to more real training that generates an optimum training level.

During this essential stage, it is possible to achieve an efficiency that it is actually possible to operate an aircraft without having previously flown it physically, though this generates doubts among some flight instructors. This constitutes a new paradox in advanced simulation (Dismukes 1998). In this case, the AQP program lets us objectively assess every stage of CRM behaviors and skills, thanks to the high level of realism in the simulation of real situations under specific characteristics. Not only does it lead us to apply theoretical and practical concepts, as their interaction between all the crew members, such as language, communication factors, situational awareness, and decision-making among others, just as expressed in the Novis/Bendito Model (2003). The latter is used in Europe and allows us to analyze the strategies applied under an operational context. The AQP program also shows the importance of training regarding the dilemma of shared situational loss of awareness, which under high stress provoke the appearance of typical cultural problems which are not fully instructed, such as the typical Macho Pilot concept, so characteristic of our Latin American operational environment, and which requires special attention.

The AQP program's major goal is to achieve *quality training* based on the continuous improvement concept, in which the instruction is assessed and checked at every stage, thanks to a permanent analysis that generates a real knowledge of the instruction level status in the company. It must also be pointed out here that the application of this kind of program is totally based on free will of the companies, so its development will exclusively depend on the company that chooses this excellency qualification.

As regards the Chilean aeronautical authority, this kind of supervision is carried out by a unique bureau, in a similar way the FAA does it: Office 230. This department centralizes the information and allows a permanent supervision of the different stages involved by the companies in the implementation of the AQP program.

In summary, this program aims at theoretical and practical training levels to be actually applied at the various stages determined by a company, and at being an integral form within the latter's instruction and training programs. It also allows the development of its operational culture and leads to a quality standard that is its main target, together with the creation of a system that can tolerate the operational error, as stated by the ICAO, as well as Helmreich (1998) in his Threats and Errors Management Model (TEM), and Reason (1996) through his concept of the human error in his famous Swiss cheese.

The AQP program integral concept

It is based on the SHEL Model (Hawkins 1975) describing the interaction among man, machine and environment, and how under certain operational circumstances human beings make stupid mistakes. Moreover, when we carry out a reactive exam according to the ICAO's Annex 13 regarding the investigation of an accident, this model allows us to visualize a part of the equation regarding this problem. Nevertheless, and in spite of ergonomic improvements to come, operational errors *are and will be* a part of the operational world, and as long as we train in the most real way that is possible, in an integral form and using agreed procedures, it will be possible to reduce our accident rate, or at least to revert certain present trends. We think that is not enough to use and apply all the operational resources allowed by our organizations (CRM) as these only ensure a certain air safety level, and that through the implementation of the AQP program it will be possible to reach better operational levels, which will match the technological level that we operate in this century of communications. We will take just an example with the different problems that occur today during the phase of undercarriage extraction. In our 21st century, the old saying: "There are two kinds of pilots, the ones who land with the undercarriage up, and the ones who will" remains valid. It is not enough to have a standard operational procedure (SOP) and isolated programs that do not interact and are copied from different operational cultures.

From the application of Helmreich's TEM Model, we may state that as long as we maintain a real training level by applying and assessing the behaviors, or CRM skills, the latter will avoid opening opportunity windows, and let us focus on the operational error itself. The AQP is precisely that, a tool that allows us to break traditional paradigms in conventional instruction, and supplies us with a friendlier system, with a major error tolerance for the operator, and thus reduces our present operational trends, at a regional or global level.

From the natural evolution experimented by the first generation CRM, when it first focused on the crews or the cockpit, to the present evolution that naturally integrates the Threats and Errors Management Model, which seeks to manage the undesirable situations know as TEM, thus allowing a more holistic vision of this problem. Man can now manage his own errors and escape from an event with possible catastrophic effects, at being able to avoid it or "successfully manage a determined event" thanks to his capacity to control undesired situations: this is what we call 3M—that is the management of threats or lapses, and thus the ability to avoid an undesired situation and its catastrophic effects. The new paradigm should now consist in learning from successful operations, which represent more than 98% of the events worldwide (Maurino 2005) instead of focusing as we currently do on the accidents and having a more reactive than proactive vision. This is our great challenge: stop being reactive, as reflected by the Heinrich pyramid (1930) and be able to invert or at least modify its base so that our actions are more proactive.

Through our present knowledge, we define as an expect level that of a crew who still makes operational errors of any kind but is able to manage them and return to a normal or low-risk level. This is what AQP is leading to our crews are training in an operational environment that is completely similar to the real operational world (LOS/LOE) and generates an environment of efficiency and safety, which leads to a change in our current trends, avoids losses to the air business, and consequently makes the world air system more efficient and eventually safer and more cost efficient.

The tools provided by the AQP program allow training that is based on what actually happens in the real operational world, and feeds with action a reliable report system (SARSEV, BASIS), an operational quality verification program (FOQA), and a line operational audit system (LOSA) that all permit, thanks to a common language, their interaction in an air safety management system (SMS). This global frame feeds the instruction processes by accessing a standard based on a continuous improvement, with an empirically validated model that allows applying coherent strategies to the distinct instruction processes destined for our air crews.

The AQP model and its certification stages

Among the qualities of this program, we can point out that it describes with full details the distinct characteristics, skills, and achievements expected to be applied in the instruction process, based on Bloom's taxonomy (1948), which allows multitasking. This stage is the basis of the AQP program, and is the longest to develop in the company, as it requires the application of the distinct agreements that tend to define the resumes and the standards the company will use for its operational system, which will have to include the necessary corrections as it advances through the different stages.

As per the above, experts are needed in all the areas involved, such as instructors, pilots, systems engineers, programmers, technicians, psychologists, and teachers. This working team will have to define the typical resume to be implemented in this phase, as well as the feedback method. This stage will also have to explain how to instruct the personnel involved, as well as the chronogram of defined events, for our operational reality. This is being implemented in the Airbus A340 fleet as an initial stage.

A second stage will check and correct the system, on the basis on the recollection of objective evidence, applying the Deming purpose together with the distinct observations found. From there the curricular models will be corrected and the changes performed, completely or partially. We can take as an example of the latter a typical maneuver in which the council or instructors committee objectively determines that the required action has been badly assessed and does not match the program's specific goal, after which the latter is corrected and a new standard is redacted. Maneuvers will also be added or modified that result from the daily operational experience, based on the information recollected by other parallel programs under the safety management system (SMS); for example, the flight safety anonymous report system (SARSEV), the flight operations quality assurance system (FOQA), and in-line safety audits (LOSA), together with the integration of a flight safety voluntary anonymous report system, which is at the official publication stage by our national aeronautical authority.

A third stage will seek the updating of all the programs, and as these systems are working and integrated in the reality and based on a common language of an SMS-type system. The creators and the council of instructors will analyze the global information together with their respective aeronautical authority (DGAC inspectors) and define the changes that will bring a real continuous improvement. This information will help provide feedback to the company and update the latter's databank, thanks to coordinated work that will tend to overcome the deficiencies of the previous stages and establish a continuous improvement as a quality standard.

In order to pass the fourth stage of this program, an empirical experience and minimum operations times will be required, which is fundamental to be able to compare the distinct observations from the previous events; for example, a deficiency in FMA operation or ACARS, the configuration of unexpected approximations, or the non-respect of standards during the stabilized approximations of the Flight Safety Foundation ALAR program, or the deficient use of language at critical moments, among others.

Eventually, once all the previous stages are concluded, the fifth stage is reached, after which the AQP program certification is obtained. We have assessed this will take 24 to 36 months to achieve, so the process will always remain under the constant supervision of the respective authority. In the case of Chile, an initial program has been launched and is now at the closing stage for the A340 fleet, after which the corrections will be applied to instruction courses, and the distinct deviations corrected by applying the Deming cycle aiming for a continuous improvement before directing the efforts to the Boeing B767 fleet, and then to the other models.

Operational cases and challenges

In our reality we have known cases that after takeoff and during the climbing phase, the crew has seen all the screens of the glass cockpit remain dark and show only the mention "Please Wait." After having tried to solve this problem without any practical results, the captain has finally taken the right decision to get back and land manually, eventually achieving a successful landing, but the analysis showed that the system initialization (INS) had not been performed correctly on the ground—a clear case of human factors and CRM skills, so it has been decided to give a higher emphasis to the FTS and FFS phases, through more theoretical as well as practical instruction hours.

It is important here to point out the situation experience by our crews when operating in extreme or high-latitude areas, which is the case in the most southern sector of Chile, and specifically in the Magellan Straits, where spring and summer are seasons of strong winds of hurricane type, averaging 28 to 35 knots with peaks up to 55 knots at evening, that generate real tempest conditions. We know the case of a high-technology aircraft that could not land normally three times in a row, as the automatic system caused the abortion at low altitude because of an excess of cross wind. The situation generated some uncertainty among the crew, who eventually decided to land manually, with all the limits involved. Once the data of this case were analyzed, it resulted that the man/machine interaction (Shell), made of human factors and CRM skill, had not been correct, which generated a reinforcement of theoretical and practical training, including typical applications in FTD and FFS simulators.

Finally, another remarkable case, still under study today, is the phenomenon called logarithmic sum, in which a qualified crew applied during takeoff an attitude beyond the one requested for this stage of flight, having the aircraft react automatically, which generates for a few seconds a total uncertainty among the crew. This unusual attitude required a study involving the company and the aircraft maker, in order to clarify this uncomfortable operational situation. These facts, once the data were checked and the parameters were corrected, required a further reinforcement in the instruction processes, the use of human factors techniques, and a practical reinforcement at FTD and FFS training.

The distinct challenges involved in the implementation of the AQP program in our operational system have generated new requirements and operational standards in the use of such systems as ILS Cat III-B, EGPWS, TWAS, TCAS II, WAAS/LAAS, RNP, ATM, and ADS-B. The instruction processes are fundamental in achieving a real man-machine-environment integration and to use it in a safe and friendly way. As long as our practical formation and qualification processes lead to a systemic implementation of AQP, as close as possible from the operational reality, we will eventually avoid the classic operator or human error and break the present trends that cause accident with catastrophic effects at regional level.

Conclusions

We have started this study showing the goals and stages necessary to accomplish an AQP program, and pointed out the importance of implementing skills in the CRM behaviors, and human factors checking in the distinct instruction processes, based on the SHEL and TEM Models and the application of different levels of basic or advances simulation through the AQP prism. This will allow us to obtain quality training with a degree of objectivity in the different theoretical and practical training processes, leading to apply a systemic application to these processes and to the friendly use of the technology available in our century.

- *From the above we may state* that the AQP program is a new standard that allows a quality training to be dispensed, using the technological discoveries of the 21st century.
- *The kind of assessment*, the methods, the innovation, and the instruction techniques constitute a process that generates valuable synergies leading to the production of a safer and more efficient air business system.
- *The evolution of the behaviors and skills in CRM and human factors* are essential in order to achieve success in this kind of advanced qualification program, or AQP.
- *In the AQP, the programs and distinct stages are clearly defined* and adapted to the company, allowing us to have clear and achievable goals.
- *In its implementation, the aeronautical authority as well as the company forms* a team that, thanks to a proactive work, will jointly generate a safer and more efficient system to be acknowledged as a leader system, at regional level as well as worldwide.

Finally, we insist in stating that the AQP program is a valuable tool that permits us to *"break the accident chain and change our traditional paradigms in the air business environment."* ◆

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Risk Analysis Methodology Application and Results for Product Safety Monitoring at Embraer

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Safety Management Systems and Product Safety Monitoring

At the beginning of the modern commercial aviation transport era, the happening of serious events showed the need to improve knowledge on new technologies. The safety challenge at that time was to develop techniques to support complex investigation processes (Figure 1). The results of those investigations led to technology and safety improvements to reach the current safety levels.

Detailed and complete investigation processes are still important nowadays to support the continuous improvement of the industry safety levels. However, some of the recent occurrence investigations indicate that many accidents contributors did not come from unknown technical conditions but resulted from the incorrect application of established techniques. In most cases, critical conditions already existed in the past but were not adequately addressed. Current industry safety focus is the monitoring of potentially unsafe conditions in the day-by-day operation and the implementation of a Safety Management System (SMS), terminology widely used within the air transport industry.

However, in this regard, as there is no definitive meaning to the term "Safety Management System," each organization has its own interpretation. The SMS components depicted as "The Ten Commandments of a SMS" in Figure 2 are only general guidelines. To reach a useful process, it is necessary to adapt these guidelines to the existing conditions and objectives. An SMS for an airline will be diverse of that for an aircraft manufacturer. Although a manufacturer is also an operator of its own prototypes and production aircraft and must manage the safety of its daily flights, additionally it is required to focus on its product safety after delivery, through the monitoring of in-service fleet performance.

The analysis and review of fleet in-service difficulties reports have

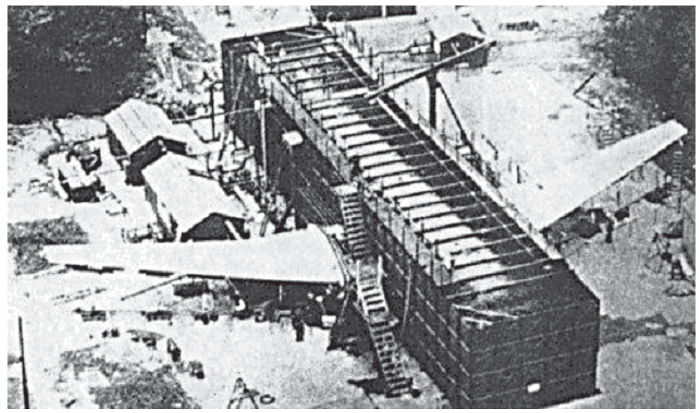

Figure 1. Special test procedures as part of the accident investigation process.

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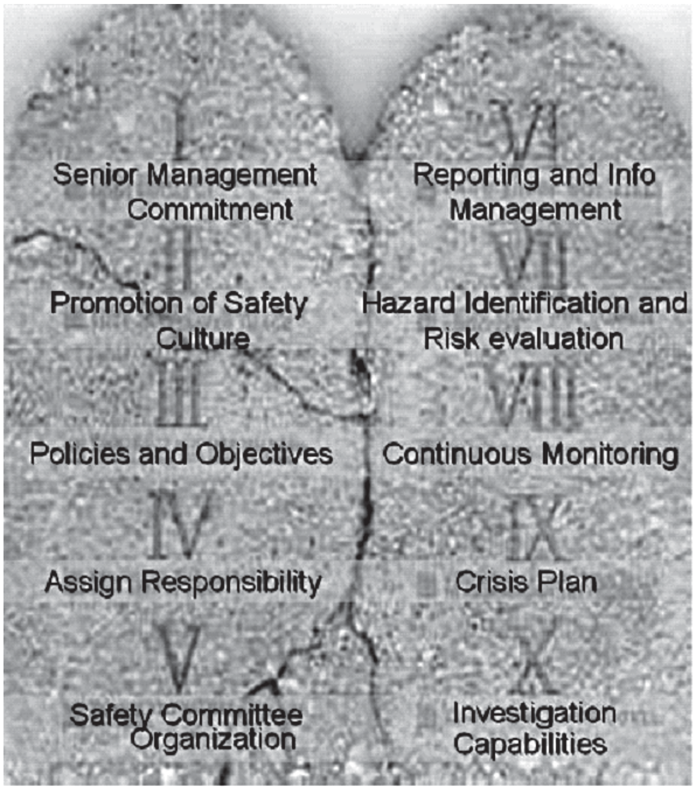

Figure 2. Safety Management System (SMS) components.

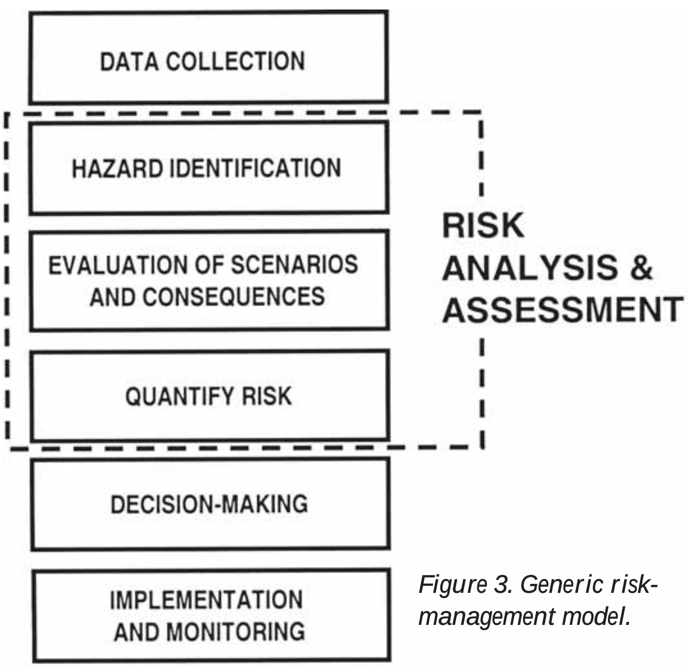

Figure 3. Generic risk-management model.

been a key part of the formal continued airworthiness process, where manufacturers and operators are required to report to the Certification Authorities the relevant failures, malfunctions, or defects of an aircraft or component. This traditional way of fleet monitoring can be improved with the use of SMS principles, resulting in a process that is being denominated "Product Safety Monitoring."

Risk analysis and Product Safety Monitoring

As with a typical SMS, Product Safety Monitoring is based on the traditional safety risk management model. The objective is to establish a systematic process to identify and evaluate safety risks, providing input to decision-making and action planning. The core of this process is the risk analysis and assessment[1] (Figure 3).

Likelihood	SEVERITY				
	No Safety Effect	*Slight Reduction In Safety Margins*	*Significant Reduction In Safety Margins*	*Large Reduction In Safety Margins*	*Potential For Multiple Fatalities*
Frequent	Low	Moderate	High	Very High	Very High
Probable	Low	low	Moderate	Very High	Very High
Remote	Low	low	Moderate	High	Very High
Extremely Remote	Low	low	low	Moderate	High
Extremely Improbable	Low	Low	Low	Low	Moderate

Figure 4. Example of risk-assessment matrix.

$$\text{Severity} \times \text{Likelihood} + \underbrace{\text{Level of control}}_{\text{Reflects the uncertainty regarding assumptions made and the knowledge and control of the related technology.}} = \text{RI}$$

Figure 5. Preliminary Risk Index (RI) calculation.

There is no universal method to identify or evaluate hazard scenarios. The appropriate procedure depends on the specific situation. Experience on the related matter is always necessary to ensure a reasonable analysis. But a standardized procedure for risk assessment is required to convert the risk analysis results into a measurement that will drive the decision-making process. The selection of an effective risk-assessment procedure must cover the following objectives:

1. The most obvious focus is to provide a realistic quantification of the associated risk. Basically, the method shall establish a standard to measure the answers of the following questions:
   - What is the severity of consequences on different scenarios?
   - How frequently these conditions can happen?
   - How confident are we about the assumptions made on the answers?
2. The second, but not-less-important, objective is to establish a safety communication standard within the organization. The selected procedure must drive the discussion and define the acceptable safety levels, allowing the involved company areas to have the same understanding regarding the priority of the related issue.

A practical risk assessment procedure

There are different interpretations and applications for a risk assessment, but the root idea is the same: risk is the combination of severity and likelihood. Usually, the risk assessment results are presented through a matrix, as shown in Figure 4.

Instead of using a matrix, the risk assessment procedure may assign a value for each hazard classification and probability level and use these values to calculate a Preliminary Risk Index (RI). The resultant index (Figure 5) will indicate the risk evaluation and, consequently, will be the reference for the priority to be given to the issue.

The use of this procedure has shown advantages of attaining the main objectives of the risk evaluation, as discussed below:

1. In addition to using the severity and likelihood evaluation, the method also takes into consideration a "level of confidence." Although the analysis should use the best available information,

	Immediate Risk Reduction			Risk Reduction			System Review
RI	≥14	13	12	11	10	9	8
Define Action	12 Hour	2 Days	3 Days	1 Month	2 Months	3 Months	6 Months
Action Availability	24 Hour	4 Days	1 Week	2 Month	3 Month	6 Months	18 Months
Time for Action Accomplishment	Next Flight	50 FH	100FH	A*- 5A*	5A*- C*	1 C*	2 C*

* Consider the equivalent to the "A" or "C" check flight interval hour for the applicable fleet

Figure 6. Example of actions priority related to the RI.

① Issue Description:			
② Reported Condition:	Severity (S)	Likelihood (L)	S x L
③ Conditions that may raise the Severity:	Severity (S)	Likelihood (L)	S x L
④ Worst Case – Highest value of S x L			
+			
⑤ Level of Control (reflecting the uncertainty regarding assumptions made and the knowledge and control of the related technology)			
⑥ **RI** =			

Figure 7. RI calculation formulary.

each estimative will always have some degree of uncertainty and the Risk Index can always be considered as "preliminary." The "level of control" reflects the uncertainty regarding assumptions made and the knowledge and control of the related technology.
2. The procedure is also a strong way to establish a safety communication standard within the organization, replacing the traditional approach to divide issues into "*safety concern*" and *"no safety concern"* categories, since this approach is very subjective and does not establish priorities for safety-related issues. Using the RI, the safety priority of each issue can be directly perceived by all involved company areas, with a time-reference table like the one depicted being constructed (Figure 6) and then taken for reference, added to other means of actions and controls.

Preliminary Risk Index (RI) calculation

As already commented previously, Product Safety Monitoring focuses on the aircraft system failure conditions and associated hazards. Evaluation of the effects on safety of foreseeable failures was already performed during aircraft design and certification processes, following system design and analysis requirements of AC/AMJ 25.1309 guidance. The risk assessment procedure adopted by Embraer also takes into consideration the AC/AMJ 25.1309 failure condition classifications and resultant safety assessment certification reports. The use of this standard helps answering basic questions such as "What is the failure condition severity?" or "What are the safety objectives?"

The RI calculation procedure intends to establish the company standard for safety risk evaluation. The basic steps for determining the RI regarding a specific issue are detailed below. The formulary shown in Figure 7 can be used as reference.

S	SEVERITY	CONSEQUENCES: Airplane	Crew	Passengers
0	*NO SAFETY EFFECT*	No effect on operational capabilities or safety	No effect on flight crew	Inconvenience
1	*MINOR*	Slight reduction in functional capabilities or safety margins	Slight increase in workload	Physical discomfort
2	*MAJOR*	Significant reduction in functional capabilities or safety margins	Physical discomfort or a significant increase in workload	Physical distress, possibly including injuries
3	*HAZARDOUS*	Large reduction in functional capabilities or safety margins	Physical distress or excessive workload impairs ability to perform tasks	Serious or fatal injury to a small number of passengers.
4	*CATASTROPHIC*	Normally with hull loss	Fatalities or incapacitation	Multiple fatalities

Figure 8. Severity evaluation.

L	LIKELIHOOD	Average Probability per Flight Hour	Qualitative description
5	***FREQUENT***	Greater than 10^{-3}	Recurrent condition that occurs many times during the operational life of each airplane.
4	***PROBABLE***	from 10^{-3} to 10^{-5}	Anticipated to occur one or more times during the entire operational life of each airplane.
3	***REMOTE***	from 10^{-5} to 10^{-7}	unlikely to occur to each airplane during its total life, but which may occur several times when considering the total operational life of a number of airplanes of the type.
2	***EXTREMELY REMOTE***	from 10^{-7} to 10^{-9}	not anticipated to occur to each airplane during its total life but which may occur a few times when considering the total operational life of all airplanes of the type.
1	***EXTREMELY IMPROBABLE***	Lower than 10^{-9}	so unlikely that they are not anticipated to occur during the entire operational life of all airplanes of one type.

Figure 9. Likelihood evaluation.

① Brief description of the issue being evaluated.
② Evaluation of the severity (S) and likelihood (L) of the reported condition.
③ Evaluation of scenarios or failure combinations that can raise severity.
④ Consider the worst condition (highest S x L).
⑤ Evaluate the level of control.
⑥ The RI will be the sum of (highest S x L) + (level of control).

Severity evaluation—The severity (**S**) of reported condition or possible scenarios being considered can be classified from 0 to 4, as detailed below (Figure 8):

Information from the system safety assessment certification reports (FHA—functional hazard analysis or FMEA—failure mode and effect analysis) shall be used for reference. Whenever necessary, additional tests or simulations can be performed, providing specific information.

Likelihood evaluation—The likelihood (**L**) must be classified in one of the levels (1 to 5) detailed in Figure 9. Unlike from the severity evaluation, the likelihood for a reported condition shall not be based on the system safety assessment certification report, but evaluated considering fleet monitoring and the rate of related reported occurrences. The likelihood of possible scenarios that can

Level of control	Uncertainty regarding assumptions	Control of the related technology	Example
0	Low	High	Severity evaluation clearly defined on Safety Assessment report and Likelihood can be based on fleet monitoring. and System provided by aircraft manufacturer or from a company with very good response history
1	Medium	Medium	Severity of conditions could not be clearly identified on Safety Assessment report or fleet monitoring does not guarantee assumed Likelihood or System provided by a company with good response history
2	High	Low	Severity of conditions could not be clearly identified on Safety Assessment report and fleet monitoring does not guarantee assumed Likelihood. or System provided by a company with poor response history

Figure 10. Level of control evaluation.

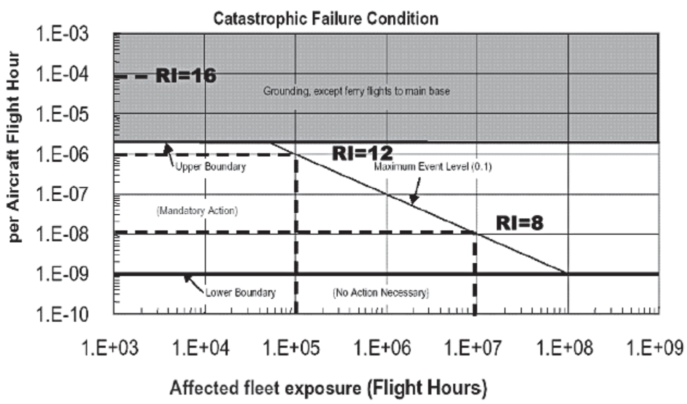

Figure 11. Relation between the RI value and fleet exposure, based on the EASA guidance material.

raise the severity level shall be evaluated based on the combination of individual probabilities of each condition being considered.

Evaluation of scenarios and failure combinations—Consider conditions diverse from the reported, like different flight phases or combination with other failures, evaluating severity (S) according to Figure 8 and likelihood (L) according to Figure 9. The extension of this analysis will depend on the issue being evaluated, as the simultaneous failure of dual systems or loss of systems on critical flight phases (takeoff, landing) must be considered whenever relevant.

Level of control—The level of control is probably the most subjective part of the RI. The idea is to quantify the uncertainty regarding assumptions.

Knowledge and control of the related technology (if the system is provided by a third-party O and M, for example) can also be considered. The evaluation of the level of control shall be based on an engineering judgment regarding the related issue. The level of control can be considered as a deviation range for the RI calculation. The practical effect is to raise the RI value whenever the uncertainty is high or there is low control of the related technology, as shown in Figure 10.

RI=8	RI=12
Define Action – 6 months	Define Action – 3 days
Issue Document – 18 Months	Issue Bulletin – 1 week
SB Compliance – 2C Check	SB Compliance – 100 Flight hour

Figure 12. Relation between the RI value and actions priority, based on the EASA guidance material.

Acceptable action schedule

Risk quantification makes no sense if not linked to an action priority reference. In search for an acceptable published reference for establishing rectification campaigns, the EASA guidance material *"AMC and GM to Part 21,"* published by the European Aviation Safety Agency proved to be a useful material. This document provides a set of charts associating the severity and probability of safety-related malfunction with the aircraft and fleet maximum acceptable exposure. The benefit of these guidelines is to form a datum for what is considered to be the theoretically maximum reaction time. As the EASA document also uses the safety assessment (AC/AMJ 25.1309) taxonomy, it is possible to position different RI values on the charts provided. This will result in a relation between the RI value and the fleet exposure, as shown in Figures 11 and 12. Similar results can be obtained by using the other charts provided in the document and the final outcome is a table like Figure 6. It is important to reinforce that the purpose of this reference is not to find the most lenient program possible within acceptable risk levels. As stressed by the EASA guidance material, "A considerable amount of judgment will still be necessary in establishing many of the input factors and the final decision may still need to be tempered by non-numerical considerations, but the method proposed will at least provide a rational 'departure point' for any exercise of such judgment. It is not intended that the method should be used to avoid quicker reaction times where these can be accommodated without high expense or disruption of services."

Building a Product Safety Monitoring System

The risk evaluation procedure is just part of the whole process and, in order to complete the Product Safety Monitoring System, the following points must be considered:

Senior management commitment and safety culture—This is the essential start for any SMS and it is no different for Product Safety Monitoring. Without an adequate Senior Management endorsement and company safety culture, the monitoring and risk analysis process may become only a bureaucratic way to justify lack of actions instead of a proactive process to identify potentially unsafe conditions and prioritize required actions.

Policies and objectives—The main objective of the Product Safety Monitoring process is to identify product-related safety issues through analysis of available information, in order to take preventive actions. As part of the aircraft manufacturer SMS, this process must follow company safety published policies.

Assigned responsibilities and product safety committee organization—It is necessary to clearly define who is responsible for the process, and, as most of the activities require involvement of dif-

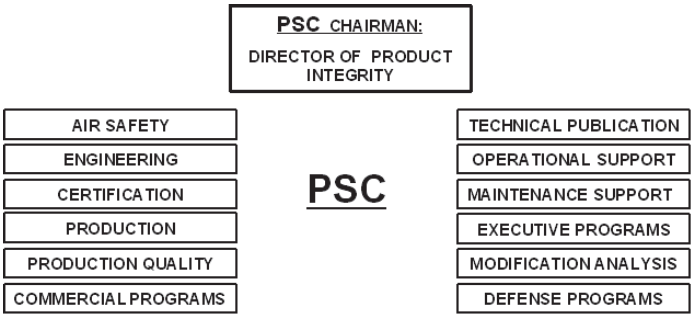

Figure 13. Embraer Product Safety Committee (PSC).

ferent company areas, the setup of a product safety committee (PSC) is essential. The committee improves communication and guarantees coordination of corporative actions, allowing the discussion of eventually different points of view. The PSC will characterize the company's evaluation regarding identified issues. The Preliminary Risk Index (RI) calculation drives this discussion since the validated RI represents the company consensus regarding safety influence of the issue and the priority of associated actions.

For example, the Embraer Product Safety Committee is composed of representatives of different areas involved with the product and is chaired by the director of Product Integrity. The Committee has regular monthly meetings, getting together in extraordinary meetings whenever an issue with preliminary RI greater than 11 is identified.

Reporting system and continuous monitoring—Although the process includes information from eventual accidents or serious incidents investigation, the main source of information are the safety reports collected or received from the field (Figure 14), to which a dedicated reporting process is in place to provide the events that may affect the safety of the aircraft operation. As most operators are already required to report these conditions to the authorities, according to local regulations (FAR Part 121, EASA Part M and similar), a communication link must be established in order to receive copies of these reports. It is also essential to engage the technical support representatives in order to ensure that all information regarding relevant occurrences will be received.

In addition, all operators are encouraged to provide an electronic copy of their formal reports to the aircraft manufacturer's Air Safety Department. The importance of this source of information is repeatedly emphasized during dedicated safety meetings. Although the rate of reports can vary from one operator to another, current fleet average is one air safety report per 2,000 flight hours. Taking the regional jet ERJ145 as a reference, since 2003, year of the Product Safety Monitoring process implementation, the rate of safety reports received from the field trends to a continuous decrease (this meaning "less events per flight hour"), reflecting fleet maturity, technical solutions effectiveness, and also the effort in prioritizing issues through this safety monitoring methodology.

The same methodology exists for the E-170 and E-190 fleets, including a process for the continuous monitoring of the recorded flight data, expanding the information source for the non-formally reported events, automatically recorded by dedicated systems.

Closing the safety loop—For the adequate closure of all safety-related issues, additional attention must be given to the fleet implementation and effectiveness of corrective actions.

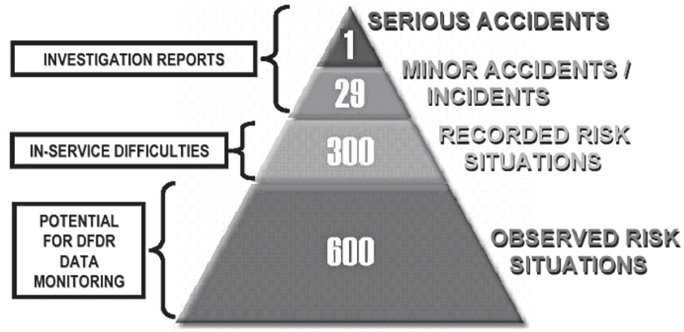

Figure 14. Heinrich Pyramid and sources of information.

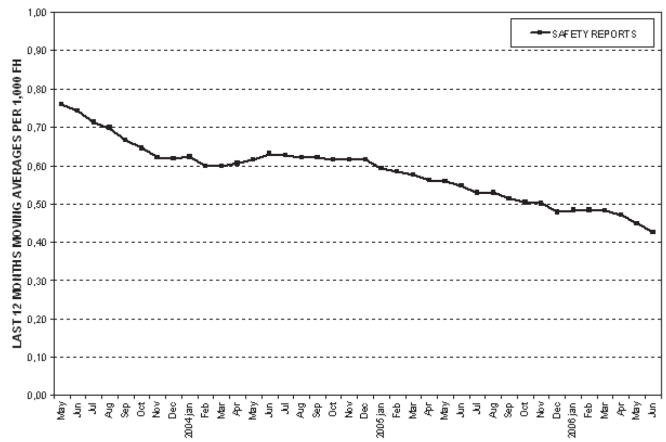

Figure 15. ERJ 145 rate of product-related air safety reports received from the field.

Operator's feedback on accomplishment of relevant actions (implementation of service or operational bulletins) is regularly presented at the PSC meetings. This also includes, for the most relevant cases, the involvement and decision of the certification authorities regarding whether or not an airworthiness directive (AD) will be issued.

The continuous monitoring of in-service difficulties reports will then indicate the level of effectiveness regarding the actions that have been taken.

The Product Safety Monitoring process—one example

The Product Safety Monitoring process as described has been very successful in identifying, discussing, and prioritizing issues that may involve product safety. Following is an example of a RI calculation and updating based on the investigation results of a reported in-service difficulty.

Occurrence: rudder control difficulties after takeoff

It was reported that, after takeoff, at approximately 100 feet above ground, 140 to 160 knots, Flaps 9 and gear in transit, the flight crew observed that the right rudder pedal went forward. The flight crew used opposite pedal and aileron to stabilize the aircraft and reported receiving the caution message "RUDDER SYS 1-2 INOP" on EICAS. The flight crew ran the appropriated checklist and elected to declare an emergency. They returned to the departure airport, landing uneventfully. The flight crew also reported that the required control pressure became lower as airspeed decreased.

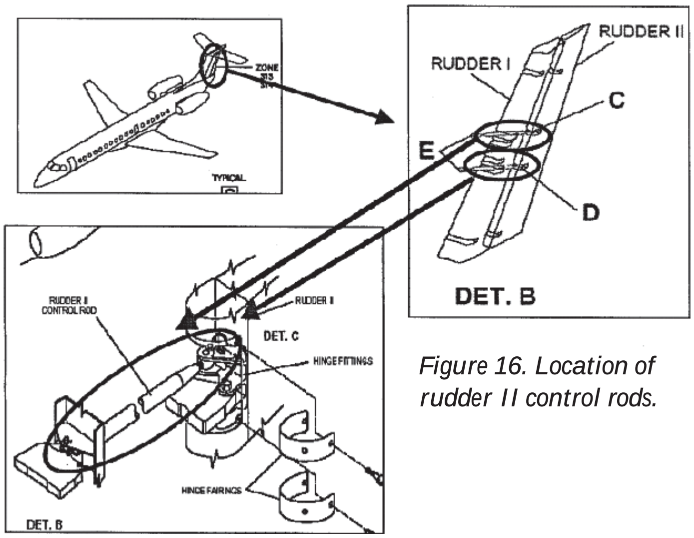

Figure 16. Location of rudder II control rods.

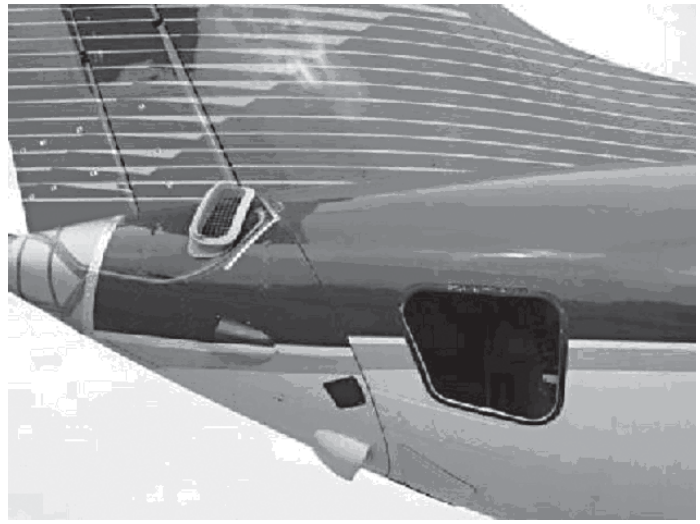

Figure 17b. Removed panel and APU air inlet of a flight test aircraft.

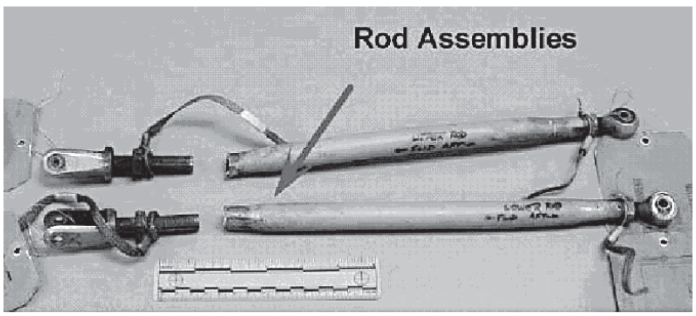

Figure 17. Both rudder II control rods found damaged and separated from the fork ends.

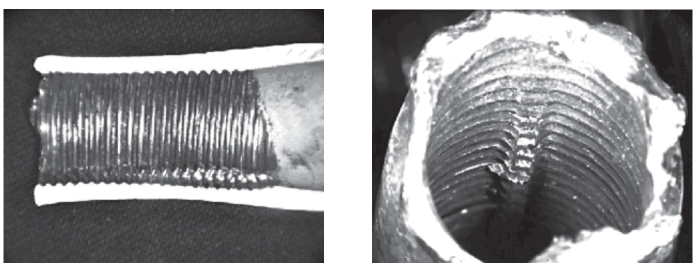

Figure 17a. Rudder II control rod end wear and damage.

① Issue Description:

Rudder Control Difficulties due to Rudder II Connecting Rods Failure

② Reported Condition:	Severity (S)	Likelihood (L)	S x L
Rudder Control jam after takeoff	2	3	6

③ Conditions that may raise the Severity:	Severity (S)	Likelihood (L)	S x L
Structural damage due Flutter at high speeds.	4	3	12
Rudder Control Jam combined with IFSD	4	1	4

④ Worst Case – Highest value of S x L	12
+	
⑤ Level of Control (reflecting the uncertainty regarding assumptions made and the knowledge and control of the related technology)	0
⑥ RI =	12

Figure 18. Initial RI evaluation for the rudder II connecting rods failure issue.

During aircraft inspection, maintenance personnel reported that the two rods that connect the trailing rudder to the vertical stabilizer had failed (Figures 16 and 17). Further feedback from the field also indicated that the involved aircraft had the rear bulkhead access panel in the CDL (configuration deviation list) removed for repairs, a configuration similar to what figure 17b depicts.

Initial evaluation—Although preliminary information was not sufficient to identify the cause for the rods fork end detachment, the risk analysis and assessment procedure was applied using the RI calculation formulary. The result is shown in Figure 18 and detailed below.

① Description of the issue being evaluated: *Rudder control difficulties due to rudder II connecting rods failure.*

② Evaluation of the Severity (S) and likelihood (L) of the reported condition: *According to the rudder system safety assessment certification report, a rudder jam as reported is considered a major condition (S=2). Based on the fleet total hour accumulated at the time and that there was no similar previous reported occurrence of rudder jam due to a dual rudder II connecting rods failure, the likelihood was initially evaluated as remote (L=3).*

③ Evaluation of scenarios or failure combinations that can raise the severity: *Although the reported effect was a rudder jam, the rudder system safety assessment for a failure of both rudder II connecting rods pointed to a "potentially catastrophic condition" (S=4). The likelihood of this scenario was also initially evaluated as remote (L=3).*

Another possible scenario evaluated was a rudder jam combined with an engine failure. The severity of this failure combination could be the same as above, but the existing engine inflight shutdown rate indicated this simultaneous occurrence as extremely improbable (L=1).

④ Consider the worst condition: *highest S x L = 12*

⑤ Evaluate level of control: *Severity evaluations were fully endorsed by the rudder system safety assessment, and conservative approaches to the likelihood were based on the rate of reports. The rods are not manufactured but the system was designed by the aircraft manufacturer, therefore,* *according to Figure 10, the level of control was considered "0."*

⑥ The RI will be the sum of (highest S x L) + (level of control): *RI=12*

As the condition itself, backed by a 12 RI preliminary index was considered high in terms of safety, an extraordinary PSC meeting took place, with the actions directly involving different areas within the company:

- Exploratory flight tests were performed to reevaluate load and vibration characteristics of the rudder versus the panel in CDL (configuration deviation list) and new APU inlet, in the configuration depicted in Figure 17b,
- Engineering developed an inspection procedure,
- Spare Parts Support checked availability of rods for replacement,
- Customer Support contacted the operators,
- Continued airworthiness informed the certification authorities, and
- Air Safety Department coordinated the whole process, together with Product Support Engineering.

An alert service bulletin was issued 48 hours when sufficient information was available, providing procedures for a dimensional and visual inspection on both control rods of rudder II within the next 100 flight hours. This inspection was further mandated by an emergency airworthiness directive.

RI calculation review—Feedback from the field, collected along the 2 weeks after the event from all operators, indicated that no other aircraft had any similar rod condition (no deformation or play found). Based on the information regarding fleet inspection and from the results of flight tests performed after the event, the likelihood of a "flutter and structural damage due to the failure of both rudder II connecting rods" was reviewed and re-classified to "extremely remote (2)." The level of control was changed from "0" to "1," as the failure mechanism was still not identified and the likelihood was not fully supported by the rate of reports. As a result, the RI was recalculated to "9," as shown in Figure 19.

A Level 9 RI issue demands attention and requires regular follow up of all involved actions. An extensive investigation was carried out, including the following:

- Additional flight tests in different configurations,
- Ground vibration testing for the control rod assembly,
- Fatigue test with different rods configuration, and
- Salt spray tests.

None of the tests performed could identify any deviation regarding the system original load analysis and design.

An inspection control plan was established through the revision of a "C check task" for rudder main control path inspection, including the detailed inspection of both rods. A sampling program was also implemented for detailed material analysis.

C-check report and further inspections/results—rudder rod found with play: During a scheduled C-check inspection of another aircraft the lower rudder II control rod was found with play at the fork end side. Both rudder II control rods were then removed and replaced for further analysis. Detailed analysis indicated that the one with play had thread wear, as shown in Figure 20.

Additional inspection on the same operator fleet found a second rod with the same kind of play. A similar assembly deviation was common to both rods: the anti-rotation tab on the fork end assembly had been found out of its slot (Figure 21). The same

① Issue Description:
Rudder Control Difficulties due to Rudder II Connecting Rods Failure

② Reported Condition:	Severity (S)	Likelihood (L)	S x L
Rudder Control jam after takeoff	2	3	6

③ Conditions that may raise the Severity:	Severity (S)	Likelihood (L)	S x L
Structural damage due Flutter at high speeds.	4	2	8
Rudder Control Jam combined with IFSD	4	1	4

④ Worst Case – Highest value of S x L	8
+	
⑤ Level of Control (reflecting the uncertainty regarding assumptions made and the knowledge and control of the related technology)	1
⑥ RI =	9

Figure 19. Reviewed RI evaluation for the rudder II connecting rods failure issue.

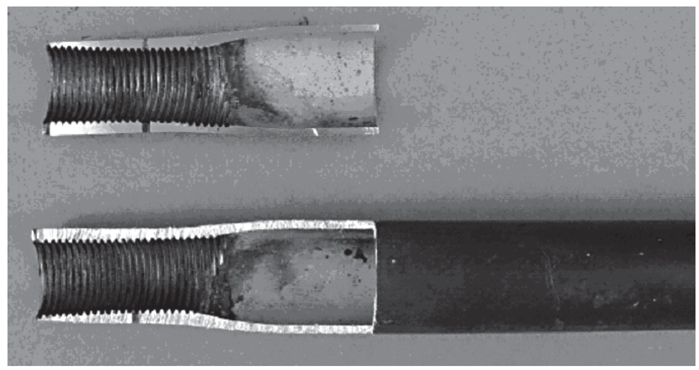

Figure 20. Lower rudder II control rod thread wear, found during a C-check inspection.

condition could also be identified on the failed rod of the first reported occurrence. The anti-rotation tab out of the slot allowed a torque loss of the fitting nut.

Engineering performed additional tests, using the worst range combination of rods and terminal diameters assembled with anti-tab rotation out of slot. These tests could then reproduce the thread wear and the rod fork end play, similar to what was verified in the removed rods.

With the root cause identified, a service bulletin was issued for inspection of all rudder II fork ends for proper locking position. As a final solution, the rod assembly was modified by replacing the locking tab washers on the rudder II control rods with new improved ones. After the accomplishment of this final fix, the likelihood of a rudder II rods failure and the level of control could be reviewed, lowering the RI to "4" (Figure 22). A Level 4 RI does not demand any action other than the continuing monitoring of the fleet, in other to guarantee the effectiveness of the corrective actions.

Final comments

As observed from the example of RI calculation, this procedure is not essential to identify critical conditions. The risk related to the reported situation could be perceived through traditional engineering analysis. Also, the procedure will not give answers to

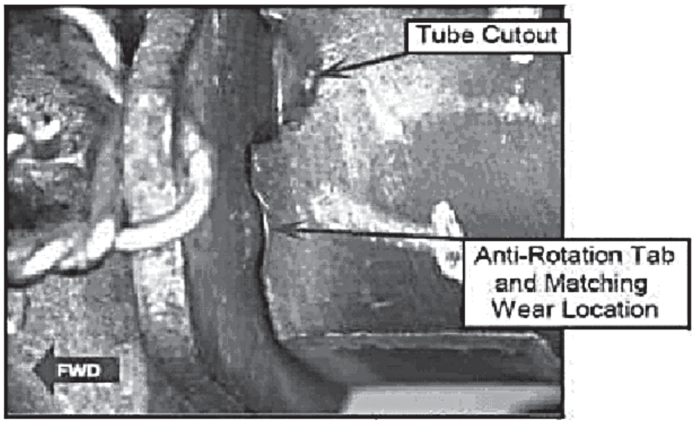

Figure 21. Anti-rotation tab found out of slot (tube cutout).

unknown questions, but creates a standard to quantify the engineering judgment regarding each specific condition. Sharing this standard with different areas within the company is the real power of the Product Safety Monitoring system. It improves communication by clearly defining the company position and actions priorities. Aligning the ideas of all areas involved and making them agree with the required pace is probably the most important gain provided by this risk analysis methodology. ◆

① Issue Description:
Rudder Control Difficulties due to Rudder II Connecting Rods Failure

② Reported Condition:	Severity (S)	Likelihood (L)	S x L
Rudder Control jam after takeoff	2	2	4

③ Conditions that may raise the Severity:	Severity (S)	Likelihood (L)	S x L
Structural damage due Flutter at high speeds.	4	1	4
Rudder Control Jam combined with IFSD	4	1	4

④ Worst Case – Highest value of S x L	4
	+
⑤ Level of Control (reflecting the uncertainty regarding assumptions made and the knowledge and control of the related technology)	0
⑥ RI =	4

Figure 22. RI review after the accomplishment of final corrective actions.

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Endnotes

1 According to AC/AMJ 25.1309, "The terms 'analysis' and 'assessment' are used throughout. Each has a broad definition and the two terms are to some extent interchangeable. However, the term analysis generally implies a more specific, more detailed evaluation, while the term assessment may be a more general or broader evaluation but may include one or more types of analysis." In this paper, the term risk analysis refers to the evaluation of a specific condition, considering the different scenarios and consequences. The risk assessment refers to the process that uses the results of the analysis to provide a measurement of the associated risk.

Defining and Investigating Incidents

By Richard H. Wood, PE, CSP (LM0598), Aviation Safety Consultant

The title of my paper comes from the theme of this semi nar, "Incidents to Accidents: Breaking the Chain." I found this to be a very appropriate and intriguing theme. It needs to be discussed.

In my 40 plus years in the safety business, I've heard one idea over and over. "If we want to prevent accidents, we have to work on preventing the incidents first."

Is that true? Yes it is. If we don't do that, we have a correction program, not a prevention program. Have we ever done anything with incidents? Not with any regularity. There is, in fact, evidence that we have ignored incidents even as we were having our noses rubbed in them.

Why? Let me suggest a couple of reasons.

First, we haven't adequately defined "incidents." We all think we know what an incident is. It's a little accident. Right? Wrong! An incident, properly defined, should be a precursor of a future accident. If you consult the various lists of incidents, you'll see that almost none of them are precursors of accidents all by themselves. They may be an initiating event or even a key factor in an accident, but there is always more to the accident than just that single event.

ICAO defines both "incident" and "serious Incident" but gives no examples. Our National Transportation Safety Board (NTSB) has a list of reportable incidents, but, taken alone, none of them would qualify as an accident precursor. This is also true of our military incident definitions and lists of incidents compiled by many airlines. Most of them are just data-collection systems. Take engine failures. If an engine failure occurs on any aircraft and there is an accident, there must be at least two causes—maybe more. While an engine failure may be the initiating event, we just don't have many accidents that are solely the result of an engine failure. Thus engine failures or inflight engine shutdowns reported as incidents don't get a lot of attention.

There is general agreement (NTSB excepted) that there are very few accidents with just a single cause. The NTSB is still mired in the mud of determining a single probable cause. According to the dictionary, "probable cause" is a legal term citing reasonable grounds for presuming guilt in someone charged with a crime. I don't find that helpful. In the accident business, insistence on a single probable cause tends to focus our actions on that cause alone.

Actually, almost all accidents have multiple causes, a lesson safety professionals learned about 70 years ago. A very workable definition of "cause" is any event that had to be present or there would have been no accident. Turning that idea around, we could say that preventing any of those events would have prevented the accident. In other words, we don't have to eliminate the "most probable cause" in order to prevent the accident. We can do that by just eliminating one of the lesser causes, particularly one that is almost always present in all accidents of that type. What's so difficult about that?

We have worked hard to develop an aviation safety system that is basically "single error safe." We started with the airplane itself. Much of the airplane design criteria is meant to provide a redundancy wherein the failure of any system or part of a system does not make the plane fall out of the sky. We've done quite well with that and our present aviation safety record owes a lot to that concept.

Realizing the advantages of this, we have gone beyond the airplane itself and included everything that makes the plane fly. That includes the airport, the flight crew, the maintenance people, the air traffic control people, and a host of others. We now apply our single error safe concept to the entire system. Since incidents are usually defined as single events, malfunctions, or mistakes, they are no longer precursors of accidents. We tend to ignore them.

That's about where we are now. Our focus is on accidents; not incidents. We can also see situations that are not single error safe. In those cases, a single event, malfunction, or mistake can result in an accident and there is no recovery. Working to eliminate those situations is well worth the effort.

Here's another reason our present system needs improvement. We have neither the time nor the resources to investigate everything that might be reported as an incident under current reporting rules. We can't do it! An actual accident is the least likely result of a particular series of events. Take mid-air collisions as an example. For each actual collision, there were probably a few hundred near collisions based on nearly identical circumstances. In studies of industrial accidents, we know that an accidental injury is a rare event. The exact same circumstances have occurred several hundred times without producing an injury. Because our ability to investigate everything is limited, we are in the position of waiting for the least likely event to occur and then investigating it thoroughly. This is not a proactive approach to safety.

Here is what we need to do.

We need to be more selective on what we choose to call an incident. Starting with the idea that each reported incident should be precursor of an accident, we should define a reportable incident to include all the factors found in actual accidents of that type. For example, let's take a specific type of runway incursion

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accident—one where an airplane has been cleared onto the runway to await takeoff clearance and another airplane has been inadvertently cleared to land on the same runway. Has that ever happened? You bet and the chances of it happening again are quite good. Let's take a look at the factors that are present in almost every accident of that type.

1. Night or bad weather.
2. One aircraft cleared "taxi into position and hold" (TIPH), while awaiting takeoff clearance. This aircraft is either making an intersection takeoff or is holding on the end of a displaced runway threshold. Sometimes it is actually "sitting on the numbers" so to speak. If so, there is a pretty good chance that the landing aircraft will notice it, because that's where those pilots are looking.
3. Another aircraft is cleared to land. The focus of those pilots is on the portion of the runway they intend to land on, not the threshold before it nor an intersection after it.
4. The crew of the plane parked on the runway "position and hold" cannot see the aircraft on landing approach. They have no rear view mirrors.
5. Obviously, a mistake has been made by an air traffic controller. If the mistake is not recognized, there will be a really bad accident because we have violated our single error safe policy. We have denied the crew in the aircraft on the runway the opportunity to avoid the accident by seeing the other plane, and we have created a situation that is not single error safe. We have left ourselves no alternative except to hope that the air traffic controller realizes the error or the pilots of the landing aircraft happen to see the other plane on the runway. That's wishful thinking, and we've had the accidents to prove it.

That scenario has existed since at least 1967, which is when I first encountered it. We are still having that type of accident based on nearly identical situations and we have (effectively) done nothing about it.

To date, most of our actions have followed two paths. One is to eliminate all air traffic controller errors, which is not possible. They are humans, for heaven sakes. Humans make mistakes! The other path is to install expensive equipment that will detect and predict potential runway collisions in time for a human to act. That would be nice, but it is not going to happen in the near future.

My question is, Why don't we do something simpler than either of those? Why don't we eliminate TIPH clearances? You are not cleared onto the runway until you've been cleared for takeoff. If there is a plane on final approach, you can see it. Position and hold is an anachronism left over from the 1930s. Then we needed to park on the centerline for about a minute to set the directional gyros and stabilize the engine temperatures. We no longer need to do that. A modern airplane can start its takeoff from the hold line, adding power as it swings onto the runway centerline.

Eliminating TIPH is an example of eliminating one of the lesser causes mentioned a page or so ago. That will eliminate a lot of those accidents even though no one would consider that the most probable cause of any of them. Better still, that could be done very quickly and wouldn't cost anything.

Author's note: This paper was written in January 2006. I used runway incursion accidents as an example of a type of accident that almost always contains the same factors.

In March 2006, the FAA directed that TIPH clearances be eliminated by March 20, 2006. Hooray! I first recommended that in an article published in *Aviation Week and Space Technology* in 1991, about 15 years ago. The FAA, I thought, has finally realized the benefits of not putting an airplane on the runway until it is cleared for takeoff.

Within a week, there was loud howling within the aviation community on how this would gum things up and slow things down. Not true! It can actually speed things up if you do it right. .

Anyway, the FAA backed down somewhat and stated that airports wishing to continue using TIPH clearances must justify their use. Although TIPH clearances may be history by the time this paper is presented, I still think it is an excellent example of how a simple change to one of the lesser causes can prevent a really big accident.

Back to the paper: Let's take another example—runway overshoots. These happen with disturbing regularity, and they usually share some common factors.

1. The length of the runway is marginal compared to the possible airspeed and gross weight of the landing aircraft.
2. The pilot either landed long or the runway was contaminated with snow or ice.
3. The overrun safety areas were either nonexistent or inadequate.
4. At some point, the pilot could neither stop the aircraft nor get it flying again and make a missed approach. The aircraft is going to depart the runway, and the result could be anything up to a serious accident. If there is no damage or injury, the event is not one of the mandatory NTSB incident reports. Because of that, we don't really know how often this has happened.

In the United States, we have nearly 300 commercial airports that do not have the required 1,000-foot safety zones at the ends of the runways. For a variety of reasons, they are going to stay that way. At this writing, the quickest and least-expensive solution appears to be what we are calling EMAS, which stands for Engineered Materials Arresting System. These are located at the ends of the runways and are made of bricks of cellular concrete materials that collapse under the weight of the aircraft. They provide rapid, but controlled, deceleration. So far, 18 airports have or will have that capability, which is certainly a step in the right direction. This won't happen overnight, and interim solutions involve better methods of calculating stopping distance and better measurements of runway surface condition. Those can be initiated fairly quickly at all airports. The FAA is working on both of those.

Getting back to the factors listed above, suppose we use those factors to define an incident that must be reported and investigated. We can call that an accident precursor, and that's where we should focus our investigative capabilities. There may be other actions we can take that may or may not be related to the most probable cause. Curing one of the other causes present may be the best solution immediately available.

Suppose we picked the top five or maybe 10 accident scenarios that occur with some regularity and analyzed them in terms of their common factors. Perhaps we would look at certain types of CFIT accidents or possibly events involving loss of aircraft pressurization. Those types of accidents do occur, and they all have certain things in common that would help us define our accident precursor. Thus we now have five (or 10) incidents that are genuine accident precursors and will attract our attention. Can that be done? Certainly. Will it work? Only if we make it work. That means that we actually have to investigate these things. Can that be done? Yes, and it needn't be difficult or costly. After all, there was no damage or injury, and everyone is still alive to talk about it. That might take a single investigator an entire day to collect the facts and fill out the report. Initiating preventive action might take longer, but that's where we should be putting our efforts anyway.

Right now, we are in the awkward position of knowing that whatever accident we are currently investigating has probably happened before, but without all the injuries and damage. When teaching aircraft accident investigation, I tell each class that once they have figured out the causes of an accident, there are three questions that should always be asked.

1. Have these events ever happened before?
2. Who knew about it?
3. What was done about it?

Unfortunately, the answers to those questions are usually:

1. Yes. Several times.
2. Lots of people knew about it.
3. Nothing. No accident occurred and no action was recommended or taken.

That will leave a bad taste in the mouth of any safety expert. The idea of waiting for an accident to happen before we do anything tells us that our investigation program is reactive, not proactive. As mentioned earlier, we're not preventing things—we are correcting things that have already happened. If prevention occurs, it is a byproduct of that process; not the process itself.

That leads me to my favorite cause factor, one that I have tried to list in many of the accidents I have investigated.

"One of the causes of this accident was failure to take action on a problem that has already been identified."

Would you like to know how often I have managed to get that cause included in the report? Never! Not even once!

Nevertheless, that cause belongs in a lot of today's reports. I don't think it would ever rise to the status of most probable cause, but that might be a good thing. Perhaps we should start with something a little easier like redefining incidents, creating some accident precursors, and seriously investigating them. ◆

Industry Working Group For Enhancing the Investigation Of Human Performance Issues

By Randall J. Mumaw, Aviation Safety, Boeing

Introduction

Each new or revised summary of accidents and incidents in commercial aviation re-emphasizes the significance of the role of humans. Accidents attributed to failures in airplane systems have decreased over the years as those elements have become more reliable. Flight crews, maintenance technicians, air traffic controllers, airplane system designers, and others are identified as significant contributors to an event 60-70% of the time (e.g., see Boeing annual statistical summary as one index: http://www.boeing.com/news/techissues/pdf/statsum.pdf). In fact, even in cases where there are failures in airplane systems that precede a tragedy, accident investigations have revealed that human performance contributed to degraded system performance. This is not only true in commercial aviation; mishaps in other highly complex socio-technical systems also reveal the important role of humans in the accident chain. This influence on the accident chain may have links to system design, operational procedures, training, and organizational policies and practices.

To “break the chain,” we need to become even better at understanding and addressing issues in human performance (HP). My personal accident investigation experience, and the experience of several colleagues at Boeing, suggests that approaches to investigating HP issues around the world can vary widely and are sometimes ineffective.

To understand the current situation better, a small research team at Boeing surveyed major accident investigation agencies to document their approaches to HP issues in accidents and incidents. The next section describes some key results from this survey, and the second half of the paper describes our proposed response to the current situation—specifically, the establishment of an industry working group to develop better guidance for investigating human performance.

Dr. Randy Mumaw is a human factors specialist and associate technical fellow in the Aviation Safety Group at Boeing Commercial Airplanes. Dr. Mumaw received his M.S. and Ph.D. in cognitive psychology from the University of Pittsburgh. Dr. Mumaw has studied human performance and safety in nuclear power plant control room operations, air traffic control, and military and commercial aviation. He is the author of more than 80 technical papers, most of which address human performance and error in complex, high-risk systems. At Boeing, Dr. Mumaw has focused on the human aspects of safety and on flight deck interface design, especially in the area of autoflight and the flight management system. He is an author on several patents for new autoflight interface designs. He has also supported a number of accident investigations that involved significant human performance issues.

Current practice

We interviewed 12 groups (those listed below plus a major airline) to attempt to establish the current state of investigating HP issues (note that there is a mix of commercial aviation and other modes of transportation):

- Air Accidents Investigation Branch (UK),
- Railway Safety & Standards Board (UK),
- National Air Traffic Services (UK),
- National Transportation Safety Board (USA),
- Bureau d’Enquêtes et d’Analyses (France),
- Bundesstelle für Flugunfalluntersuchung (Germany),
- Transportation Safety Board (Canada),
- Civil Aviation Department (Hong Kong),
- Aviation Safety Council (Taiwan),
- Australian Transport Safety Bureau, and
- Transport Accident Investigation Commission (New Zealand).

For each interview we covered a range of topics, including the following:

- the framework used for addressing HP issues,
- existing guidelines, checklists, and procedures used for investigating HP issues,
- types of HP expertise available to them,
- how they assign HP specialists to investigations,
- HP-related data-gathering techniques,
- HP-related analysis techniques,
- how HP accident data are structured for input to an accident database, and
- what gaps have been identified in investigating HP issues.

The following are summaries of our findings for two of these issues: HP expertise and HP guidance materials.

HP expertise and training. One question concerned the number of investigators or staff formally trained as HP experts. More specifically, we identified the number of people with an M.S., M.A., or Ph.D. in a human factors-related (HF) field of study.

0 HF investigators	5 agencies
1 HF investigator	1 agency
4 HF investigators	2 agencies
6 HF investigators	2 agencies
10 HF investigators	2 agencies

The above shows that responses varied considerably. While there were five agencies that had no investigators trained in an HF field, there were two agencies that each had 10 people with HF training, and another two with six HF investigators. Those agencies that have no HF expertise in house often hire consultants with that expertise. However, our investigation experience also indicates that agencies that may not have a full-time existence (but come together when an accident occurs) may have no ready access to this type of expertise.

We also talked to agencies about the types of training they provide their investigators on HP issues. Most agencies reported that all investigators receive some HF-related training. For four agencies, the HF training is part of a broader investigation course. Four other agencies expose each investigator to a dedicated HF course (usually a week in length). The remaining four agencies have no HF training that is required of all investigators; instead, a few investigators may get some HF training.

Train all investigators on HP/HF—part of broader course	4
Train all investigators on HP/HF—dedicated HP/HF course	4
No HP/HF training for all investigators	4

So, the overall picture is a mixed bag—some pockets of strong HP expertise and other agencies with little training or in-house expertise.

HP guidance documents. A key question concerned the procedures that agencies have in place to guide the investigation of HP issues. Guidance can take many forms, for example, checklists (types of data to collect, HP issues to consider); methods/techniques for data gathering; a framework for identifying important actions, decisions, and conditions; a system for classifying human errors; methods for identifying contributing factors that may have influenced performance; or analysis techniques.

The responses spanned a wide range. Four of the 12 investigation agencies had no guidance documents at all for HP investigations (see below). Four agencies had one or more checklists (typically one) that investigators could use for identifying potentially important issues. The remaining four agencies actually had an accident investigation manual or a general guidance document that aided them in investigating HP issues.

No HP guidance material	4
Checklists for guidance	4
More complete guidance document(s)	4

Interestingly, there was more development of guidance for agencies that had more expertise. We believe that the reason for this finding is that the expertise is required to develop the guidance. Agencies with no expertise are unable to develop the types of guidance that could benefit their investigators, and they are unable to obtain guidance from other sources.

One potential solution to this apparent dilemma is to get guidance from an outside source. However, when we looked at potential sources—the ICAO HF Digest (ICAO 1993) and several recent books on the topic (Dekker 2002; Strauch 2002)—we found little guidance that could be readily adopted by an investigation agency. The ICAO document provides guidance at a very high level and focuses on the checklist from the SHELL Model. Strauch's book provides some background knowledge on a number of potentially relevant topics (e.g., computer displays) but little in the way of guidance for conducting an investigation. He does offer some practical guidance for various aspects of field work. The Dekker book focuses on describing inappropriate ways to conduct an investigation but offers little guidance on conducting an investigation.

Thus, there are several agencies with strong skills in HP investigation that are leading the way in defining how to conduct an HP investigation: what questions to ask, what data to collect, how to frame the data and identify the underlying causes, etc. In addition, there are investigation agencies outside of aviation (e.g., nuclear power) that are also establishing more detailed guidance, especially in the area of organizational factors. Unfortunately, the work of these few groups is not easily conveyed to other agencies that lack HP expertise.

Boeing response

Our data gathering reinforced our beliefs that

- HP expertise exists primarily within the larger investigation agencies and is not readily acquired from a consistent source when it is needed. Those with training both in accident investigation and HP issues are too rare for today's needs.
- HP guidance is either insufficiently detailed or is being developed within the agencies that have the most expertise (and it is not formally shared outside of that agency).
- There is no shared framework across agencies for understanding and describing HP issues; the Reason (Swiss cheese) Model has been influential but falls short of creating a unifying approach. Without this shared framework, the findings from individual accidents cannot be easily compiled and analyzed as a set.

The initial Boeing response was to begin developing the HP investigation guidance that most agencies are missing. We laid out a plan to develop a set of individual modules on specific HP topics. These modules would cover a range of topics:

- data-collection techniques (e.g., cognitive interview),
- human performance issues (e.g., spatial disorientation),
- factors that contribute to human performance problems (e.g., fatigue, stress),
- analysis techniques (e.g., speech frequency analysis), and
- safety assessment techniques (e.g., barrier analysis).

Each module would provide a brief background on the issue and then lead into practical guidance for investigators on techniques, references for more information, names of experts in the area, and training that is available. We targeted each module to about five pages; the idea was to have a quick, easy-to-use reference document for investigators on key HP topics.

Further, we wanted to ensure that the topics covered were tied to actual performance data—that is, areas in which there are data on the effects of a factor on human performance. For example, quite a bit is known about how inadequate sleep affects task performance. By limiting our topics to those that can be backed up with data, we hope to avoid the speculative arguments made about what "may have" influenced actions and decisions. This is not to say there is no place for speculative arguments when there is little hard data about performance, but this type of account needs to be clearly labeled as such.

Industry working group

As we proceeded with module development, we realized that it was important to create guidance that would be acceptable to all major stakeholders in commercial aviation accident investigation. Expertise is distributed across these stakeholders and a consensus position is required to make a significant change to industry practice. These stakeholders include the following:

- airplane manufacturers,
- accident investigation agencies,

• aviation regulators,
• those representing the people who may be "blamed" (pilots, ATC, maintenance technicians),
• airlines,
• aviation safety organizations, and
• training organizations.

Therefore, we turned our attention to organizing stakeholder representatives to develop an industry solution to this problem. We started by seeking and being granted sponsorship from ISASI. ISASI appointed Capt. Dick Stone as the ISASI chairman of an industry working group; Capt. Stone has since added an Advisory Board that, under Capt. Stone, will approve our development plan and review guidance material before it is distributed. The group has been named the ISASI International Working Group on Human Factors (IIWGHF).

The next step was to bring together the HP expertise in the industry. We have a team of 10 human factors professionals with accident investigation experience who are continuing to develop guidance modules. This team will work with a set of reviewers (industry representatives) who will make an early evaluation of a module to ensure that it is fair and useful for the work of investigators. Through a number of review-and-rewrite cycles, we hope to produce a significant set of guidance modules that we can then package and distribute through ISASI.

Another potential role of the IIWGHF is to put forward position statements that can establish a standard on how HP issues should be investigated. There are a number of potential issues to be addressed here. An example being considered is the following:

• the collection of human performance data should not be seen as implying that human error is a working hypothesis for the investigation. Initial interviews of operational personnel involved in the accident or incident (e.g., pilots, air traffic controllers, maintenance technicians) should be conducted in a way to maximize the retrieval of information about the event; they should not focus on finding fault with the actions taken or decisions made.

As of this writing, the IIWGHF is just ramping up. We plan to deliver a number of guidance modules by the end of 2006. After a core set of materials is developed and approved, we will use ISASI to distribute them to key industry stakeholders. If these materials achieve a good level of acceptance within the industry (and perhaps within other areas of accident investigation), they will start to shape how investigations are conducted and reports are written. Ideally, we will eventually establish a well-defined set of expectations about the policies and practices of HP investigations. ◆

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Failure Analysis of Composite Structures in Aircraft Accidents

By Joseph F. Rakow, Ph.D., P.E. (AO4926), Engineer, Exponent Failure Analysis Associates, and
Alfred M. Pettinger, Ph.D., P.E., Managing Engineer, Exponent Failure Analysis Associates

Abstract

The impending generation of aircraft, represented by the Boeing 787, the Airbus 380, the newly emerging very light jets, and the new generation of military fighters, marks a shift in airframe technology in which primary structural components that have been traditionally constructed of metal are being constructed of composites. This advancement creates the possibility of aircraft accidents involving composite failures. Despite this possibility, the current body of knowledge and experience regarding aircraft accidents is largely dependent on metallic aircraft. This paper introduces some of the basic concepts involved in analyzing failed composites under a variety of fundamental loading conditions such as tension, compression, bending, impact, and fatigue. These concepts are demonstrated by discussing the analysis by the NTSB of the failed composite vertical stabilizer involved in American Airlines Flight 587. For perspective, this paper frequently compares the analysis of failed composites to the analysis of failed metals.

Introduction

Composites are not new. Composite structures have been developed and used for military aircraft for more 50 years, and composite aircraft have been commercially available to home-builders for decades. Even an all-composite spacecraft, *SpaceShipOne,* has flown to space with repetitive success. As an extension to the history of composites, aircraft structures of the current decade are progressing through a major transition from metallic structures to composite structures, similar to the transition from wood to metal in the 1920s.

The next generation of aircraft, coming to market this decade, is a generation of composite aircraft. Historically reserved for control surfaces and secondary structures, composites are now being employed for primary structures in major aircraft programs.

Dr. Joseph Rakow is an engineer with Exponent Failure Analysis Associates, a leading scientific and engineering consulting firm. Dr. Rakow specializes in aeronautical structural engineering, structural failure, and the design of mechanical components. Dr. Rakow's work has addressed products, failures, and initiatives of a variety of commercial and government organizations. He has published a number of articles in scientific journals and frequently speaks at international conferences.

Dr. Alfred Pettinger is a managing engineer with Exponent Failure Analysis Associates. He specializes in the evaluation and design of metal as well as composite aerospace components. Dr. Pettinger has been retained in numerous accident investigations and design reviews for transportation-category aircraft. (No photo available.)

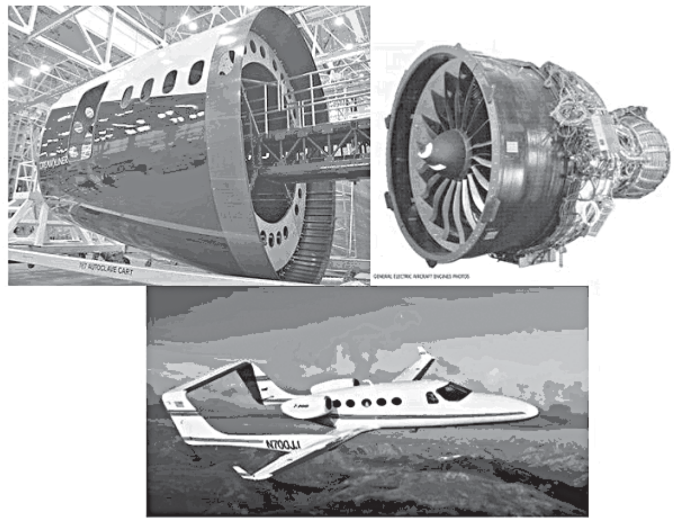

Figure 1. Examples of composite structures: Boeing 787 fuselage, General Electric GEnx fan blades and case, Adam Aircraft A700 VLJ (clockwise from top).

The airframe of the Boeing 787 will be approximately 50% composite structure by weight, with nearly 100% of the skin, entire sections of the fuselage with integral stiffeners (Figure 1), and the wing boxes constructed of composites.

For perspective, the Boeing 777 entered the market just more than a decade ago with an airframe of 10% composite structure by weight. Powering the B-787 will be the GEnx turbofan engine with fan blades and containment casing made of composites (Figure 1) rather than traditional metals. In advance of the B-787, the new Airbus 380 is scheduled to enter service with an airframe that is approximately 25% composite structure by weight. One notable feature of the A380 is an all-composite central wing box. Complementing this transition in the large transport market are the all-composite airframes for very light jets, such as the Adam A700 (Figure 1). Parallel advances continue with military aircraft. The F-22 contains approximately 60% composite structure compared with slightly more than 20% for the F/A-18C/D, which entered production just a decade earlier. Figure 2 illustrates the growing use of composites in military and commercial aircraft.

With the increased use of composites in primary structures, accident investigators will likely encounter failed composite structures with increasing frequency in the coming decades, and these structures may be primary structures of significance in the investigation. Why would these composite structures fail? First, we are building composite structures on a scale never before achieved. The B-787 fuselage will be the largest composite pressure vessel ever built. Second, we are building composite structures through

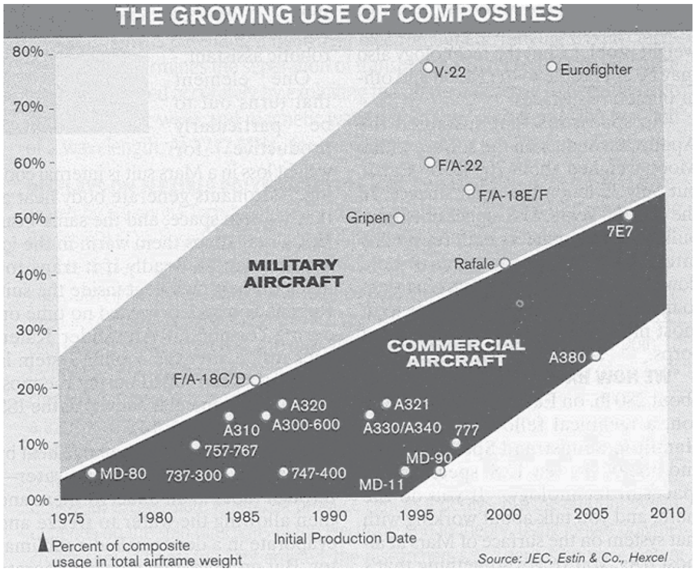

Figure 2. The growing use of composites with time in major aircraft programs by percent of the total airframe weight (JEC, Estin & Co, Hexcel).

Figure 3. The ductility of metal structures provides macrostructurally visible information regarding an accident (Wanttaja 1994).

relatively new, automated techniques rather than relying on traditional methods of constructing composites by hand.[1] And third, our inspection and maintenance requirements will no longer be driven by fatigue and corrosion performance, as they are for metallic structures, because composites are not as susceptible to these failure mechanisms. Instead, accidental subsurface damage and subsequent failure progression will be more important. Past experience with metallic structures will be relevant, but new methods and techniques particular to composite structures will be required. These advances, a collective departure from applications, techniques, and methods of the past, may lead to landmark lapses in safety with subsequent "lessons learned" for composites. Such lapses in safety may provide lessons learned in the manner that the Comet accidents provided lessons learned regarding stress concentrations and metal fatigue and that Aloha Airlines Flight 243 provided lessons learned regarding aging aircraft structures.

It is through experience and effort that the community of aircraft accident investigators has developed a considerably mature understanding of failure in metallic structures. This has been a process spanning more than 80 years of accidents involving metallic aircraft. The accrued knowledge and experience must be extended to composite structures. This paper is intended to contribute to that effort by introducing some of the basic concepts of failure in composite structures as a result of a variety of loading conditions—tension, compression, bending, impact, and fatigue. Select failure characteristics are then illustrated through a discussion of the failure of the composite vertical stabilizer of American Airlines Flight 587. For perspective, the analysis of composite failures in this paper is frequently discussed with respect to corresponding failures in metallic structures. In that vein, this paper first addresses some key features particular to failed metallic structures that may no longer be available in the analysis of failed composite structures.

Examination of failed metallic structures

The science and art of analyzing failed metallic structures has matured in part as a result of the analysis of accidents involving metal aircraft. Employing knowledge accrued during this period of time, investigators often rely heavily on their ability to analyze failed structures in an effort to determine the cause and events of an accident. Some investigators have emphasized the role of such analysis—

"The bent metal speaks."[2]

"The story is written in the wreckage."[3]

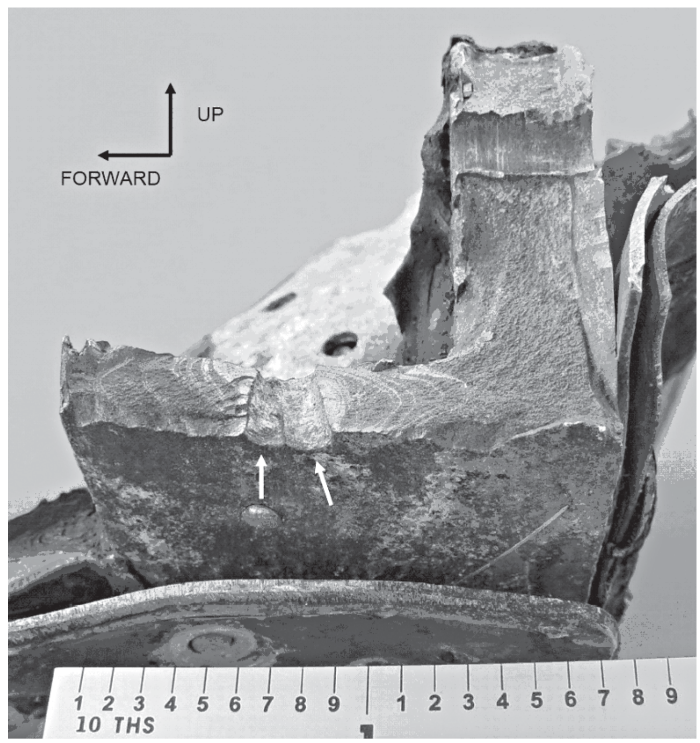

Figure 4. Indications of fatigue cracking in the lower right wing spar cap of the Chalks Ocean Airways Grumman Mallard G73 that crashed during takeoff Dec. 19, 2005. This is an example of using accumulated knowledge and experience with metallic structures to identify possible factors in an accident (NTSB 2005).

"You have to learn how to read the bent metal."[4]

For the purposes of this paper, the evidence contained within the wreckage will be referred to in two categories—macrostructural evidence and microstructural evidence. Macrostructural evidence refers to the overall deformation of failed structures—a buckled fuselage panel, a twisted propeller blade, a dented leading edge. Figure 3 shows an example of macrostructural evidence, a collection of dents on the leading edges of an aircraft.

The value of macrostructural evidence in failed metal structures is enhanced by the fact that typical aircraft metals, such as aluminum, are ductile, which means they undergo significant deformation prior to final failure. Ductility allows for the permanent bending, twisting, and denting of structures, essentially recording evidence of events in the accident. The evidence contained in Figure 3 immediately identifies impact as a factor in this accident. Moreover, the evidence identifies the possible size, shape, and energy associated with the impactor or impactors. According to the NTSB, this aircraft impacted a set of power lines on approach (NTSB 1995).

Ductility in metals provides macrostructural evidence in a variety of ways. One method for determining whether a jet engine was powered at the time the aircraft impacted the ground is to examine the fan blades. Metallic fan blades of a powered turbofan will generally bend upon impact in a direction opposite the direction of rotation. This deformation can reveal whether the engine was powered at the time of the accident. Another example is the deformation produced by an explosion occurring inside a metallic fuselage. The bulging of fuselage panels, the curling of ruptured edges away from the explosion, and the stretching and unzipping of panels along rivet lines all indicate the role of an explosion in an accident.[5]

Typical aircraft composites are not ductile; they are brittle, which means they undergo relatively minor permanent deformation prior to final failure. Without ductility, the macrostructural evidence from an accident, such as the examples discussed above, will likely change. What evidence would be produced by a failed composite structure? What evidence would be produced by a GEnx engine, with its composite fan blades, impacting the ground? What evidence would be produced by an explosion inside a B-787 composite fuselage?

With changes in macrostructural evidence associated with the change from ductile to brittle structural materials, the analysis of microstructural evidence becomes paramount. Microstructural evidence refers to relatively local deformation and changes in the structure, such as fracture surfaces, that typically require close visual or microscopic analysis. To interpret microstructural evidence in failed metallic structures, investigators rely upon a well-established and widely used body of knowledge, which has, in the past, often provided rapid and insightful results.

One example is the recent crash of Chalks Ocean Airways Flight 101 in December 2005 off the coast of Miami, Fla. Initial evidence indicated that the right wing had separated in flight. Within days, the NTSB had identified fatigue damage in metallic structural components in the right wing (Figure 4), with corresponding damage in the structure of the left wing. As shown in Figure 5, an unaided visual inspection of the wing spar cap reveals beach marks, which is evidence widely accepted to be indicative of fatigue failure. As a result of this established analysis, the microstructural evidence, supported by an accrued body of knowledge

Figure 5. Tension failure in composites. Macroscopically, even simple tension can produce fractures with a wide variety of features. Microscopic analysis is paramount (Ginty and Chamis 1987).

regarding the interpretation of fracture surfaces in metals, rapidly established the wing spar cap as a critical component to consider in this investigation.

The analysis of failed composite structures cannot rely solely on the knowledge and experience accrued for metallic structures. The analysis of failed composite structures involves terms such as fiber pullout, delamination, and interfacial failure. These terms do not even exist in the analysis of failed metallic structures. These and other rudimentary components of knowledge must be understood by accident investigators in order to analyze failed composite structures.

Examination of failed composite structures

Transitioning from failed metallic structures to failed composite structures requires, in many ways, a new mindset. Although composites are often considered to be materials and are generally classified as engineered materials, composites are actually structures, made of multiple materials. Typical aircraft composites are made of two materials, long fibers that are stiff and strong (typically carbon or glass) and a matrix, essentially hardened plastic glue, that holds the fibers together. The glued fibers are typically assembled layer by layer, called plies. The fibers in each ply typically run parallel to each other or are woven together in the manner of a textile. Ply-wise variations in fiber orientation and other variables often exist in a composite.

In contrast to typical aircraft metals, the physical properties of composites vary from location to location, and their response to loads usually varies with the direction in which the load is applied. Composites can respond to loads in ways aircraft metals cannot. A simple tensile load, for example, can cause a composite to twist; a simple twisting load can cause a composite to bend. While designers know of, understand, and can predict these phenomena, accident investigators must be able to recognize and reconstruct them.

Composites have design variables that are not available in metals. Some of these variables are fiber orientation, fiber-to-

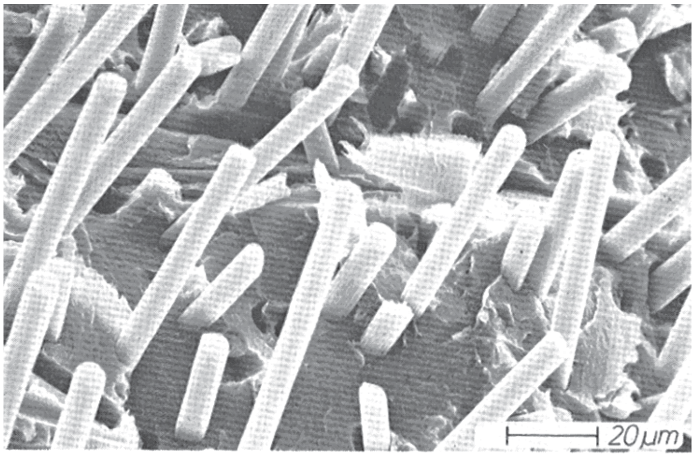

Figure 6. Example of fiber pullout as a result of tensile loads (Friedrich and Karger-Kocsis 1989).

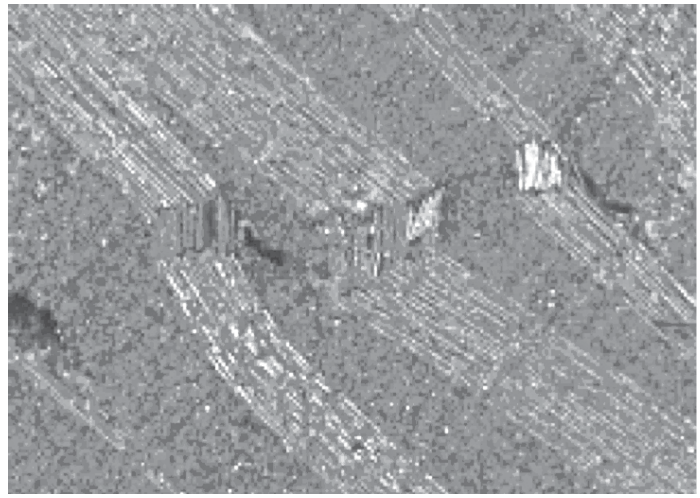

Figure 7. Example of fiber kinking as a result of compressive loads (Bolick et al 2006).

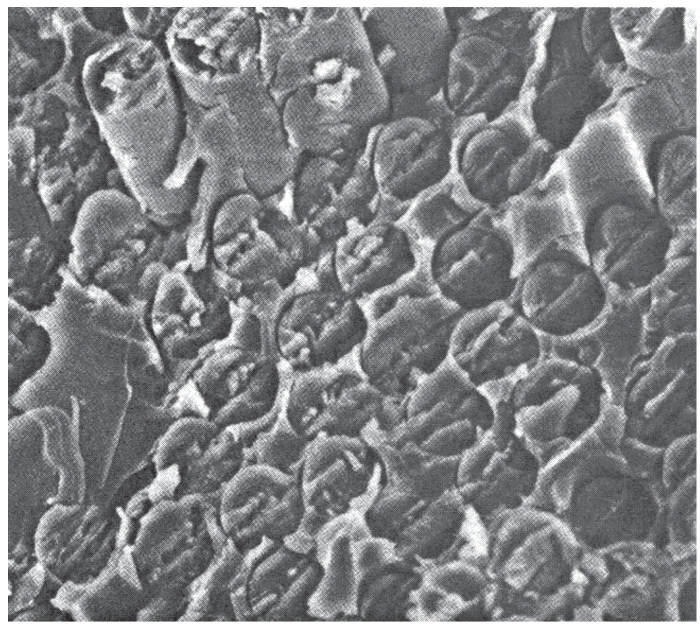

Figure 8. Chop marks can be produced on the ends of broken fibers that have buckled and failed under compressive loads (Stumpff 2001).

matrix volume ratio, ply thickness, and ply stacking sequence, among others. With new variables come new opportunities for manufacturing errors or imperfections. Some of these imperfections are fiber waviness, poor adhesion between fibers and matrix, poor adhesion between plies, excessive voids in the matrix, and an improperly cured matrix, among others. Changes in design variables and accumulated imperfections directly affect the failure of a composite.

For example, Figure 5 shows 20 failed composite specimens, four groups of five specimens, representing four different ply-wise fiber orientations. Each specimen was subjected to simple tensile loading. Despite the similarity in loading, the failure in each specimen looks unique. Some of the failed specimens have a shredded appearance with a very rough fracture surface; some of the specimens have a smoother, angular appearance. Some specimens even broke into three pieces, rather than two. The differences in the appearance of these failures are a result of two primary sources of variation among the specimens. The first source of variation is the intentional variation in design variables, in this case, fiber orientation. The second source of variation is the accumulation of imperfections, as discussed above. The result is that these composites, all of which failed in tension, appear very different from each other. This is one of the challenges of analyzing failed composites. In many cases, this challenge can be addressed by performing a microscopic analysis of the failure surfaces to identify common features that indicate failure in tension.

Tension

Regardless of the macroscopic variation of the fractures discussed above, tensile fractures of fibrous composites typically exhibit some common characteristics that can help identify failure under tensile loads. One characteristic is that the fracture surface generally has a rough appearance, as can be seen in the failed specimens in Figure 5. Figure 6 shows a microscopic view of a fracture surface of a composite that failed under tensile load, with the fibers aligned with the direction of the load.

One clear characteristic of the fracture surface is that fractured fibers are sticking out of the fractured matrix, contributing to the rough appearance of the fracture surface. Called fiber pullout, this characteristic is a typical indication of tension failure in a composite. Fiber pullout is the result of a fiber breaking and being extracted from the matrix. Close inspection of Figure 6 reveals, in addition to pulled-out fibers, holes in the matrix that were created by other pulled-out fibers. In some cases of tensile failure, the fibers do not completely fracture and only the matrix completely fractures. The fibers then span the matrix fracture in a phenomenon called fiber bridging. In either case, the investigator can use the pulled out fibers to identify tensile loading, and in the case of stacked laminates, identify those plies that have been loaded in tension. The length of the pulled out fibers can provide perspective on important fundamental conditions present in the composite at the time of fracture, such as temperature, exposure to moisture, and rate of loading.

As long, thin members, the fibers are designed to carry tensile loads, and composites are nominally designed such that the fibers run parallel to the tensile loads. However, in the common case of composites with ply-wise variations in fiber orientation,

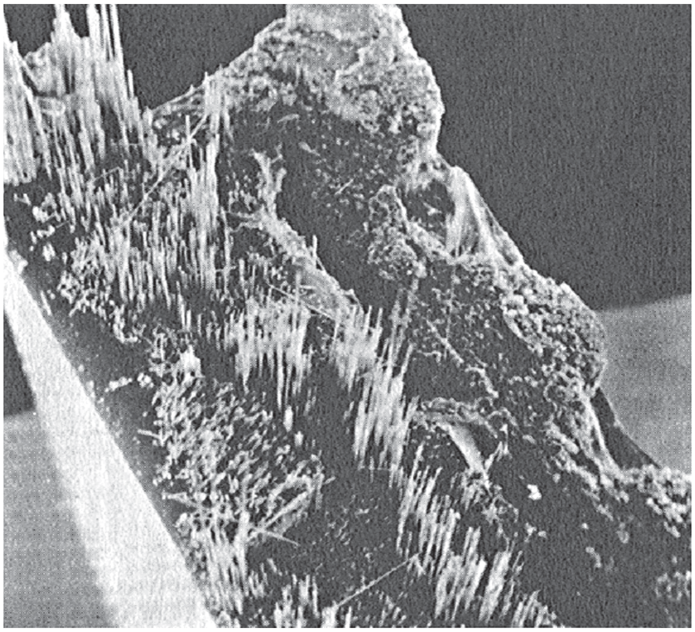

Figure 9. Composite specimen that failed in bending. The relatively rough area of tension failure and the relatively smooth area of compression failure are clearly identifiable (Beaumont and Schultz 1990).

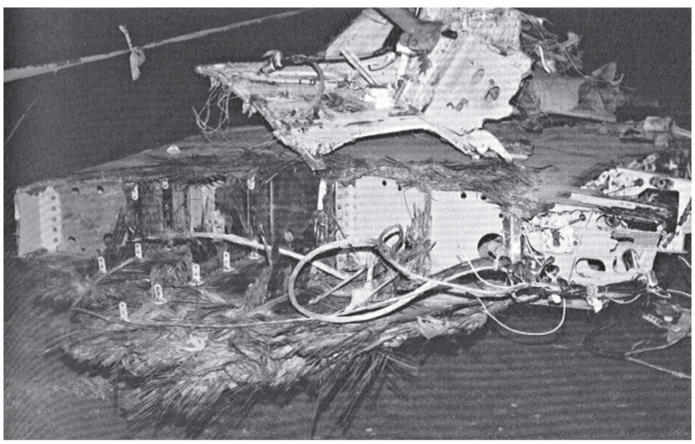

Figure 10. Composite wing that reportedly failed in bending. The relatively rough area of tension failure with significant fiber pullout, and the relatively smooth area of compression failure are clearly identifiable (Stumpff 2001).

tension loads do not run parallel to the fibers, and failure can occur in the matrix. Common matrix failures associated with such loading conditions are tension failures between fibers, particularly at the fiber-matrix interface, and shear failures in the matrix-rich region between plies, typically associated with rough features on the fracture surface called hackles. Such inter-ply shear failures can also be produced under compression.

Compression

Under compression, the fibers are relatively less effective. One common characteristic of the compressive failure of fibrous composites is the formation of kink bands, as shown in Figure 7. Kink bands are a result of structural instability, much like a person standing on and eventually crushing a soda can. The fibers buckle as the compressive load approaches a critical level, which is a function of material, geometric, and environmental factors. Fiber buckling can also be identified by examination of the fiber ends.

As shown in Figure 8, chop marks indicate fibers that have buckled and have bent to failure. The chop marks coincide with the neutral axis of the fiber in bending, separating the tension side of the fiber from the compression side of the fiber.

Often associated with kink bands is matrix splitting, which can be seen in Figure 7 as gaps in the matrix. Matrix splitting occurs at weak points in the matrix or at areas of high stress concentration, such as at the fiber-matrix interface and the interface between plies. Matrix splitting at the interface between plies is referred to as delamination and is discussed further in the paragraphs below regarding impact.

Bending

The difference between tensile and compressive fracture surfaces is readily demonstrated in composites that have failed in bending. Figure 9 shows a specimen that has failed in bending. Divided by a neutral bending axis, one part of the fracture surface contains pulled-out fibers and the other part is relatively flat. This is a result of the fact that, in bending, one part of the cross-section is in tension and the other part is in compression. These characteristics can readily translate to a macroscopic level.

Figure 10 shows a composite aircraft wing that has reportedly failed in bending (Stumpff 2001). The bottom surface of the wing, which was subjected to tension in bending, has a very fibrous texture relative to the top side of the wing, which was subjected to compression in bending.

Impact

As discussed above, typical aircraft composites are brittle rather than ductile. Ductile metal structures undergo relatively high levels of permanent deformation prior to final failure, and this deformation provides information regarding the events preceding structural failure. As brittle structures, composites exhibit relatively little permanent deformation prior to final failure. The metallic aircraft discussed above and shown in Figure 3 provides a clear indication of impact by a foreign object. Impact evidence may not be as readily observed in a composite structure.

In fact, impact loading can cause damage to a composite without any visible evidence on the surface. Consider an aircraft mechanic dropping a wrench on the top surface of a wing. If the wing is made of aluminum, the impact may leave a dent, essentially recording the impact and providing some rudimentary indication of the significance of the resultant damage. If the wing is a brittle composite, the impact of the wrench may produce local crushing of the fibers and matrix or it may not produce any damage on the surface at all. In either case, the level of damage below the surface of a composite can be much more extensive than that indicated on the surface.

One common type of sub-surface damage from impact is delamination. A delamination is a split between plies in a composite. The split can propagate along the interface at which neighboring plies were joined during manufacturing or it can propagate along the fiber-matrix interface. Figure 11 shows a couple views of the cross-section of a composite plate after impact.

As indicated in the figures, the impact caused extensive delamination among multiple plies. Such damage can dramatically degrade the load bearing capability of the composite even though

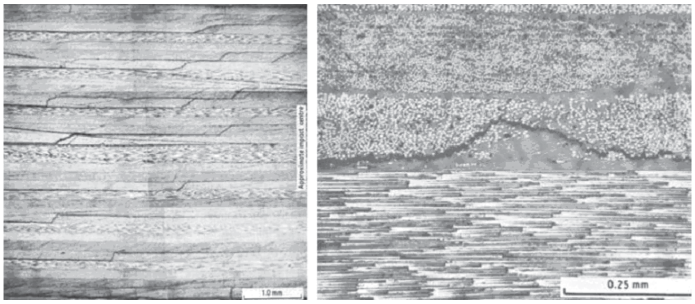

Figure 11. Example of composite failure involving delamination (Bascom and Gweon 1989).

the fibers may remain intact. Moreover, the damage, if unnoticed, can continue to propagate upon further loading of the composite.

Without visible evidence on the surface, delaminations must be identified by cross-sectioning the composite in the location of the delamination or by employing non-destructive techniques such as ultrasonics or X-ray tomography. If destructive techniques are employed, delaminations may be identified visually. In graphite-epoxy composites, delaminations can be identified by a dull, whitish appearance, relative to the shiny, black appearance of neighboring areas free from delamination.

Fatigue

One of the attractive qualities of composites is that they generally have better fatigue performance than typical aircraft metals such as aluminum. Despite this fact, composites can fail under fatigue loading and such failures result in particular failure features.

Fatigue failure in metals can be readily identified, in many cases, by an unassisted visual inspection. A typical fatigue failure in metals will produce a fracture surface with beach marks. An example of beach marks was already discussed above and shown in Figure 4. Fatigue fracture surfaces in composites, on the other hand, do not typically have visible beach marks. In fact, fatigue fractures in composites typically do not appear any different from a corresponding overload failure.

While fatigue fractures lack macroscopic evidence, some evidence may be identified microscopically. Figure 12 shows striations at the fiber-matrix interface of a composite.

One striation typically corresponds to one load cycle. Although these striations indicate fatigue failure, areas containing striations are typically small in size, few in number, and may be dispersed over multiple locations in the composite. In addition, the striations are often identifiable only under high magnification and oblique lighting (Figure 12 was captured under a magnification of 2000x). In short, the identification of fatigue failure in composites can be very challenging. One macroscopic feature that can provide evidence of fatigue is abrasion between mating fracture surfaces. With repeated loading, the growing fracture surfaces may rub against each other and leave abrasive marks on the ends of broken fibers and in the matrix.

American Airlines Flight 587

Soon to be eclipsed by the center wing box of the A380 and the fuselage of the B-787, the vertical stabilizer of the Airbus A300-600 is one of the largest composite principal structural elements in commercial aviation. Although the structure was originally designed with metallic materials, the metallic design was eventu-

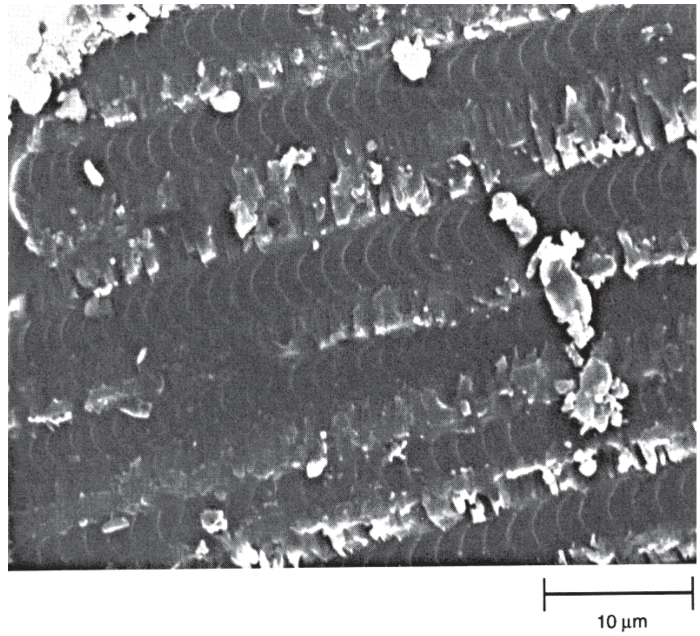

Figure 12. Striations at the interface between fibers and matrix (Stumpff 2001).

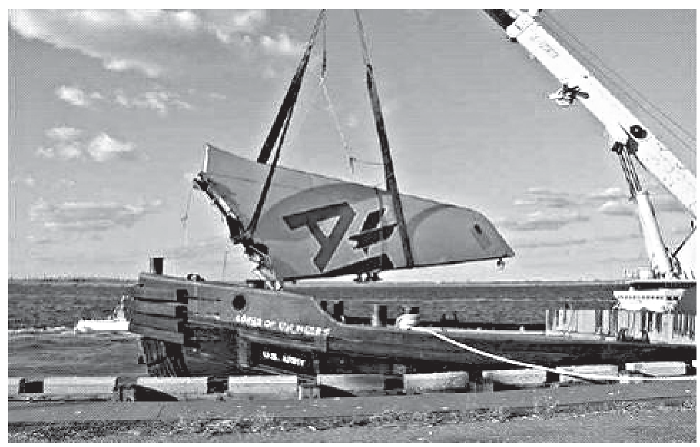

Figure 13. A300-600 composite vertical stabilizer that failed during American Airlines Flight 587 in November 2001 (NTSB 2004).

ally replaced by a composite design employing carbon fibers in an epoxy matrix. Since that time, the composite stabilizer has accumulated more than 20 years of service. In November of 2001, American Airlines Flight 587's composite stabilizer failed (Figure 13). As a potential harbinger of the failures discussed in this paper, the failure of this composite structure is discussed in the paragraphs below. The discussion frequently refers to the features of failed composites discussed in the section above.

The vertical stabilizer of the A300-600 is attached to the fuselage by three pairs of composite lugs—forward, middle, and aft—along the union between the stabilizer and the fuselage. The lugs transfer bending moments applied to the stabilizer through large diameter bolts. Between each pair of lugs is a composite transverse load fitting that transfers lateral loads applied to the stabilizer to the fuselage. Analysis of flight recorder data by the NTSB indicates that the aircraft was subjected to a violently changing oscillatory sideslip motion, causing loads in excess of the ultimate design loads of the stabilizer. The NTSB determined that

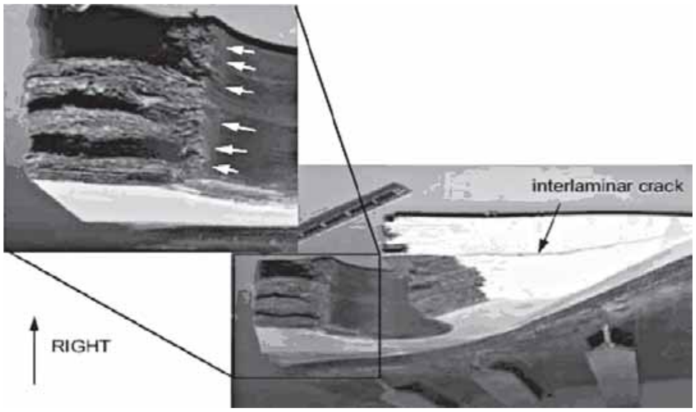

Figure 14. Along with several other fractures, the fractures of the right aft lug were rough, consistent with tensile loading (NTSB 2002).

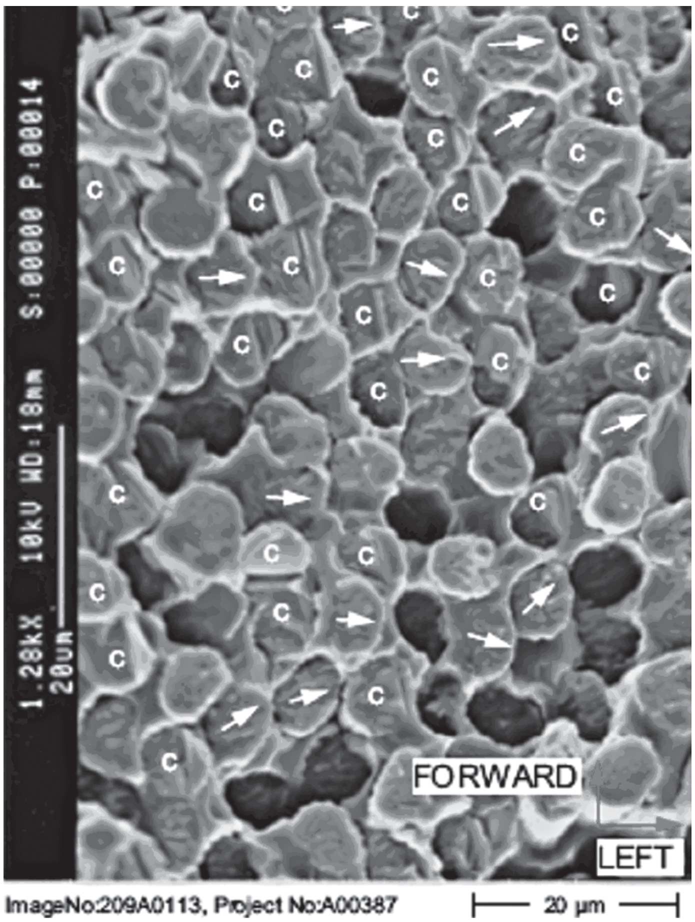

Figure 15. Fractures in multiple locations exhibited chop marks (marked with a "c") on the ends of fractured fibers, consistent with compressive loading and buckling of fibers (NTSB 2002).

the right rear lug of the stabilizer suffered a tensile overload failure that caused the progressive failure of the remainder of the attachment points.

As discussed above, tensile failures in composites generally produce rough fracture surfaces. Figure 14 shows the fracture surface of the right aft composite lug. The rough appearance of this fracture surface helped the NTSB determine that the lug failed under tensile loads. Similar rough fracture surfaces were

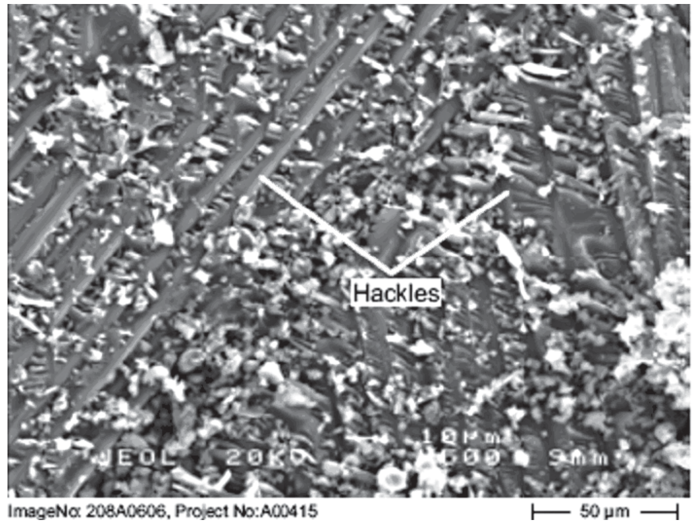

Figure 16. Interlaminar fractures in multiple locations exhibited hackles, consistent with failure in shear (NTSB 2002).

found on the other two lugs on the right side of the stabilizer. As a result, the NTSB concluded that the lugs on the right side of the stabilizer failed due to overstress under tensile loading.

According to the analysis by the NTSB, after the lugs on the right side failed, the damaged stabilizer deflected from right to left, loading the lugs on the left side of the stabilizer in bending. In bending, tension developed on the inboard side of the lugs and compression developed on the outboard side of the lugs. The NTSB identified evidence consistent with tension failure on the inboard side and compression failure on the outboard side of the lugs on the left side of the stabilizer. This is consistent with failure in bending, as discussed above. An example of the evidence associated with compression failure is presented in Figure 15, which shows chop marks found on the left aft lug.

As discussed above, when fibers are subjected to compressive loads, they can buckle and the fracture surface on the end of a failed fiber may indicate chop marks. The left aft, left center, and left forward lugs of the failed stabilizer each contained fractured fibers with chop marks. Also found on the left aft lug were hackles associated with shear failure in the matrix-rich region between plies (Figure 16), as discussed above. Hackles were found on the left forward lug as well.

Evidence consistent with bending was also found in the aft transverse fitting. Fractures on the attachment points on the right side of the transverse fitting were rough in appearance, indicating tensile failure, while the fracture on the left-most attachment point had a relatively smooth appearance, indicating compressive failure. This evidence was found by the NTSB to be consistent with bending of the stabilizer from right to left. Finally, it must be noted that the NTSB did not find any indication of fatigue damage in the vertical stabilizer.

Conclusions

With the impending generation of composite aircraft, the analysis of failed composite structures will be of significance to aircraft accident investigators. The introduction of composites introduces new variables into the analysis, such as fiber orientation, geometric variations among plies, and curing processes, among others. With new variables come new failure modes, such as fiber pullout, fiber kinking, and delamination, as well as the prevalence of brittle failure in composites as opposed to ductile failure in metals. Consequently, the analysis of failed composite structures cannot rely solely upon the body of accrued knowledge and experience related to failed metallic structures. This paper has introduced some of the basic concepts involved with analyzing failed composites under a variety of fundamental loading conditions. Fractographic details have been presented and subsequently illustrated by a short discussion of the analysis by the NTSB of the failed composite vertical stabilizer involved in American Airlines Flight 587. It must be emphasized, though, that the above discussion is very limited in nature. With a broad range of associated design variables, the investigation of composite structural failures requires particular expertise. It is likely that, given such complexity, future investigations involving composite primary structures will require significant input from accident investigators with expertise in the analysis of failed composite structures, as was required by the investigation of Flight 587. ◆

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Footnotes

[1] Conversely, automation will eliminate some sources of error associated with the construction of composites by hand.

[2] M.P. Papadakis (McCormick and Papdakis 2003).

[3] S. Taylor (McCormick and Papdakis 2003).

[4] S. Taylor (McCormick and Papdakis 2003).

[5] Such events typically produce microstructural evidence as well.

Solving FDR Readout Problems: A Proactive Approach

By Guillaume Aigoin and Guilhem Nicolas, Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (France)

1. Introduction

In order to develop its role in improving safety, the BEA has progressively given over a larger part of its investigation activity to incidents. A team dedicated to dealing with incidents in commercial air transport was created 3 years ago. The team's tasks include analyses of airborne recordings, either from flight data recorders (FDR) or non-protected data recorders. This activity requires that recordings be processed more rapidly, though recorder readouts often bring to light a variety of problems such as inappropriate decoding documents or absent or badly recorded data. This may significantly block or delay the validation of the readout work and subsequently the investigation. These recurrent difficulties were also mentioned by recorder specialists in other countries, and they do not depend on the aircraft model or on the country of registration. The present paper takes its inspiration from a dedicated study[1].

After a review of parameter recording formats, this paper will present the principles of recording system operational checks and discuss regulations pertaining to these checks. ICAO Annex 6 Part I recommended practices will be compared with two representative regulations: the European JAR OPS 1, which was transposed into national regulations of JAA members, and the American FAR Part 125. Then typical problems related to FDR readout and their origins will be brought together with the results of a survey on FDR maintenance conducted among French operators. The last part will be dedicated to the BEA's conclusions on what needs to be done to improve the overall quality of FDR recordings and the BEA's corresponding recommendations.

Guillaume Aigoin received a masters degree in aeronautics from the French National Civil Aviation School (ENAC) and a masters degree in automatics from the Paul Sabatier University (Toulouse, France) in 2001. He joined the BEA Engineering Department in 2001 as a safety investigator. He was incorporated into the performance group and developed tools for trajectory computations and radar data analysis. He has also been involved in the development of standards for airborne recorders, such as EUROCAE and ARINC.

Guilhem Nicolas received a masters degree in aeronautics from the French National Civil Aviation School (ENAC) in 2000 after an exchange program with Embry-Riddle Aeronautical University (Florida, USA) and an internship at the NTSB regional office in Miami. He joined the BEA Safety Analysis Division in 2000 as a safety investigator. He received a degree in human factors from the René Descartes University, Paris, in 2003. He has been involved in safety studies and participated in international investigations. These have included the accident to a Britair CRJ100 (June 2003, Brest, France) and an Air France Airbus A340 (August 2005, Toronto, Canada). He has also been involved in international working groups such as GAIN and JSSI (ODA).

2. Principles of data decoding

The FDR records information coming from a data acquisition unit that centralizes and formats data coming from sensors, onboard computers, and other instruments. Data are recorded as binary files that are sequenced in "frames" and "subframes" (see Figure 1).

Each subframe itself is divided into a number of "words," each with a fixed number of bits. Words are numbered from the beginning to the end of the subframe—the first word being called the "synchronization word" since it contains a marker indicating the start of the subframe in the binary file.

As Figure 1 illustrates, a parameter is recorded on one or several bits of one or more words. It may be recorded once or several times on every subframe or it may be recorded on every other subframes, or with a lower frequency. The information on where a parameter's data are to be found in terms of bit numbers, word numbers, and subframe numbers is called "*parameter location.*"

In order to save memory space, a parameter value is generally not recorded as such, but rather converted using a conversion function defined by the aircraft manufacturer. The reverse conversion function must be applied to the recorded parameter value in order to retrieve the actual parameter value. The information on the reverse conversion function is called "*parameter conversion.*"

The data frame layout document of a FDR installation contains complete information on parameter locations and conversions so that decoding software can be programmed to retrieve any recorded parameter automatically (see Figure 2). Such a document is provided by the aircraft manufacturer or equipment installer at initial installation, and the operator is then responsible for keeping and updating it.

According to ICAO Annex 6 Part I, operators should archive all documents "*concerning parameter allocation [and] conversion equations*" obtained from the initial installation of the equipment. The explicit purpose is to ensure "*that accident investigation authorities have the necessary information to read out the data in engineering units.*. The JAR OPS 1 and the FAR Part 125 also state that aircraft operators must keep such a document. Each of these regulations provides a list of parameters to record and requirements on their accuracy, range and resolutions.

3. Recording system operational checks

Periodic operational checks are necessary to verify that the FDR complies with requirements on recording quality. When these

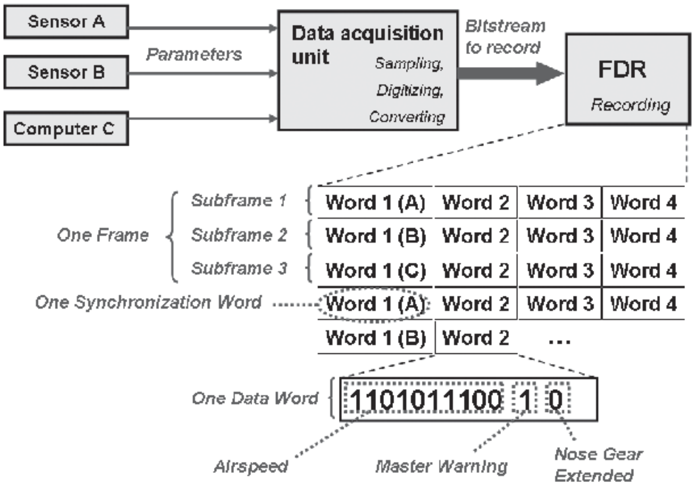

Figure 1. Parameter acquisition and coding.

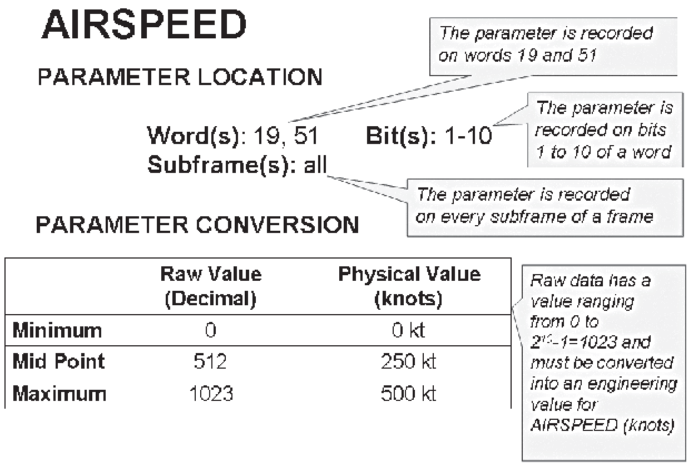

Figure 2. Information related to a parameter in the data frame layout document.

Parameter	Value range	Evolution	Bias	Corrective action
Computed airspeed	Consistent: values between 0 and 400 kt	Consistent: parameter cycles correspond to the history of flight between the dates xx/xx/xx and xx/xx/xx	0	None
Longitudinal acceleration	Consistent: values between -0.3 g and +0.3g	Consistent: positive when computed airspeed increases, negative when computed airspeed decreases	***+0.08***	***Adjust conversion to have this parameter zero-centered***

Table 1. Extract of an FDR inspection report.

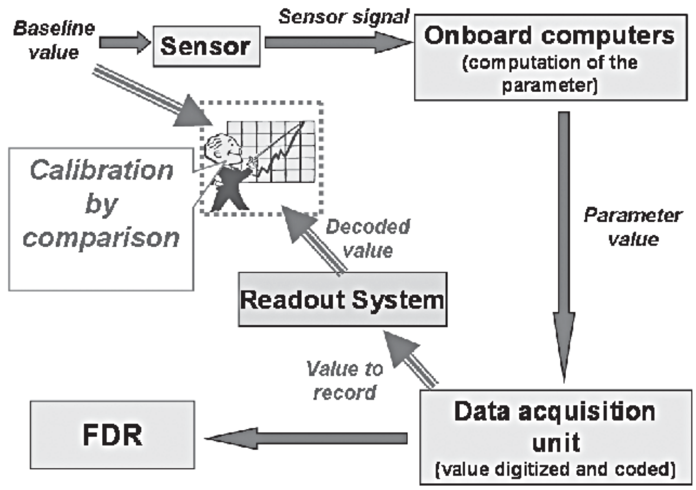

Figure 3. System calibration involves comparing baseline values with data acquisition unit output values.

requirements are not met, various types of actions can be taken: replacement or repair of malfunctioning elements or modification of the data frame layout document. Two complementary maintenance tasks are presented below that would allow an operator to guarantee the continuous serviceability of installed FDRs and regulatory requirements pertaining to these tasks. References to non-mandatory guidance are also provided.

The first task is the FDR recording inspection. It starts with processing the entire FDR recording with decoding software that has been programmed according to the data frame layout document. Decoded parameters are then analyzed for quality. The operator should produce a report including the detailed results of the recording inspection and take corrective actions. Table 1 illustrates an extract of the recording inspection report.

A comprehensive inspection has at least four components—

- Firstly, to check consistency of parameter values and evolutions with operational knowledge.
- Secondly, to check the consistency of the parameters' patterns in typical phases of flight such as causal relation between a flight control and associated flight surfaces in the context of takeoff.
- Thirdly, to check that the total accumulated time of unreadable data is limited and that there are no cyclical areas of unreadable data.
- Finally, to check that data were recorded in proper chronological order and without any overlapping.

ICAO Annex 6 Part I states that operators should carry out annual inspections of FDR recordings. It recommends that *"the FDR data from a complete flight … be examined in engineering units to evaluate the validity of all recorded parameters."* A report of this inspection should be made available to the state's regulatory authority and the recorder should be considered unserviceable *"if one or more of the mandatory parameters is not recorded correctly."* In contrast, neither JAR OPS 1 nor FAR Part 125 recommends any type of FDR recording inspection. However JAR OPS 1 requires a flight data monitoring (FDM) program for those aeroplanes with a maximum certificated takeoff weight in excess of[2] 27,000 kg, as recommended by ICAO Annex 6 Part I. Numerous problems can be detected when FDM is put in place, even if this is not equivalent to a regular inspection of FDR recordings. Indeed, FDM sources are generally non-protected recorders, whose recording media can be removed and replaced quickly. Problems related to the FDR may, therefore, go undetected.

The second maintenance task is the calibration check of the FDR measuring channels. Indeed, conversion functions provided by manufacturers are the result of tests performed on prototypes and can, therefore, differ from the functions appropriate for a given aircraft. Several factors can alter the quality of the measurements such as sensor aging and disassembly of mechanical elements during an overhaul causing a sensor to go out of adjustment. These problems can go undetected since sensors used for recorders are sometimes different from the ones feeding data to flight instruments and other aircraft systems. In addition, parameters that are used to warn of unusual situations, such as GPWS warnings, are not activated during normal flights and do not appear on FDR recordings. For these reasons, a specific test is needed.

For a given parameter, this test consists of generating a series of baseline values and entering these values into a sensor (see Figure 3). The corresponding output values of the data acquisition unit are processed by a compatible readout system that computes the physical values using conversion functions of the data frame layout document. Deviations between input and readout system output are entered in a so-called "calibration table" and compared with the required accuracy, as shown in Table 2. The operator should produce a report containing parameter calibration tables and take corrective actions.

Actual position measured with a clinometer (degrees)	**Raw output** value from the acquisition unit	**Converted value** using conversion functions (degrees)	**Deviation** (degrees)
+ 25.5 (right stop)	2,880	+ 25.2	- 0.3
0	2,065	0.5	+ 0.5
- 25 (left stop)	1,246	- 22.3	***+ 2.7***
Maximum allowable deviation: +/- 2°			***Corrective action: adjust sensor setting***

Table 2. Example of a calibration check table for a flight surface.

ICAO Annex 6 part I indicates that such a calibration check should be performed at least every 5 years for the mandatory parameters and more frequently for those parameters provided by sensors dedicated to the FDR. The documentation related to calibration should be kept up-to-date accordingly. In contrast, neither JAR OPS 1 nor FAR Part 125 recommend a calibration check of the FDR measuring channels.

Apart from regulatory requirements, non-mandatory guidance on FDR operational checks has been issued by national authorities. For example, the FAA's Advisory Circular AC 20-141 provides guidance about maintenance operations on FDRs. It recommends that the operator maintenance program include an FDR recording check to determine "*the reasonableness of mandatory parameters recorded by the DFDR*" and a functional check "*to verify the performance of any mandatory parameters not verified from the flight data.*" Guidance on FDRs has also been issued by non-state organizations such as EUROCAE. EUROCAE Document 112 contains recommendations and means of conformity for FDR maintenance.

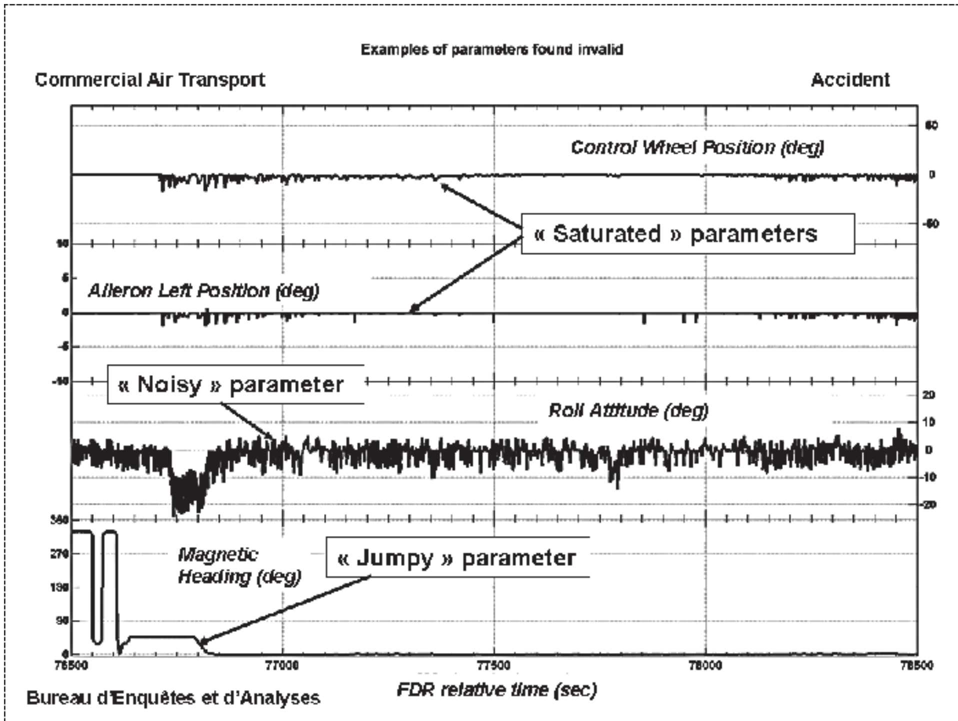

Figure 4. Various problems may affect parameters from the same aircraft.

4. Problems related to FDR readout and analysis

With about 30 FDRs read out and analyzed each year, half of them in the context of technical assistance to foreign investigation bodies, the BEA Engineering Department has broad experience of the readout problems that can be encountered.

These problems generally occur due to airlines failing to adequately ensure the operational serviceability of FDRs. For this reason, the problems were categorized and grouped with the results of a survey conducted by the BEA in 2002 and 2003 on a representative sample of 20 French airlines. The survey was aimed at analyzing areas related to FDR maintenance and the use of FDR data, including the readout equipment used, the update of data frame layout documents as well as FDM implementation.

The first category of problems pertains to missing or incomplete data. In many recordings, several parameters are found to be invalid and unusable—they have values that are not physically possible, or are very noisy (see Figure 4). Sometimes, large or cyclical periods of invalid data are found in a recording. In some recordings, flights overlap with each other, upsetting data chronological order. There are multiple causes for these problems, such as defective sensors, a connection or programming problem, or a defective recording medium. However, the main reason for the frequency of failures is the absence of adequate FDR recording inspection by operators.

As explained above, FDM is not strictly equivalent to FDR recording inspection but it helps the operator to detect problems in the recording and is required by European regulations. The BEA survey revealed that only 9 out of 20 operators performed systematic FDM. These were mainly large airlines (more than 500 employees). Eight operators were found to perform regular but not systematic FDM, i.e., they limited data monitoring to a part of the fleet or to specific categories of events.

The second category of problems pertains to the operator retaining a copy of the generic documentation provided by the aircraft manufacturer instead of an up-to-date data frame layout document. This is often associated with corrupt data in the FDR recording since the operator does not have the document needed to perform an adequate recording inspection.

The retrofit of a FDR installation without modification of the data frame layout document is one identified cause: new parameters may not be documented or a parameter location may have been changed. Information related to FDR installation is also

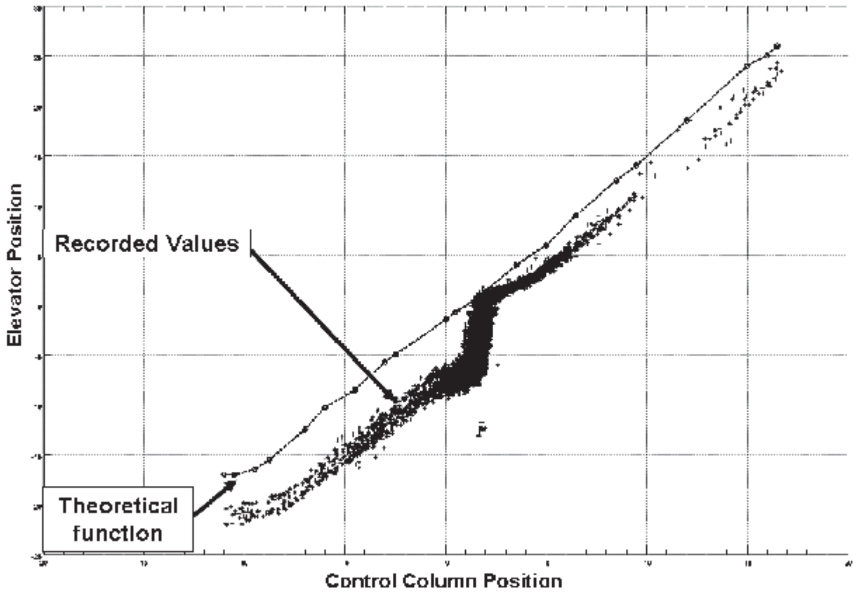

Figure 5. Example of deviation from theoretical equation.

lost throughout the lifetime of the aircraft at each change of operator. The BEA survey revealed that only 11 out of 20 operators had complete data frame layout documents. These included operators performing FDM, as parameter analysis is not possible when data frame layout information is missing. Four operators had either incomplete or outdated documents; five operators did not store any documents.

The third category of problems pertains to absent calibration check reports. Generally the operator does retain generic parameter conversion equations but no parameter calibration tables. However, the difference between the decoded value and the actual value of a parameter happens to be higher than the required accuracy, as illustrated by Figure 5. Unchecked parameters may then lead investigators to erroneous conclusions, or excursions of a parameter beyond operational safe limits may go unnoticed by the operator FDM.

The BEA survey showed that no operators were performing any kind of calibration check of FDR measuring channels, which is no surprise since European regulations do not require this as a basic maintenance task. The operators checked elements of the measuring channels separately but did not test any measuring channels overall.

5. Progress and challenges

The BEA concluded that recurrent FDR readout problems are due to factors including data frame layout documents not being archived or properly updated, inadequate inspection of FDR recording, and absence of calibration checks of FDR measuring channels. These issues are often linked to poor specific knowledge about FDRs, especially among small- and mid-sized operators. In addition, national regulations trail behind ICAO recommended practices and fail to give detailed and constraining requirements on FDR operational checks, even though valuable guidance already exists. Consequently, the BEA study dedicated to FDR maintenance contained several recommendations.

In order to improve the quality of data frame layout documents on a worldwide scale, the BEA recommended that the ICAO ensure, through its audit procedures "*that contracting states ensure that their operators can rapidly provide comprehensive and up-to-date data frame layout documents.*"

At the European level, the BEA recommended that European regulations be updated "*in terms of necessary corrective actions when a mandatory parameter is not correctly recorded or the chronological recording structure does not match the history of the flights performed.*" It also recommended "*a comprehensive calibration program for mandatory parameters measuring and processing channels,*" so that calibration problems are detected. In order to ensure that some kind of information related to parameter decoding can be retrieved readily by investigators, the BEA recommended that regulatory requirements be defined to get data frame layout information "*recorded on FDR's themselves.*"

Nationally, the BEA's study showed that regional civil aviation services have the most appropriate means at their disposal to check the quality of data frame layout documents. As a result, the BEA recommended "*that all operators and regional services of the French Civil Aviation authorities possess identical, up-to-date and comprehensive data frame layout documents.*" The BEA also recommended the study of "*a formalized report template for the verification of mandatory parameter recordings.*" The objective is to make FDR recording inspection reports more understandable through standardization.

Through its study, the BEA aimed at alerting the aviation community on a global safety problem. Improving FDR recording quality is only possible if most national authorities and operators commit themselves to more stringent FDR operational serviceability requirements. The safety benefits, though not immediately apparent, are significant enough to justify an additional effort being made and international cooperation being further extended. Improving safety is the way ahead, realizing the full potential offered by FDRs is the means to achieve it. ◆

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ICAO Annex 6 part I, *International Commercial Air Transport—Aeroplanes* (July 2001). See Subchapter 3.2 and Attachment D.

JAR OPS 1, *Commercial Air* Transportation—*Aeroplanes* (March 2006). See Paragraphs 1.037, 1.160, and paragraphs 1.715, 1.720, and 1.725.

FAR Part 125, *Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6,000 Pounds or More* (November 2003). See Section 125.226.

FAA Advisory Circular 20-141, *Airworthiness and Operational Approval of Digital Flight Data Recorder Systems* (May 1999).

United Kingdom CAA Safety Regulation Group CAP 731, *Approval, Operational Serviceability, and Readout of Flight Data Recorder Systems* (May 2004).

United Kingdom CAA Safety Regulation Group CAP 739, *Flight Data Monitoring* (August 2003).

Australia CASA, CAAP 42L-4, *Flight Data Recorder Maintenance* (October 2002).

EUROCAE Document 112, Minimum Operational Performance Specification for Crash Protected Airborne Recorder Systems (July 2003). See Chapter II-6, Annex II-A, and Annex II-B.

Endnotes

1 *Flight data recorder readout: technical and regulatory aspects* available on the BEA website.

2 The French transposition of JAR OPS 1 is more stringent, since it requires flight data monitoring for turbine-engine-powered aircraft with a maximum certificated takeoff weight in excess of 10,000 kg or with a number of seats in excess of 20.

Using the Threat and Error Management (TEM) Framework as An Analytical Tool in ATC

By Bert Ruitenberg, ATC Team Leader–Tower & Approach Units, Schiphol Airport, Amsterdam

Introduction

The Threat and Error Management (TEM) framework was developed by the University of Texas and is the basis for the successful Line Operations Safety Audit (LOSA) programs that have been adopted by airlines around the world. The air traffic control (ATC) community is also starting to embrace the TEM framework after its introduction as the basis for a program called Normal Operations Safety Survey (NOSS), i.e., the ATC equivalent of LOSA.

This paper will discuss the potential value of the TEM framework for application as an analytical tool in ATC incident investigation. A case study is used to illustrate how the effectiveness of draft recommendations can be evaluated by using the TEM framework before finalizing the investigation report.

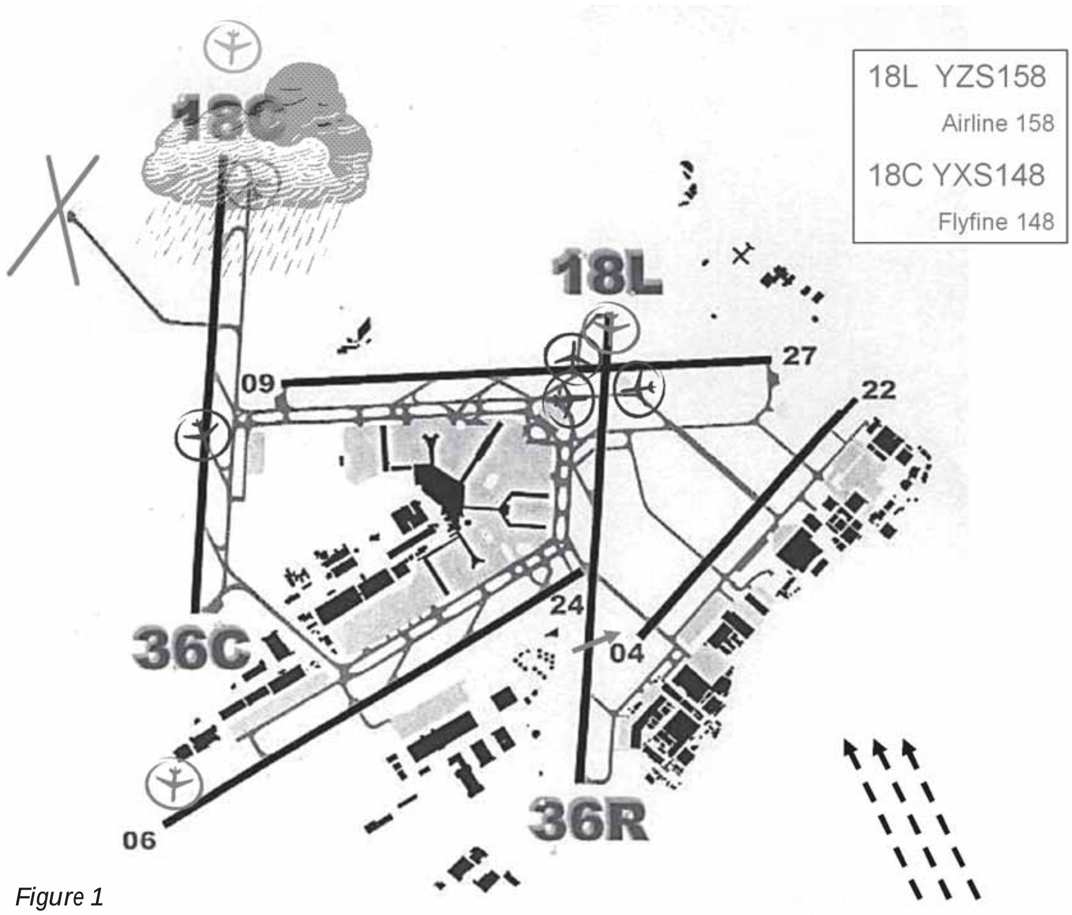

Figure 1

Case study (Amsterdam Airport)

It was a day with frequent showers and a strong, gusty wind. There was one runway available for departures (18 left), and only one other runway available for arrivals (18 center) as opposed to two, normally. Because of the gusty wind, quite a few aircraft made a missed approach on the landing runway.

For operational reasons, one particular flight had requested permission to use Runway 18C for its departure, and that request was approved by ATC.

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the regular holding points, and one aircraft at an infrequently used holding point on the other side of the runway. The airport fire brigade was crossing the runway (with clearance) in response to a minor emergency at an aircraft parking stand. The callsign of the aircraft on the runway was very similar to that of the aircraft intending to depart from 18C: YZS158 ("Airline 158") was on Runway 18L, and YXS148 ("Flyfine 148") was near Runway 18C.

After the fire trucks had crossed the departure runway (18L) the tower controller, who also was the tower supervisor that day, wanted to clear the aircraft waiting on the runway for takeoff. When giving the takeoff clearance, however, he mixed up the callsign and flight number of that aircraft with those of the aircraft near the landing runway (18C). Although he did include the correct runway identifier (18 left) in his clearance, the takeoff clearance was acknowledged by the aircraft near the landing runway. In their readback of the clearance, the pilots used the same runway identifier that the controller used (18 left) which in their case was incorrect for the runway they were about to enter (18 center). The aircraft subsequently departed from Runway 18C, which by chance occurred between two successive landing aircraft of which the second made a missed approach because of the wind.

At the time of this occurrence, a rain shower passed over the beginning of Runway 18C, obscuring the view of the holding point from the tower. The tower controller didn't realize what had happened until the aircraft was airborne from Runway 18C, flying in front of the aircraft that had to make a missed approach, which he observed on his radar display. The aircraft waiting on Runway 18L reminded the controller a few moments later that they were still lined up, after which the controller cleared them for takeoff.

Based on the information presented above, preventive measures that could be proposed include (but are not limited to) the systemic deconfliction of callsigns, having a dedicated supervisor on duty, or using separate controllers for each of the runways. In order to find out which of those measures is potentially the most effective one, the occurrence is analyzed using the Threat and Error Management (TEM) framework.

TE-based analysis

In the air traffic control adaptation of the TEM framework, threats are defined as "events or errors that occur beyond the influence of the air traffic controller, increase operational complexity, and which must be managed to maintain the margins of safety." The threats that can be identified in the case study above comprise (in no particular order):

1. Strong gusty wind conditions.
2. Only one landing runway available (as opposed to two, normally).
3. Several earlier missed approaches because of weather.
4. Controller also is the tower supervisor.
5. Departure from non-standard runway.
6. No extra markings for non-standard runway on flight strip YXS148.
7. No heads-up remark from Ground Controller with transfer of YXS148 near 18C.
8. Departure 18C to be integrated with landing traffic.
9. Departure 18L from non-standard holding point.
10. Fire engines requiring to cross the departure runway.
11. Similar company identifiers on flight strips of departing traffic (YXS and YZS).
12. Company identifiers do not resemble the corresponding callsigns (Flyfine and Airline).
13. Similar flight numbers (148 and 158).
14. Acceptance and acknowledgement of clearance for incorrect runway by YXS148.
15. YZS158 doesn't challenge the clearance for the other flight to take off on 18L.
16. Beginning of runway 18C obscured by rain shower.

The TEM framework defines error as "actions or inactions by the air traffic controller that lead to deviations from organizational or air traffic controller intentions or expectations." The controller from the case study made the following errors:

1. Did not notice that YXS148 was at the holding point for Runway 18C.
2. Provided incorrect information ("several departures in front") to YXS148.
3. Used incorrect callsign/flight number/runway identifier combination in takeoff clearance ("Flyfine 158 cleared for take off 18 left").
4. Did not notice that the take off clearance was acknowledged by YXS148.

A third category in the TEM framework is that of undesired states, which are defined as "operational conditions where an unintended traffic situation results in a reduction in margins of safety." Undesired states can be managed effectively, restoring margins of safety, or the air traffic controller's response(s) can induce an additional error. Undesired states are transitional states between a normal operational state and an outcome. Outcomes can be "uneventful" in the case of successful management of the undesired state, or be a reportable occurrence (an incident or an accident) in the case of unsuccessful management of the undesired state.

The undesired states that can be identified in the case study are

1. YXS148 departing from Runway 18C on the takeoff clearance intended for YZS158 on Runway 18L.
2. YZS158 remains lined up and waiting on Runway 18L.

According to the TEM framework there is a link between threats, errors, and undesired states. Not every threat leads to an error, and not every error leads to an undesired state, but mismanaged threats frequently lead to errors, and mismanaged errors frequently lead to undesired states. The following paragraphs explore the links for the case study:

Threats linked to errors 1 and 2

T4. Controller also is the tower supervisor.
T5. Departure from non-standard runway.
T6. No extra markings for non-standard runway on flight strip YXS148.
T7. No heads-up remark from ground controller with transfer of YXS148 near 18C.
T8. Departure 18C to be integrated with landing traffic.
T16. Beginning of Runway 18C obscured by rain shower.

Those threats were not managed and are linked to error 1 (Did not notice that YXS148 was at the holding point for Runway 18C). Error 1 was not managed and is directly linked to error 2—provided incorrect information ("several departures in front") to YXS148.

Threats linked to error 3

T11. Similar company identifiers on flight strips of departing traffic (YXS and YZS).
T12. Company identifiers do not resemble the corresponding callsigns (Flyfine and Airline).
T13. Similar flight numbers (148 and 158).

Those threats were not managed and are linked to error 3—used incorrect callsign/flight number/runway identifier combination in takeoff clearance ("Flyfine 158 cleared for take off 18 left").

Threat linked to error 4

T14. Acceptance and acknowledgement of clearance for incorrect runway by YXS148.

This threat was not managed and is linked to error 4—did not notice that the takeoff clearance was acknowledged by YXS148.

The remaining threats from the original listing were either managed or inconsequential:
T1. Strong gusty wind conditions.
T2. Only one landing runway available (as opposed to two, normally).
T3. Several earlier missed approaches because of weather.
T9. Departure 18L from non-standard holding point.
T10. Fire engines requiring to cross the departure runway.

Errors linked to undesired states

E1. Did not notice that YXS148 was at the holding point for Runway 18C.
E2. Provided incorrect information ("several departures in front") to YXS148.
E3. Used incorrect callsign/flight number/runway identifier combination in take off clearance ("Flyfine 158 cleared for take off 18 left").
E4. Did not notice that the takeoff clearance was acknowledged by YXS148.

As noted earlier, error 1 was not noticed and not managed by the controller and resulted directly in error 2. That error was also not noticed nor managed, however, its outcome was inconsequential.

Error 3 is linked with threat 14 (Acceptance and acknowledgement of clearance for incorrect runway by YXS148), which in turn is linked to error 4. This last error was not noticed nor managed by the controller, resulting in an undesired state:
US1. YXS148 departing from Runway 18C on the takeoff clearance intended for YZS158 on Runway 18L.

This undesired state was not managed; the outcome was a departure from another runway than intended by the controller.

Although error 3 was not noticed by the controller, it was noticed by the crew of YZS158 on Runway 18L. This error, therefore, is also linked with threat 15 from the list:
T15. YZS158 doesn't challenge the clearance for the other flight to take off on 18L.

This threat is not managed and leads to an undesired state:

US2. YZS158 remains lined up and waiting on Runway 18L.

This undesired state is noticed by the controller after a subsequent remark from YZS158 and managed by clearing the aircraft for take off. Its outcome is, therefore, inconsequential.

Effectiveness of potential countermeasures

Now that the links between the identified threats, errors, and undesired states are established, it becomes possible to check the effectiveness of the preventive measures mentioned earlier against the list of threats. The first potential measure mentioned was the systemic deconfliction of callsigns. This measure addresses the following threats:
T11. Similar company identifiers on flight strips of departing traffic (YXS and YZS).
T12. Company identifiers do not resemble the corresponding callsigns (Flyfine and Airline).
T13. Similar flight numbers (148 and 158).
T14. Acceptance and acknowledgement of clearance for incorrect runway by YXS148.

The potential measure to have a dedicated supervisor on duty in reality only addresses one specific threat:
T4. Controller also is the tower supervisor.

The third potential measure mentioned, i.e., using separate controllers for each of the runways, addresses the following threats:
T5. Departure from non-standard runway.
T6. No extra markings for non-standard runway on flight strip YXS148.
T7. No heads-up remark from ground controller with transfer of YXS148 near 18C.
T8. Departure 18C to be integrated with landing traffic.
T11. Similar company identifiers on flight strips of departing traffic (YXS and YZS).
T12. Company identifiers do not resemble the corresponding callsigns (Flyfine and Airline).
T13. Similar flight numbers (148 and 158).
T14. Acceptance and acknowledgement of clearance for incorrect runway by YXS148.
T15. YZS158 doesn't challenge the clearance for the other flight to take off on 18L.
T16. Beginning of Runway 18C obscured by rain shower.

Each controller would be working on a dedicated frequency, so the flights involved in this incident wouldn't be able to hear each other. YXS148 would be the only departing flight on the frequency of the controller for Runway 18C, to which the appropriate level of attention could be given especially if there was a shower over the beginning of the runway. When realizing that T1, T2, T3, T9, and T10 comprise the list of threats that were either managed or inconsequential, it is evident that this third preventive measure is the most effective one.

Conclusion

The TEM framework can potentially be applied in incident and accident investigation by quantifying elements in the context of air traffic control operations and by providing an understanding of the relationships between those elements. Application of the TEM framework can assist in validating countermeasures that are proposed in investigation reports. ◆

Reference

ICAO, *Threat and Error Management (TEM) in Air Traffic Control* (ICAO, preliminary edition 2005, in print).

The ATSB Approach to Improving the Quality of Investigation Analysis

By Michael B. Walker, Senior Transport Safety Investigator,
Australian Transport Safety Bureau

Summary

The Australian Transport Safety Bureau (ATSB) is developing a Safety Investigation Information Management System (SIIMS) for its investigation activities. A key component of the System will be a set of tools for the analysis phase of a safety investigation. These tools were developed as part of a broader framework for improving the quality of investigation analysis activities. This paper will provide a brief overview of SIIMS, and then describe the new ATSB analysis framework.

The Safety Information Investigation Management System (SIIMS)

In 2004, the ATSB was successful in obtaining substantial Australian government funding to replace its existing occurrence[2] database (OASIS) with a new system. There were several drivers for the change, including the fact that OASIS was based on a very complex data model, which made trend analysis and research difficult. The previous system also had limited functionality beyond being an occurrence database. The ATSB wanted to take advantage of developments in information technology to build a system that could enhance the quality of the investigation process.

To meet this aim, SIIMS will have an investigation workspace for each investigation with the following components:

- Investigation log: a form to record and categorize significant events and decisions made during the investigation;
- Document management: a structured set of folders to store and organize all of the evidence collected during the investigation, including text documents, images, and other multimedia files;
- Evidence tracking: a tool to manage the movement and examination of original items of evidence (e.g., logbooks, wreckage, recorders) held by the investigation team;
- Analysis: a set of tools to help guide the analysis phase of the investigation, as well as document the results of analysis activities;
- Project management: a tool to identify and manage risks to the investigation, as well as project management software to formally manage the tasks and resources of an investigation;
- Report workflow: tools to assist the development of an investigation report, and its modification through the different stages of review;
- Search: tools to search the investigation documents and forms in the workspace, as well as tools to search the occurrence database;
- Contact lists: a means to organize all relevant contacts for the investigation, and therefore facilitate communication with external parties about the investigation;
- Access to a reference library (i.e., a set of documents and links that provide useful reference material to investigators, such as ICAO Annexes, ATSB manuals, and technical manuals); and
- Access to the occurrence database.

The system is being developed in consultation with a multidisciplinary team of investigators. In addition, the system design has been aided by discussions with the Canadian Transportation Safety Board (TSB), which has been developing a similar system. SIIMS is expected to be fully operational in early 2007.

Need for a new analysis framework

The analysis phase of a safety investigation is where the available data are reviewed, evaluated, and then converted into a series of arguments, which produce a series of relevant findings. The quality of an investigation's analysis activities obviously plays a critical role in the determining whether the investigation's findings are successful in enhancing safety.

The analysis phase is also rarely easy. Safety investigations require analysis of complex sets of data, and situations where the available data can be vague, incomplete, and misleading. There are no detailed, prescriptive rules that can be applied in all situations and provide guaranteed success, and analysis activities ultimately rely on the judgment of safety investigators.

Despite its importance, complexity, and reliance on investigators' judgments, analysis has been a neglected area in terms of standards, guidance, and training of investigators in most organizations. Many investigators seem to conduct analysis activities primarily using intuition rather than any structured process. It also appears that much of the analysis is typically conducted while the investigation report is being written. As a result, the writing process becomes difficult, supporting arguments for findings may be weak or not clearly presented, and important factors can be missed.

To help address this situation, the ATSB wanted to introduce a comprehensive framework (including tools in SIIMS) to guide and support the analysis activities of its investigators. The ultimate aims

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of this framework were to improve the rigor, consistency, and defendability of investigation analysis activities, and improve the ability of investigators to detect safety issues in the transportation system. The framework will therefore have a direct role in more effectively "breaking the chain" of accident development.

The ATSB initially reviewed existing analysis frameworks and methods applicable to safety investigation. None of these were found to meet the ATSB's needs. Common limitations included applicability to a narrow domain (e.g., aircraft maintenance), focus on a limited part of the analysis process, lack of flexibility to handle novel situations, lack of flexibility to deal with both small and major investigations, and lack of guidance material about the process.

Consequently, the ATSB developed its own analysis framework, borrowing useful ideas from other organizations and its existing processes where appropriate, but also substantially adding to this material in many areas. The resulting framework is described by the following components:

- Standardized terminology and definitions for analysis-related terms;
- an accident development model;
- a defined process or workflow;
- analysis tools in SIIMS; and
- policies, guidelines, and training.

Standardized terminology

The ATSB recognized the need for clear definitions and consistent usage of analysis-related terms. This included terms such as risk, safety, and hazard. More importantly, it included terms to represent the types of events and conditions to be found by an investigation. Rather than use terms based on "cause," which are associated with a range of semantic and communication problems, the ATSB decided to use "safety factor," "contributing safety factor," and "safety issue."

A **safety factor** was defined as an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include a wide range of events and conditions, such as accident events, technical failures, individual actions, local conditions, and a range of organizational or systemic conditions.

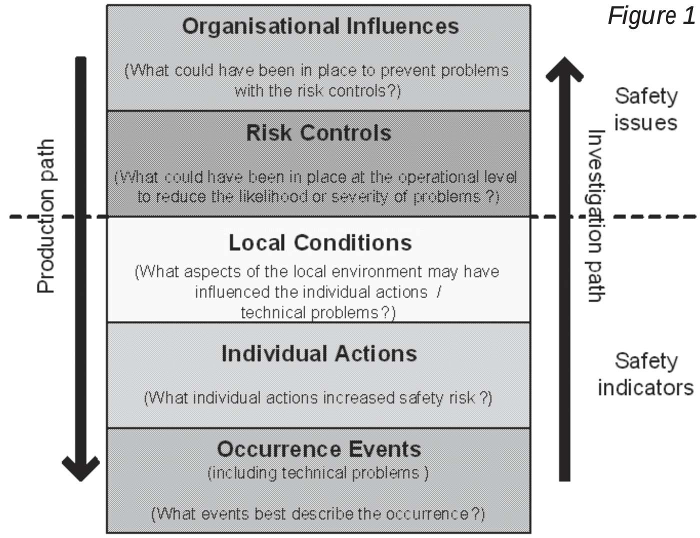
Safety factors can be classified in terms of whether they contributed to the occurrence of interest. More specifically, a **contributing safety factor** was defined as a safety factor that, if it had not occurred or existed at the relevant time, then

- the occurrence would probably not have occurred;
- adverse consequences associated with the occurrence would probably not have occurred or have been as serious; or
- another contributing safety factor would probably not have occurred or existed.

This definition is based on a counterfactual conditional (i.e., if "A" did not happen, then "B" would not have happened), which is a common way of defining cause. However, the definition has been expanded to more easily allow the reasoning process to move in steps from one contributing safety factor to the next. This mechanism provides a clearer basis for identifying organizational conditions as contributory to an occurrence.

The definition also specifically includes the term "probably,"

Figure 1



which was defined as meaning a probability of 75% or more[3]. This ensures that the standard of proof used in safety investigations is a practical compromise between a low standard such as "on the balance of probabilities" (which could produce factors that may be considered weak by external parties) and a high standard such as "beyond a reasonable doubt" (which would usually produce few factors other than those involving technical failures or the actions of flight crew).

Safety factors can also be classified in terms of their future influence on safety. More specifically, a **safety issue** was defined as a safety factor that

- can reasonably be regarded as having the potential to adversely affect the safety of future operations, and
- is a characteristic of an organization or a system, rather than a characteristic of a specific individual or characteristic of an operational environment at a specific point in time.

Not all contributing safety factors will be safety issues (e.g., pilot handling and fatigue during approach may contribute to a landing accident, but they are not safety issues). Similarly, not all safety issues will be contributing safety factors (e.g., an investigation may identify problems with an operator's fatigue-management system, but cannot conclude that these problems probably contributed to the flight crew's fatigue). Accident and incident investigations have traditionally focused on identifying the contributing safety factors, as this is what is of most interest to stakeholders, news media, and the public. However, for safety-enhancement purposes, investigations should also focus on identifying safety issues, regardless of whether they can be demonstrated to have contributed to the occurrence.

Although the definition of contributing safety factor uses the term "probably," the definition is not the same as "probable cause." In the ATSB framework, contributing safety factors are not ranked in terms of the degree to which they contributed to an occurrence. If safety factors are to be ranked in any way, it should be in terms of the safety risk level for future operations. In other words, only safety issues should be ranked, and the ranking should be in terms of the risk level associated with the issue.

Accident development model

A large number of different models or theories have been proposed about how accidents develop. Such models can play a

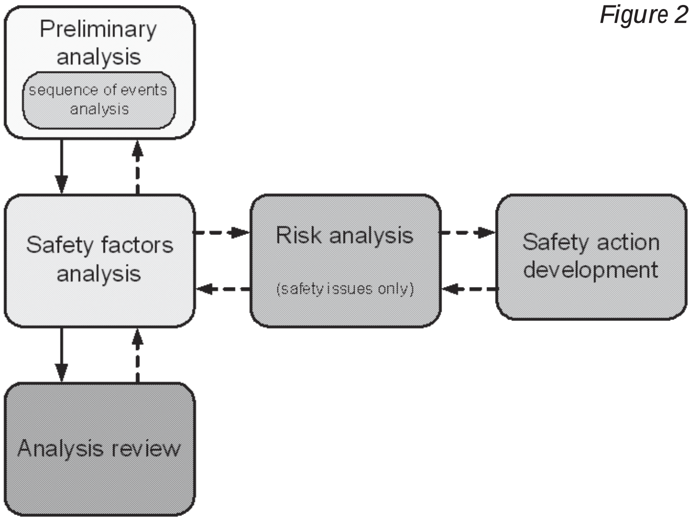


Figure 2

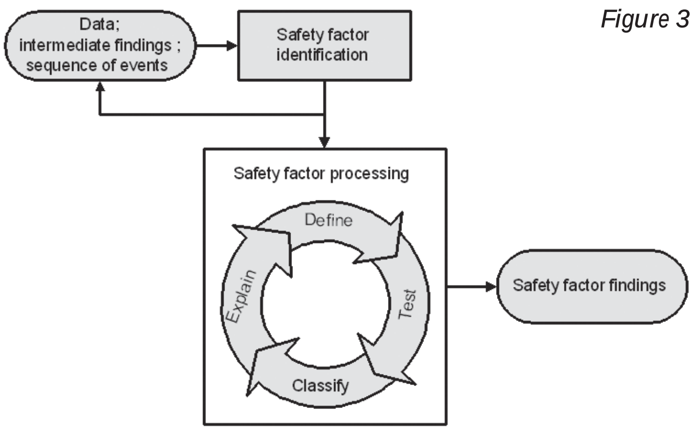


Figure 3

useful role during an investigation by helping investigation teams identify potential safety factors, and also providing a framework for classifying safety factors in a database. Unfortunately, some analysis methods provide no guiding model to assist with the identification of factors, whereas some other methods focus too much on a model and not enough on the identification process.

In recent years, the ATSB and other safety investigation agencies have successfully used the Reason Model of organizational accidents (Reason 1990, 1997) to guide the analysis phase of some investigations. Although this Model is widely accepted, it has some features that limit its usefulness. The ATSB has adapted the Model to better suit the requirements of safety investigation and to make the Model more applicable to a wider range of investigations.

The primary changes from the Reason Model include broadening the scope beyond a focus on human factors, and to more functionally define the components of the model in order to reduce overlaps and confusions when categorizing a factor. In particular, the ATSB model clearly distinguishes between the things an organization puts in place at the operational level to minimise risk (i.e., "risk controls," such as training, procedures, warning alarms, shift rosters), and the conditions that influence the effectiveness of these risk controls (i.e., "organizational influences," such as risk-management processes, training needs analysis processes, regulatory surveillance).

The resulting model can be arranged into a series of levels, as shown in Figure 1. Representing the model in this format facilitates the identification of safety factors, and can also help the investigation team maintain awareness of their progress when identifying potential factors during the investigation.

The analysis process

A major part of the ATSB analysis framework is a defined process or workflow to be used when conducting analysis activities. The overall process is divided into five separate processes, each of which is further broken down into a set of stages. The relationship between the five processes is shown in Figure 2. The five processes can be briefly described as follows:

- **Preliminary analysis**: A range of activities to convert data into a format suitable for the analysis of safety factors. This involves the use of techniques to interpret and organize data, including the systematic review of the sequence of events associated with an occurrence. Preliminary analysis may require the use of arguments to develop intermediate findings on a range of topics (e.g., angle of impact, who was the pilot handling, wind speed during approach).
- **Safety factors analysis**: A structured process to determine which events and conditions were safety factors, with an emphasis on determining the contributing safety factors and safety issues. Further information on safety factors analysis is provided below.
- **Risk analysis**: A structured process to determine the risk level associated with any verified safety issues. This involves determining the worst feasible scenario that could arise from the safety issue, and ranking the consequence and likelihood levels associated with such a scenario. The resulting risk level is classified as "critical," "significant," or "minor."
- **Safety action development**: A structured process of facilitating safety action by communicating safety issues to relevant organizations. The nature and timeliness of the ATSB communication is determined by the risk level associated with the safety issue.
- **Analysis review**: A review of the analysis results to identify gaps or weaknesses. This process involves checking the investigation findings for completeness and fairness. It also involves reorganizing the findings into a more coherent format and sequence (if required).

As indicated in Figure 2, safety factors analysis is the heart of the analysis process. It is composed of two main components: safety factor identification and safety factor processing. An overview of safety factors analysis is presented in Figure 3.

During safety factor identification, potential safety factors are identified by asking a set of generic questions about the occurrence (based on the accident development model), and asking a set of focussed questions to explain specific factors. In some situations, specialized techniques may also be useful to identify explanations for specific types of factors (e.g., barrier analysis, problem analysis, failure mode effects analysis).

Safety factor identification activities start early in the investigation and are repeated at regular intervals until there is sufficient data available to conduct safety factor processing. Investigators are encouraged to use charting techniques to display the relationships between potential factors. They are also encouraged to regularly review the list of potential factors to determine if there may be critical safety issues that need to be urgently addressed, as well as to determine needs for additional data collection.

Safety factor processing focuses on each potential safety factor that has been identified and selected for further analysis. This further analysis involves defining and testing the factor. Each verified factor is then classified in the occurrence database. The final stage is to ensure that, where possible, the factor has been potentially explained by other factors (i.e., a revision and extension of safety factor identification).

The "test" stage of safety factor processing is an area where the ATSB framework has placed substantially more emphasis than other analysis frameworks. For every potential safety factor that is identified as needing further analysis, a series of tests are performed to determine whether the factor can be "verified." These tests include the test for existence, test for influence, and test for importance. An overview of the flow of the testing process is presented in Figure 4.

The result of the testing process will determine whether a potential safety factor is a contributing safety factor (existence plus influence), another safety factor of interest (existence plus importance), or of no consequence to the investigation. The existence and influence tests are based on concepts presented in an ICAO human factors document (ICAO 1998). However, the guidance for conducting the tests has been extensively expanded. For example, to help conduct the test for influence, investigators are provided guiding questions on the following criteria: relative timing, reversibility, relative location, magnitude of proposed factor, plausibility, known history of influence, presence of enhancers, presence of inhibitors, characteristics of the problem (i.e., factor being explained), required assumptions, alternative explanations for the problem, and directionality of influence.

SIIMS analysis tools

Each of the five analysis processes is supported by tools in SIIMS, as summarized in Table 1. The tools provide a broad level of guidance when conducting the analysis process. They also provide a means for the investigation team to document their thoughts and activities when doing analysis activities. This documented trail of reasoning is invaluable when reviewing the investigation or keeping track of its progress.

Evidence tables are a critically important part of the ATSB analysis framework. Prior to discussing these tables further, it is useful to discuss the different types of findings produced by an investigation. Borrowing a concept from the Canadian TSB[4], the ATSB has started dividing the findings section of its investigation reports into three subsections:

- **Contributing safety factors** (as defined in the section on standardized terminology above);
- **Other safety factors**: safety factors identified during the investigation that did not meet the definition of contributing safety factor but were still considered to be important (i.e., they passed the test for importance);
- **Other key findings**: any other finding considered relevant to include in the findings section of the final report. This may include findings to resolve ambiguity or controversy, and findings about possible scenarios or safety factors when firm safety factor findings were not able to be made. It may also include positive safety factors, or events or conditions that "saved the day" or played an important tole in reducing the risk associated with the occurrence.

The intention of this format is to more clearly communicate the important safety messages from the investigation. In addition to the "key findings," an investigation may also develop a number of intermediate findings (during preliminary analysis) to help facilitate the process of moving from the collected data to a key finding.

Figure 4

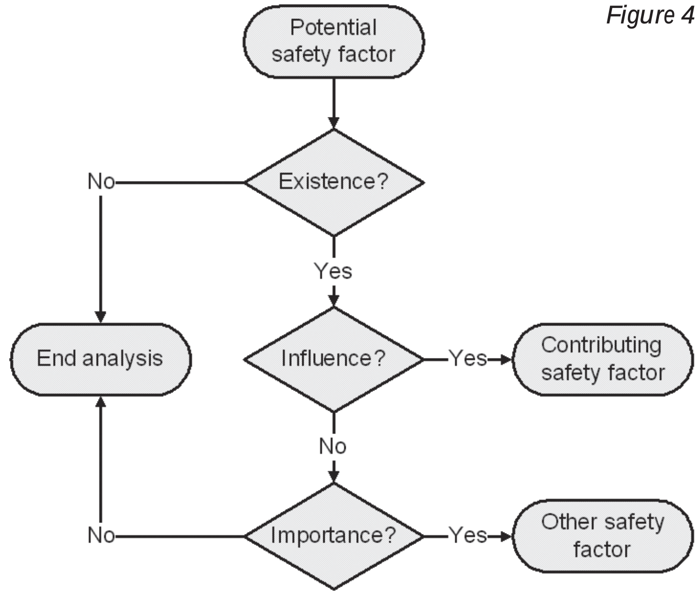


Table 1

Process	Tool	Purpose
Preliminary analysis	Basic evidence table	Tests the supporting argument for a non-safety factor finding
	Sequence of events list	Records summary data of key events associated with an occurrence, and produces various types of charts of this sequence
Safety factors analysis	Safety factors list	Records summary data of potential safety factors identified during the analysis
	Safety factor form	Records the results of the define, test, classify, and explain stages of safety factor processing
	Safety factor evidence table	Tests the supporting argument for a safety factor finding (built in to the safety factor form)
Risk analysis	Risk analysis form	Records the results of each stage of a risk analysis conducted on a safety issue
Safety action development	Safety action form	Records details of communications with external organizations regarding a safety issue, as well as any proposed or completed safety action
Analysis review	Summarize findings form	Reorganizes key findings of an investigation into a more coherent format for the final report (if required)

In the past, investigators have not always clearly presented the supporting arguments for their findings, other than in paragraph form in an investigation report. This format can be ambiguous, incomplete, and time consuming to finalize. The ATSB wanted investigators to present their supporting arguments in a more structured and understandable way prior to writing up the analysis section of a report.

The traditional way of presenting arguments in the field of critical reasoning is use a series of statements—premises followed by the finding. Developing an argument in this format can be a difficult process, particularly when dealing with complex sets of data, or situations where there are concerns regarding the credibility or relevance of items of evidence. The ATSB developed the evidence table to be more a flexible and easier to use format.

Basic evidence tables are used to test proposed "other key findings" and proposed intermediate findings. The tables consist of three columns: one for the items of evidence or information that may be relevant to the finding, one for clarifying comments about

Figure 5 Basic Evidence Table (Hypothetical Example)

Title: Flight crew qualifications / fitness

Description: It is very unlikely that there were any medical or physiological conditions that impaired the crew's performance during the approach and landing.

Item	Comments	Supports?
Regulator's annual medical records indicated no ongoing or potential medical fitness concerns	Records not always reliable indicators of existing problems – but do contain some medical testing	supports
Interviews with pilots revealed no indications of ongoing or recent medical problems likely to influence performance	Crews typically unlikely to volunteer such information during investigation interviews – no overt indications	unsure
Doctor who interviewed crew 2 days later concerned re pilot in command's concentration	Problems likely due to trauma of accident – no problems encountered in subsequent interviews	no effect
Operator arranged for crew to undertake eyesight tests – no problems identified	Results not actually sighted firsthand. However, no reason to doubt operator	supports

Summary: No reliable, conflicting information. Enough information to justify finding.

Supported? Yes   Add to key findings? No

each item, and one for rating how the item may impact on the finding (i.e., supports, opposes, no effect, or unsure). Based on the information in the three columns, an overall assessment can be made as to whether the proposed finding is supported. A simple example of a basic evidence table is provided in Figure 5. In SIIMS, investigators will be also able to provide links to supporting evidence in the document-management system for each of the items or comments in the table.

Safety factor evidence tables are used to test proposed safety factors. They have separate parts for the test for existence, test for influence, and test for importance. The existence and influence parts are essentially the same as the basic evidence table. The influence part (if required) is simply a free-text box allowing investigators to justify why they think the safety factor should be analyzed further.

Investigators are provided with guidance for developing an evidence table in four stages: review related information, identify relevant items of information, evaluate the strength of each item, and evaluate the overall strength of the potential finding. The guidance consists of a series of questions or criteria to consider at each stage.

Policies, guidelines, and training

To emphasize the importance of using the terminology, model, process, and tools in the analysis framework, the ATSB has developed a set of policies for its investigators. Examples of these policies include requiring a sequence of events analysis for each occurrence investigation, completing an evidence table for each key finding, conducting a risk analysis of each verified safety issue, and encouraging external organizations to initiate safety action prior to ATSB issuing any recommendations.

The policies are supported by a comprehensive set of guidelines. These guidelines provide information on analysis terminology, accident development models, and principles of critical reasoning (e.g., components of arguments, deductive versus inductive arguments, common fallacies of reasoning, characteristics of evidence that influence its credibility and relevance, preferred terminology to use for describing probabilities, and similar concepts). The guidelines also provide detailed guidance on how to conduct each of the processes and stages of the analysis phase. For many of the stages in the analysis process, the guidance is presented in the form of a series of questions or criteria to consider. This approach breaks down the general "why" question into more useful and manageable components.

The guidelines and tools are being introduced and reinforced through a 4-day training course for all investigators at the ATSB. The training involves a large component of practical experience in applying the framework's concepts, process, and tools.

One feature of the guidelines and training worth mentioning is the strong emphasis on teamwork. Investigators have excellent skills and knowledge of particular domains, but it is unlikely that any one investigator is going to have sufficient knowledge in all relevant domains to deal with the complexity that arises during investigations. As the range of experience that contributes to analysis judgments is broadened, then the quality of the resulting findings will improve.

Concluding comments

Analysis activities ultimately rely on the judgment of investigators. The ATSB analysis framework is designed to guide and support these difficult judgements, rather than replace the central role of its investigators. By providing standardized terminology, a generic accident development model, a defined process, tools, policies, guidelines, and training, the ATSB believes that it will improve the rigor, consistency, and defendability of its investigation analysis activities, and improve the ability of its investigators to detect safety issues in the transportation system.

The ATSB analysis framework will be fully operational when SIIMS comes on line by early 2007. Prior to then, investigators are being encouraged to start using the new analysis guidelines in their current investigations. Preliminary feedback has been positive. Although the new framework may require more effort initially as investigators become familiar with the concepts, process, and tools, it is widely appreciated that it will provide more assurance of quality in the longer term.

The new ATSB analysis framework is just a starting point. The intention is that, as investigators become more familiar with it, they will actively contribute to its ongoing improvement. In other words, the framework is a platform for documenting the ATSB's organizational learning about analysis methods.

The ATSB has disseminated information about earlier versions of its analysis framework to other agencies. It also intends providing further information to interested organizations in the near future. Any feedback anyone has for enhancing the quality of the ATSB framework would be gratefully received. ◆

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Endnotes

1 Prior to July 1999, the aviation investigation section of the ATSB was known as the Bureau of Air Safety Investigation.

2 The ATSB uses the term "occurrences" to refer to both accidents and incidents.

3 The definition of "probable" being equal to 75% or more was based on a review of research into how different groups of people understood verbal probability expressions, as well as standards used in fields such as climate change and intelligence analysis.

4 The Canadian TSB format for findings uses different titles but similar concepts.

An Investigation as to How Aviation Safety Will Be Maintained in the Light of the Major Change Processes Taking Place in the Norwegian Civil Aviation Sector

By Dr. Kaare Halvorsen (presenter) and Dr. Grete Myhre, Accident Investigation Board/Norway (AIB/N)

Introduction

In November 2004, the Accident Investigation Board/Norway (AIB/N) was commissioned by the Norwegian Ministry of Transport and Communications to investigate how aviation safety was maintained in the light of the comprehensive change processes that had been taking place in the Norwegian civil aviation sector in the 5-year period from Dec. 31,1999, to Dec. 31, 2004.

The Ministry of Transport and Communications requested AIB/N to undertake this study because of the concern that had been communicated from parts of the Norwegian aviation community, as well as three, then fresh, AIB/N reports from serious incidents, in which a significant contributory factor was distraction caused by someone's "psychological state." One of these reports, SL rep 42/2004, as well as two earlier reports, 05/94 and 49/2000, concerns incidents associated with the air traffic service.

As far as the AIB/N is aware, partly through this investigation, no such aviation study has been carried out in Norway or abroad, without having been initiated by serious accidents. The AIBN would like to thank the Ministry for the confidence it has placed in us, by awarding us such a broad-based and ground-breaking accident prevention investigation.

The AIB/N has carried out this important project in full knowledge that in a "normal situation" it is the responsibility of the CAA/N to evaluate how aviation safety is maintained in the Norwegian aviation industry.

Within the extremely wide-ranging project description and the relatively short timeframe, the AIB/N had to place a number of priorities, among them to "only" investigate the most "prestigious" players in the Norwegian aviation industry. Some people, including the many small- and medium-sized commercial aircraft and helicopter companies, might therefore feel that the challenges they face were not (sufficiently) discussed, while the "major" companies might have felt that there was perhaps more than enough focus on them.

In our opinion, however, both the main conclusions and large parts of the background material will also prove to be useful reading for others than the "investigated" players. The same also applies, in principle, for other transport sectors and industries.

The Norwegian Civil Aviation Authority is the supervisory agency for Norwegian aviation, under the auspices of the Ministry of Transport and Communications. The Authority was founded on Jan. 1, 2000, with the Aeronautical Inspection Department as a point of departure. The Aeronautical Inspection Department was previously a part of the Norwegian Civil Aviation Administration (now Avinor AS). The Authority encompasses all operations in Norway related to aviation safety in terms of equipment, organization, techniques, procedures, or individual skills—regardless of whether these operations are carried out in the air or on the ground. This goal is to be achieved by keeping the rules and regulations updated and by monitoring to ensure that the regulations are complied with.

Avinor AS is one of the central players in the Norwegian aviation sector and has undergone major changes in the period from 2000 until today. These changes are

- Jan. 1, 2000: The current Norwegian Civil Aviation Authority was removed from the former Civil Aviation Authority, which changed its name to the Civil Aviation Administration, becoming a government corporation under the Ministry of Transport and Communications.
- Jan. 1, 2003: Luftfartsverket was reorganized into a separate public limited company (PLC), and has been in the process of carrying out major organizational changes and staff reductions. Air traffic control has been reorganized with the closure of the Trondheim ATCC and transfer of its area of responsibility to a

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Grete Myhre is currently the acting director in AIB/N. She has a masters in experimental psychology and a Ph.D. in biological psychology. She has been responsible for accident investigation, crises management, and education of human factors in NRAF for 20 years before becoming responsible for human factors in accident investigation in the AIB/N.

newly created ATCC North at Bodø. The decision has been made to close the ATCC at Røyken (presently south/east). Air traffic control in southern Norway will be unified in one ATCC South at Stavanger (Sola) (presently west).

• The Civil Aviation Administration is established as a limited company owned 100% by the state, changing its name to Avinor AS.

• Dec. 4, 2003: Avinor AS decides to implement a major cost-saving program, the project Take-Off-05 (the project had, however, been in preparation since the autumn of 2002).

Avinor is responsible for the total range of air navigation services in Norway and owns/operates 46 airports, including one heliport. At the end of 2004, the Avinor Group had a total of 2,732 full-time employees, compared with 3,072 the previous year (according to the 2004 annual report). In addition to its directly aviation-related activities, the company also has commercial interests in the form of property, rental, hotels, parking, etc. OSL (the main national airport at Gardermoen "close" to Oslo) is a separate limited company, owned by Avinor, and is a part of the Avinor Group.

In addition to these changes, there have been other major and minor changes, including a major change in 2001 when 11 regions were reduced to 5. This study focused on the most comprehensive process of change, Project Take-Off-05. The Air Navigation Services Division is the unit in Avinor that affects safety to the greatest extent, although all of the divisions must function optimally and in coordination if Avinor's contribution to total aviation safety is to be ensured.

The mandate of Norwegian Civil Aviation Authority is from 1999, and its strategic plan dates from 2000. The mandate states that CAA/N shall strive to ensure that air traffic in Norway is carried out in a safe and expedient manner. Section 3 of the mandate sets the stage for a detailed supervision in which specific work tasks with respect to the supervision objects are spelled out. It is clearly stated, however, that the Norwegian Civil Aviation Authority does not have responsibility for safety; this lies with the individual aviation company. However, the Norwegian Civil Aviation Authority assumes responsibility for its own operations in fulfilling of international requirements.

In 2002, Prime Minister Bondevik's second government examined the various government supervisory agencies' dependency relationship with their respective Ministries. A proposal for wide-ranging independence for the supervisory agencies was submitted in Report to the Parliament No. 17 (2002–2003)), Supervision Report Doc. 2 proposed that the Norwegian Civil Aviation Authority should be relocated to Bodø, in the north of Norway. The result of this new supervisory arrangement was intended to help make the various supervisory agencies more independent, clarify their roles, and enhance their professional expertise.

In this relocation matter, it appeared that financial, legal, and regional considerations carried the most weight. Safety was mentioned, but in our opinion it did not play an active enough role in the assessments. Nor did safety appear to be one of the key concepts in the final decision.

In addition to the changes that have taken place and are taking place in connection with the movement of the CAA/N from Oslo to Bodø and the reorganization of Avinor AS, several other changes have taken place in parallel in Norwegian aviation since 2000:

• There have been major changes in the company structure in several Norwegian airlines. SAS acquired Braathens in 2001. In both SAS and Braathens the technical services have been separated and organized as separate companies, SAS Technical Service (STS) and Braathens Technical Service (BTS)—a subsidiary of STS. Lately it has been decided that BTS will be shut down and the activity moved to Sweden. The ground staff at Braathens were absorbed into SAS Ground Service (SGS), a subsidiary of SAS—which was also created in that period. In the spring of 2004, the airlines SAS and Braathens were merged into one—SAS Braathens. Similar restructuring has taken place at CHC (formerly "Helikopter Service"), which has new Canadian owners and where technical maintenance has also been moved into a separate company, Astec.

These are changes took place concurrently and, in some cases, at high speed.

In addition to these changes in the domineering airlines in Norway, new players entered the market, primarily Norwegian Air Shuttle, which competes against SAS Braathens on both domestic and international routes. Air miles programs on domestic flights was terminated, and the prices of domestic flights were heavily reduced as a result of increased competition, both national and international.

The increase in competition, with its increased focus on costs, led to changes in the jobs of major groups in Norwegian aviation. Pilots now have a more active flight service duty—in other words, they have increased their airborne time when they are on duty. Time on the ground between flights has been reduced, and a number of technical maintenance routines have been transferred from aircraft technicians to other personnel. The number of airports having technical maintenance staff available has been reduced, etc.

The word "safe" in the expression "safe aviation operations" is an abstract expression for a result, goal, or vision that is understood in different ways, according to the user's point of view and safety needs. If the safety of a state, condition, transport activity, or a transport system is to be expressed in an understandable way, it is completely necessary to be able to understand which element could potentially be unsafe or a threat. It is the understanding of unsafe that expresses the level of safety. Safety or level of safety is often stated quantitatively as how probable it is that an unsafe situation can arise, or qualitatively with what would be the consequence of a state or condition.

As a basis for this investigation, we defined (aviation) safety as a state in which

• the significant sources of danger linked to a system, or an activity, are under control.

• the level of risk is acceptable and/or as low as practically possible.

By risk, we understand the danger that undesirable incidents represents for human beings, the environment, or material property. In this study, we only considered the danger of acute, unintended events. The risk of terrorist incidents was, for example, not considered. Risk concerns the possibility of unwanted incidents. Incidents that have been experienced and possibly quantified in accident frequencies are, therefore, not a direct expression of risk. In principle, one or more sources of hazard may be out of control, even if accidents have not occurred in connection with these sources.

The basis for AIB/N's assessments in this study were the authorities' and industry players' expressed, and partly written, overall guidelines and goals stating that

• levels of aviation safety must be continually improved, and

• levels of aviation safety must, at least, be maintained during and after the period of major changes.

These changes affect virtually all groups working in the aviation sector. The changes have led to loss of jobs, transfer to other work tasks, relocalization, and redundancies in the companies. Especially the decisions concerning relocation of the ATCCs and the CAA/N led to strong protests from employees.

It is entirely possible that such comprehensive and concurrent changes to private and public players do have an impact on the level of safety in the Norwegian aviation sector. Unlike road traffic, aviation safety can only be investigated to a limited extent using statistics, quite simply because relatively few accidents happen. In this way, it is better to compare aviation with advanced production facilities that also have stringent safety and reliability requirements, such as atomic power stations and oil production.

The generally high safety levels, with their attendant low number of accidents and serious incidents, make it difficult, not to say impossible at a national level, to apply accident statistics to measure or confirm that the level of aviation safety has become better or poorer as a result of the changes in the past years. Research and experience from abroad demonstrate that any negative air safety consequences rarely materialize in the form of accidents until several years after the implementation of the changes has taken place. It has, therefore, been necessary to use other types of indicators as a basis when assessing whether levels of aviation safety have been maintained in Norway during the current period.

Methods

In this present project, we have chosen to use an open method of approach in which we emphasize our information sources' own assessments and interpretations of the link between actual processes of change and aviation safety. We have, as far as resources and access to data have allowed, used methods based on triangulation between various data sources and methods of approach. This means that we have retrieved and analyzed both qualitative and quantitative data.

In addition to studying existing documents and analyses, we have interviewed persons in various positions (e.g., management, operative personnel, supervisory personnel, and union representatives). In all, we have been in direct contact with several hundred informants. We have also investigated result indicators (for example, numbers of accidents and incidents) and activity indicators (for example numbers of inspections carried out, system audits, inspection visits, corrective orders and initiatives implemented).

An anonymous questionnaire was sent to a majority of employees who, directly or indirectly, were engaged in safety-related work in the Norwegian aviation industry. The assessments made by different groups have provided useful background information to the study and its analyses.

One challenge for AIB/N was that several of the available documents/studies had been produced by persons or groups with vested interests. The various groups often come to differing conclusions concerning the same issue. In such cases, AIB/N chose to illuminate the different points of view, so that the issues discussed could be subject to greater consideration in order for a choice to be made that will achieve the highest possible level of aviation safety.

The airlines

In order to obtain presumably best/most quantitative data, the AIB/N decided to approach the airlines trough the maintenance side. The main purpose of the maintenance review was to consider whether the company had implemented changes of a technical, maintenance, operational, administrative and personnel/organizational nature, or a combination of these in a way that could affect aviation safety.

The airline companies that have been investigated are SAS Braathens, Widerøes, Norwegian Air Shuttle, CHC HS, and Norsk Helikopter. The selection was made to include a representative basis for assessing the Norwegian aviation sector. There is a significant difference between fixed-wing airlines and offshore helicopter companies (CHC HS and Norsk Helikopter), so they were investigated and discussed independently.

The changes in the external framework conditions laid down by aviation authorities, political authorities, and the market were the basis of the study.

Changes in the external framework conditions were illustrated graphically using the Sequentially Timed Events Plotting (STEP) and used to explain different trends for the safety indicators between the companies.

Activity levels and changes in them have been surveyed for the whole period for each of the airlines, both to compare indicators and standardize them, in order to compare the companies and form an, as far as possible, objective picture of Norwegian aviation.

The safety-related indicators are based on the principle of barriers. Each indicator is a measure on how the company is able to perform the maintenance and keep the barriers intact. One example—The rate of TECHREPs is decreasing while the rate of PIREPs is increasing. This indicates a reduction in the level of safety in maintenance.

The following safety indicators were defined for the study:

- Reported incidents,
- Technical dispensations,
- MEL excesses,
- Technical fault reports,
- PIREPs (reported by flight personnel),
- TECHREPs (reported by maintenance),
- HIL/backlog,
- Cancellations/unscheduled downtime, and
- Absence through illness.

A basic model for safety management was formed for the investigation. This model is used to give a holistic and equal assessment of the respective companies.

A satisfactory level of safety cannot be ensured solely by setting regulations. Individual operators need a system of safety management that allows the maintenance and development of a desired level of safety. The level of safety is determined at any time by the threats that are present and what actions are taken to maintain risk control and develop safety. The model shows that a desired level of safety can be achieved by a structured process in which safety goals are defined on the basis of a safety policy. A continual process of monitoring and control also takes place in which the necessary actions (reactive approach, lower loop of the management model) are taken. Good safety management means that you do not exclusively invest in a reactive approach; new threats must be identified, and risk surveyed, in order for initiatives to be implemented before undesirable incidents take place (proactive approach; upper part of the figure). The emphasis on being proactive or reactive in safety work decides whether the company has a risk-based or an action-based approach to safety management. The process agrees with a general management

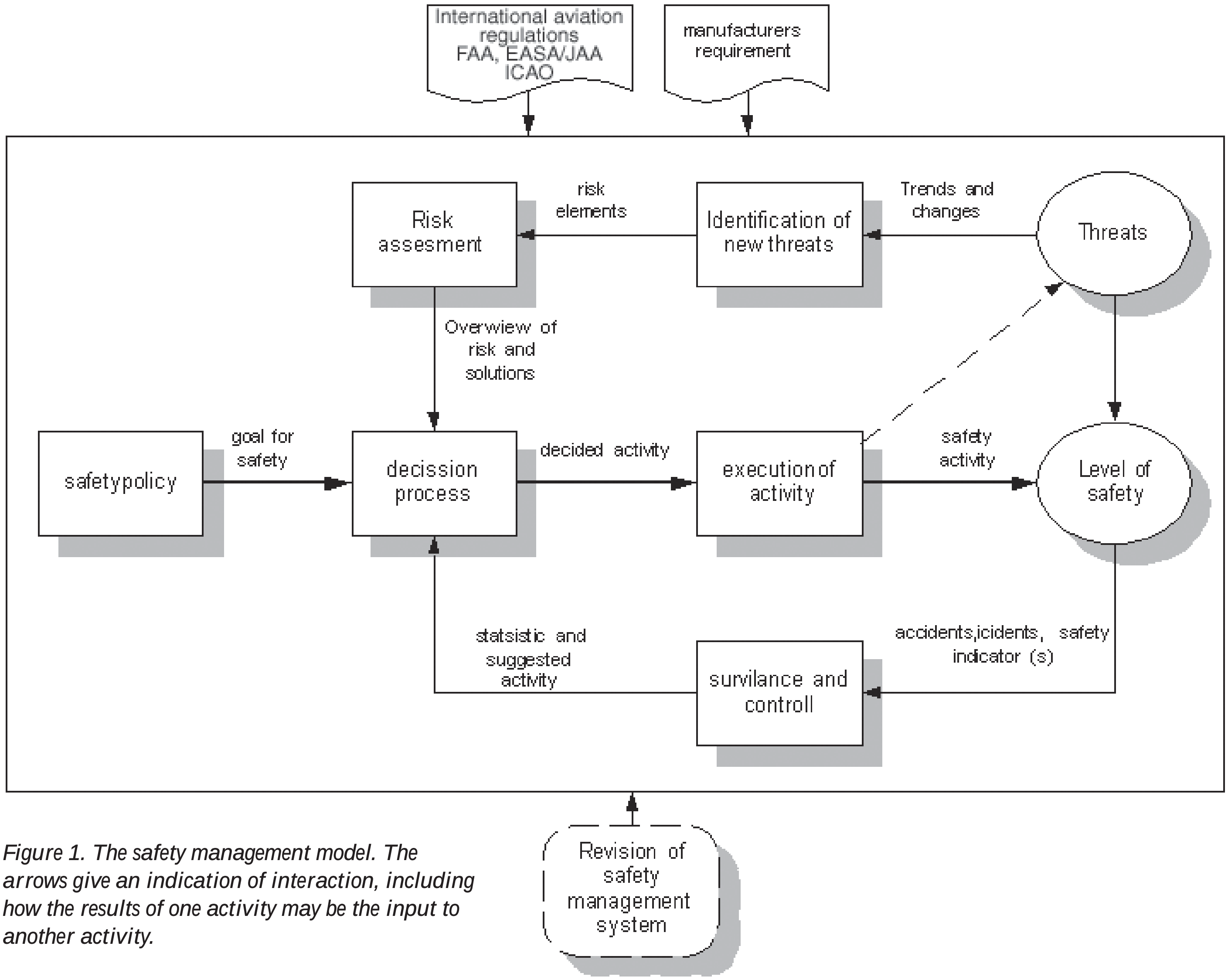

Figure 1. The safety management model. The arrows give an indication of interaction, including how the results of one activity may be the input to another activity.

model for achieving defined goals: "plan➔perform➔check➔act," which we recognize from quality management.

Results from the maintenance review

Fixed-Wing

Activity level in the airlines

Production per individual aircraft was decreasing in the first part of the period but is back at an equivalent level at the end of the period in relation to the beginning. Contributions to the decreasing trend have been stronger from certain companies. This is, in part, linked to acquisition of new aircrafts and decommissioning of older aircraft.

Trends in safety-related indicators

Reporting

During the period, the investigated companies showed an increased tendency to report. All of the companies attribute this increased reporting to a rising awareness of the importance of reporting. All of the companies have focused on incident reporting in the period and the increase is a result of this work.

Technical dispensations

This is a measure of the companies' ability to perform maintenance on the aircrafts. All of the dispensations were within the limitations stated in the maintenance program. Changes over the period are different for the different companies, which may indicate that some changes have been more comprehensive than others. Toward the end of the period, use of dispensations normalized.

MEL remarks

MEL as the indicator may say something about the aircrafts' technical condition in relation to safety-critical systems and the company's ability to carry out maintenance.

MEL contains criteria for the type of faults in systems that may be significant to safety. This is a strong safety indicator, as there is reduced redundancy in the aircraft's safety-critical technical systems. There was differing practice at the different companies in the way they reported and analyzed data. Some companies counted the number of departures with MEL remarks while others counted the number of remarks. Analysis is part of the reliability analysis per system or per MEL overrun.

MEL is an indicator that shows both the incidence of faults in systems and the company's ability to correct the fault. MEL is registered as a PIREP, as an MEL departure normally takes place while the aircraft is operational.

MEL follow-up contribution to risk management:

• The number of MEL notations per 1,000 departures. This figure tells us the regularity of MEL departures. Individually, these departures represent an acceptable risk contribution in which the pilot forms a compensatory barrier. The total of MEL departures provides a picture in which the total risk for the company is affected more than each individual departure. It can, therefore, be an indicator of where an acceptance criterion can be set.
• MEL departures that fly past the time limit are a deviation in which the risk of an individual MEL departure is affected more than the total risk for the company. It can, therefore, be an indicator of where an acceptance criterion can be set.

Based on the number of MELs, airlines with the same aircraft show a slight increase in the number of MELs. The trend for the industry shows a negative development in numbers of MEL per flying hour/departures, but there are certain exceptions in the 2000-2004 period. The reason for this was given as lack of spare parts in stock, or reorganization of the spare part supply for some operators.

PIREPs

One of the reasons that this study examined the number of PIREPs and the number of TECHREPs was because these two together say something about where in the barrier chain the incidents are detected. If it happens that an increasing number of incidents are detected by PIREPs, and fewer by TECHREPs, this is a signal that the faults are detected at a later point in time. This is equivalent to a reduction in safety margins.

TECHREPs

As with PIREPs, the numbers of TECHREPs are mainly stable. One company that had a high initial number of TECHREPs also had a large decrease. In 2004, the number of TECHREPs for this company was at the same level as the other companies. It is possible that the initial high number is a natural result of a higher level of reporting during the phasing-in period (new aircraft).

Open Hold Item List (HIL items)

The indicator "Open HIL items" provides information about the company's ability to correct detected technical faults quickly. However, the Hold Item List contains all types of fault, including faults that have no significance for aviation safety.

There was different practice at the various companies in the study, both in the way they report as well as the starting time for collection of HIL.

For fixed-wing companies that have data on this indicator, all of the companies in the study showed a mainly declining trend in the numbers of reported HIL. This means that the backlog at the various companies is being reduced.

Reduction of the backlog shows a positive trend for maintenance not carried out according to plan.

Cost of maintenance

The data for the indicator was very limited because of lack of specification of these costs within the companies. At those companies that were able to provide these costs, there were no significant changes to the indicator in the period.

Absence through illness

Absence through illness, which is often synonymous with work-related illness, even if this is not the case here, is a regularly used and concrete indicator. Even so, it is not always easy to read safety-related conditions from the figures without more information about what is happening in the companies and what could cause the illness. We saw both negative and positive trends in absence figures in the analysis of these companies.

As a whole, we can see absence as stable throughout the period. If a company wants to follow up safety-related indicators linked with this, the focus must be moved from absence through illness as the only indicator to the actually perceived situation for the employees and the degree of loyalty to decisions and regulations that is present in situations where this is safety critical.

Offshore helicopter companies

There are two main players in movement of personnel and offshore SAR on the Norwegian continental shelf. The helicopter companies work in a contract market, in which oil companies award contracts of 3 to 10 years' duration for flights out from land and/or offshore bases. The typical average contract duration is approximately 6 years. Each contract is awarded under full competition conditions in which the two main players, CHC Helikopter Service and Norsk Helikopter, so far have secured all of the contracts, although there are also tenders from two to three other helicopter companies wishing to enter this market.

It is not unusual for one of the companies to win a contract for an operation that, at time of award, is run by the competing company. This results in a reduction in its activities for the losing company and an equivalent upswing for the winner, involving acquisition of helicopters, employment and training of pilots and technical personnel, acquisition of hangars and office facilities, official approvals, etc.

This type of contract-oriented activity, with large and relatively long-term contracts and associated major changes involved in gain or loss of tenders, is particular to the offshore, ambulance, and state-subsidized STOL aviation in Norway. However, the companies that have chosen to operate in these markets have to a large degree established the flexible and adaptive culture that is necessary to maintain aviation safety through the actual processes of change.

Activity

The total market for helicopter flights on the Norwegian continental shelf has decreased by around 2,100 flying hours (approximately 5%) in the period from 1999 to 2004, while the market share of the two players has been stable.

Trends in safety-related indicators

Air Safety Reports ASAR

There was a steady level throughout the period. The level in both companies was at 10-15 ASR per 1,000 flying hours, which is regarded as normal.

Technical dispensations

The levels for both companies were low throughout, between approximately 4 and 7 technical dispensations per 1,000 flying hours. This indicates that the companies are careful in deviating from maintenance programs and other defined technical limits. One of the companies had a significant increase from 2003 to 2004. The company states that "reorganization of the supply service" is the cause of this increase.

MEL
For one of the operators the indicator showed a very stable and low level throughout the period, while the level was considerably higher for the other. This company is the same as the above-mentioned reorganization of the supply service.

HIL
Only one of the companies kept statistics of the HIL items. The curve showed a relatively stable trend throughout the period, with somewhat of an increase from 2003 to 2004. The above reorganization of the supply service may be one reason for this increase.

PIREPs
There was relatively stable levels for 2000-2002, and a decreasing tendency for both companies in 2003 and 2004. The level, 100-130 PIREPs per 1,000 flying hours, is regarded as normal in the industry.

TECHREPs
Stable or decreasing trends for both companies.

Cost of maintenance
Both companies had seen an increase in maintenance costs per flying hour, which is equivalent to general inflation levels.

Absence through illness
"Company A" showed a decreasing trend throughout the period, although the level was relatively high, on average approximately 6%. The 2004 level, approximately 4.5%, is regarded as normal for this sort of activity.

"Company B" had a stable and very low level of absence through illness.

Discussion

In general, it is accepted that as the degree of change increases, it is no longer sufficient to establish good safety management solely through routines and regulation (Hale & Baram 1998). When circumstances are predictable and fixed, such safety management is adequate; but when circumstances are in the process of continual change, efforts must be made to internalize employees' safety awareness. Safety cultures and safety climates, which can be seen as latent and manifest expressions of organizations' degree of focus on safety, have, therefore, come steadily more in focus in modern safety management.

The starting point for the AIB/N was not that change equivalent to those that have been taking place in Norwegian aviation are ipso facto a threat to aviation safety. The study has attempted to point out the necessity of holistic thinking and use of thorough safety analyses in order to reveal which weaknesses the change(s) can lead to in different safety levels. Such analyses will normally say something about compensatory measures that should be put in place before the change takes place. If this is done, there is high likelihood that safety levels are maintained and may even be improved through the process(es) of change.

There has been only a limited focus on safety in the political processes when the CAA/N was separated from the old Civil Aviation Authority and the latter changed to a state-owned company. There has also been little focus on the fact that deregulation means increased demands on supervision and control. This became especially clear when the Authority was moved at the same time as Avinor carried out/planned major changes to its organization.

In addition to the surroundings for all organizations becoming more dynamic, surveys indicate that major organizational changes may have negative impact on levels of safety. Ytrehus and Østerbø (2002) state that they can document organizational changes as indirect contributory factors in several major accidents, including the Norwegian Åsta rail accident in 2000. In general, "disturbance" in organizations, which often occurs during organizational changes, will be an expression of employees' impression that they are not listened to and taken into account. Larsson (2005) has recently documented the connection between such conditions in the working environment and the risk of accidents.

Rasmussen (1997) points out that modern changes to a great extent concern deregulation and exposure to competition, and that this may lead to reductions in attention to safety and the barriers that have been erected. Research around the so-called "High Reliability Organizations" (HRO) emphasize *organizational redundancy* as an important safety factor. Put simply, it means that the organization contains "slack" and that this forms a barrier against accidents. Modern processes of change often involve downsizing, leading to the extent of such barriers shrinking. This may lead to a higher risk of accidents.

The results of research around the impact of change on safety are not unambiguous. One possible reason may be that the changes and deregulation lead to clearer divisions of responsibility and that such changes lead to some inappropriate safety cultures and practices being weeded out. Basically, therefore, it is an open question as to what consequences the major changes on so large parts of the Norwegian aviation sector have on safety.

In order to achieve ever-improving levels of safety, the pertinent regulations are updated on a continuing basis. Initial surveillance and operator surveillance are carried out, and service is provided for the users while keeping open lines of communication with users and the public alike. Tasks are carried out in accordance with sound administrative principles, consistent with the demands of national and international aviation legislation, and in accordance with the stated needs of the users in the air transport market.

During the actual period, the companies have carried out organizational changes for adaptation to JAR-OPS 1 and JAR 145. The companies have carried out the changes to varying extents internally in existing organizations and by splitting the company into technical and operative independent companies. The challenge in relation to splitting the companies into operative and technical companies lies in the new interfaces for administration and checks of the activities. It seems, according to the indicators, that this has been for certain companies a period of adaptation that has had an impact, but that has normalized after a short while.

Training

In the period, technical training has been complicated by the changes in the regulations. The changes in the regulations have taken place quickly, which has led to a gap between skills and the requirements placed on the training departments (ICAO M to JAR/Part 66 B1 and -2, CRM concept/human factor training, Part 147/Part M approval).

It must be noted here that these are trends over a short time, and that the companies, through a number of initiatives in the last part of the study period (2002-2004), have had a positive trend in most of the statistics that are covered by this study, and that the level at the end of the period is equal to, or better than, the start of the period. One exception is where one company has had a slight regular increase in the Airline Risk Index (ARI) throughout the period, without notification of it increasing (although within acceptable limits).

It can be seen from the data that have been collected that the number of technical cancellations increased when pilot checks were introduced. This tells us that the pilot barrier works, as aircraft remain on the ground, rather than leave, when pilots are unsure about what they see. This trend decreased as they felt safer in the task.

The industry is traditionally reactively (event-based) oriented in its management and control of activities. This normally is a characteristic of stable companies, which have been historically authority and market regulated. During the study period, certain companies have undergone major organizational changes and market adaptations that the company has not experienced to the same extent before. It is typical of such changes that incident escalations have, to a greater extent, underlying causes related to the organization and human error. Root causes can be less overt if direct or trigger causes form the basis for assessment of incidents. Human error may, for example, occur in different technical systems and aircraft types but have the same underlying cause. The study shows that the companies, in this connection, have initiated a number of positive processes and has shown, through clearer requirements for reporting and access to reporting systems, that the degree of reporting has been improved.

The commercial players in Norwegian aviation are all facing stiff competition, financial constraints, and greater demands for profitability. Partly as a consequence, major and potential restructuring processes that are critical to safety are under way, such as rationalization, downsizing, mergers, organizational changes, and a dividing up of responsibility. This is exactly the kind of situation that calls for a strong, alert supervisory authority, one that is capable of monitoring and ensuring that air safety is safeguarded in an acceptable manner. Experiences from Sweden and other countries confirm that there is a need for strong supervision when many changes and restructuring efforts are going on simultaneously in a given line of business. AIB/N feels that this need is not currently being satisfactorily met. The informants in the airline companies have been impressed that the Norwegian Civil Aviation Authority has been able to maintain a high level of service in the wake of the decision to relocate. As for Avinor, AIB/N has the impression that the Norwegian Civil Aviation Authority has not been able to satisfactorily follow up on changes and plans. In a number of key areas, the Norwegian Civil Aviation Authority accepted solutions that, in hindsight, they are not comfortable with (the training of personnel when ATCC North was established, the splitting off of AFIS and air traffic controllers into their own divisions, and much else). The main reason for this, as AIB/N sees it, is that major challenges have grown out of the decision to relocate and the move itself.

Nevertheless, the action plan that has now been presented for the new Norwegian Civil Aviation Authority appears credible and realistic enough to ensure that the Authority's expertise, resources, and capacity will—in time—reach a level consistent with the challenges and tasks the agency will face.

• The Civil Aviation Authority should consider putting greater emphasis on system-oriented, all-round, risk-based supervision and develop/recruit personnel with the necessary expertise—not the least so it can follow up and pick up on possible negative safety ramifications in the wake of restructuring initiatives on the part of those being monitored.
• The Civil Aviation Authority should consider extending the transitional phase with double staffing in Oslo and Bodø, in order to ensure that new employees receive the experience and acquire the competence they need. This is necessary for carrying out the supervision tasks in a satisfactory manner during the transition, thus maintaining market trust.

The Ministry of Transport and Communications, and other responsible ministries, should consider including a total impact assessment of safety conditions as a basis for political decisions in the transportation sector when there are legitimate questions about whether safety is at issue. Alternatively, a broad consultation hearing should be conducted in which the appropriate agencies are given an opportunity to submit their comments and views *(AIB/N is in the process of becoming an independent investigative authority for accidents/incidents within the transportation sector as a whole; as a result, it feels entitled to submit this trans-sector safety proposal).*

The change from a regional model to a divisional model at Avinor has clarified routes of reporting and responsibility and represents a contribution to improvement of aviation safety.

A challenge is presented by having airport services and air traffic services under different management. Internationally, there is currently great focus on "runway incursions" and ground accidents and incidents. An organizational split can make it more difficult to maintain focus on these safety areas, unless compensatory coordination measures are put in place. It seems that this is being taken seriously.

The decision to have air traffic controllers and AFIS officers in separate divisions seems somewhat strange to the AIB/N, and it is difficult to see it as a positive contribution to aviation safety. AFIS duty officers are now sidelined compared with air traffic controllers and did not, among other things, participate in CRM meetings together with the air traffic controllers. Compensatory measures should be initiated.

The process linked to gathering reports from the four ATCCs, in which they assessed their own capacity to take over others' jobs in a potential merger, was unsatisfactory. All four ATCCs were aware that the two ATCCs Stavanger and Røyken should merge and the same for the two ATCCs Trondheim and Bodø. Which two out of the four should remain was yet to be decided. The various parties returned different views, and this led to conflict in relations between Stavanger and Røyken and between Trondheim and Bodø. The result was that Bodø and Stavanger became the new ATTCs. Bodø is already up and running while Stavanger still remains. The questionnaire and discussions with air traffic controllers indicate that the working environment at Bodø is so poor that something must be done to correct it, to avoid aviation safety to be compromised. Better work should be carried out in relation to the creation of the ATCC South so that a good working environment can be maintained. The safety culture score based on the survey was very low.

The estimated number of necessary air traffic controllers made by Avinor is not adequate. The need for air traffic controllers in the future seems to be far greater than the new training center's capacity. Continued safe management of air traffic depends on a sufficient number of competent air traffic controllers.

The technical platform for control of Norwegian air space has, to a great extent, been developed by Avinor's own technicians at Røyken. Unease around the localization and in the relationship between central administration and the employees has led to several skilled technicians leaving the company, with more on their way out. Management claims that new recruitment will correct this—this is not AIB/N's opinion.

Training of air traffic controllers will be significantly weakened if it is not possible to carry out OJT and PFO at a time when there seems to be a discrepancy between tasks and the number of air traffic controllers. Training of personnel at Bodø following the merger of Trondheim ATCC and Bodø ATCC was not according to the regulations, and questions can be raised as to whether there was sufficient training.(Several incident reports lately supports it was not.) A repetition of this should be avoided in the creation of ATCC South.

Redundancy and the EMP situation, particularly associated with Bodø, seem to have been inadequately studied, and there seem to be questions as to whether the intentions of the Ministry of Transport and Communications and the CAA/N have been met.

The hasty creation of ATCC North meant that the decision was made to continue to control air traffic with outdated equipment, not choosing a solution that would have provided improved air safety.

The interpretation of BSL E 4-4 for staffing fire and rescue is based on an absolute minimum interpretation, and the opportunity to allow for concurrent firefighting and rescue has not been taken. The opportunity to vary airport categories in relation to planned aircraft activity allows the non-participation of all available equipment in the contingency and will, therefore, lead to a reduction in air safety.

Training and testing of fire and rescue crews has improved, and those participating today are better prepared for their tasks. This has not always been the case previously.

Avinor did not allow sufficiently time for the CAA/N in the Take-Off-05 project. However, the CAA/N has kept to its self-imposed deadline of one month time for processing and decision-making. There may be reason to question whether this has affected the quality of the decisions made by the CAA/N.

There has been a conflict between the CAA/N and Avinor, which has been present since the "divorce." The Ministry of Transport and Communications has contributed to maintaining the conflict by allowing the creation of a Avinor, which has retained some supervisory tasks. The supervisory activities that have been retained by Avinor (RFL I and AIP) should be transferred as soon as possible to the CAA/N.

There is doubt as to whether the competence requirements set by the CAA/N for acceptance/approval of key Avinor personnel are sufficient.

Follow-up and control of the company demand more of the owner (the Ministry of Transport and Communications) now that Avinor has become a state-owned company. The "political management" of Avinor should focus just as highly on Avinor's societal/safety-related duties as on the financial return. The owner seems to have assumed that the CAA/N will cover any potential weakness associated with aviation safety.

The main conclusion is that a number of major and minor changes have not been sufficiently assessed, individually or holistically, with regard to their impact on aviation safety. When such assessment has been carried out, there often seems to be a lack of follow-up and documentation of "closure" of the conditions and results and recommendations. All of the aviation players that we have investigated, including the authorities, have potential for improvement.

There is nothing in the statistical material that we have studied that indicates any reduced technical standard in the aircraft, or reduced maintenance quality.

Recommendations

- The airlines that have been studied should consider looking more holistically at their initiatives, and carrying out analyses to see how concurrent changes and use of dispensations and MEL and HIL lists affect safety. (The study has revealed that MEL is not regarded as a safety reduction as long as the regulations concerning type and time are adhered to.)
- The airlines are advised to survey cultural differences before considering association/mergers, and to integrate courses from the original companies in such a way that a "new" corporate culture can be established in a clear way for everyone involved.

Finally, the AIB/N would like to remind you that commercial civilian aviation is an especially safe form of transport, especially in our "western" part of the world and that the assessments and safety recommendations that appear in this report are intended to contribute to ensuring that the major changes occurring in the Norwegian aviation sector do not take place at the expense of aviation safety. ◆

Reference

AIB/N report, SL REP 35/2005 Safety in Norwegian Aviation during the process of change (5th of Aug. 2005): www.aibn.no/default.asp?MARK_SEARCH=YES&SEARCH_ID=1&V_ITEM_ ID=1246

Incident Investigation: A Diversion of a Boeing B-747 Resulting In a Serious Low-Fuel Situation

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Introduction

For decades, air accident investigation has contributed significantly to the improvement of flight safety in civil aviation. Standardized methods and procedures of accident investigation are in use almost all over the world. The sole purpose of accident investigation is the prevention of future accidents. The investigation does not determine blame or liability.

Already during the 1970s and 1980s, accident investigators and flight safety experts started to discuss the investigation of incidents because of the success accident investigation showed regarding flight safety improvement. The justified question arose: Why investigate accidents but not incidents?

As a result of the ICAO Accident Investigation Divisional Meeting (AIG 92) in 1992, the term "serious incident" was included into Annex 13, which paved the way for the investigation of serious incidents.

Over the years, many countries have incorporated the investigation of incidents and serious incidents into their national regulations as part of the work of independent investigation authorities. In 1994 the European member states were asked through Council Directive 94/56/EC of May 16, 1994, establishing the fundamental principles governing the investigation of civil aviation accidents and incidents to enact national procedures that include the investigation of serious incidents. As a result, the Federal Republic of Germany, for example, passed the Air Accident Investigation Law, which provides for the investigation of accidents and serious incidents. According to this law, serious incidents which occur with commercially operated aircraft with a maximum takeoff weight exceeding 2,000 kg are investigated. The Air Accident Investigation Law incorporated the list of serious incidents listed in Annex 13, Appendix C.

How can reality be assessed almost 15 years after AIG 92? In some countries, serious incidents are treated like accidents by the investigation authority. Even the flight safety departments of many airlines investigate incidents and serious incidents. Nevertheless, not all incidents that should be defined as serious incidents are investigated.

It is very clear to anyone that the investigation of a serious incident can contribute as much to flight safety as the investigation of an accident with a fatal outcome. It is equally clear that to spend as much time and effort on this kind of investigation is almost impossible.

The motto of the ISASI 2006 seminar in Cancun "Incidents to Accidents—Breaking the Chain" describes the current challenge for accident investigators and flight safety experts.

The presentation "Incident Investigation: A Diversion of a Boeing B-747 Resulting in a serious low-fuel Situation" shall show that

- the investigation of a serious incident through an independent investigation authority can provide valuable insights for the improvement of flight safety, and
- serious incidents caused by a low-fuel situation are extremely relevant for flight safety and may have complex causes.

Example

History of flight

A Boeing B-747 was on a scheduled passenger flight from Singapore to Frankfurt with 4 pilots, 14 cabin crew, and 378 passengers on board. At the time of flight planning in Singapore, the terminal aerodrome forecast for Frankfurt indicated CAVOK conditions at the estimated time of arrival, and there was no requirement to plan for an alternate airport. The Boeing 747 departed Singapore on July 27, 2005, at 15:21 UTC. The ETA for Frankfurt was 03:19 UTC on July 28, 2005.

The 02:20 UTC Frankfurt routine weather report obtained by the crew included the information that CAVOK conditions existed, with no significant changes expected. The crew of the B-747 commenced descent into Frankfurt at 03:00 UTC. The Frankfurt automatic terminal information service provided the crew with information that CAVOK conditions existed. About 35 nm from Frankfurt, the air traffic controller instructed the crew to enter a holding pattern.

As the B-747 was in the holding pattern, radio transmissions from crews of other aircraft alerted the B-747 crew to the fact that weather conditions at Frankfurt Airport had suddenly deteriorated and that there were thunderstorms and heavy rain.

The crew elected to divert to Munich where the B-747 landed.

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The reserve fuel remaining aboard the B-747 was less than the operator's Civil Aviation Safety Authority (CASA) of Australia-approved fuel policy permitted. Fuel remaining was 3.5 t (total) and 4.3 t (FMC calc).

Investigation

Notification

The incident was reported by Munich Airport with the following wording:

• The crew decided to divert to Munich due to a delay because of a thunderstorm at the destination airport Frankfurt/Main.

About 10 hours later, the TSB of Australia sent a notification:

• We have been advised by the Australian operator of an incident involving a B-747 in diverting from Frankfurt to Munich due to unforecast thunderstorms resulting in a serious low-fuel situation.

The facts contained in the report from Munich Airport did not meet the BFU's criteria for an investigation into the incident. The additional information "unforecast thunderstorms" and "serious low-fuel situation" provided by the TSB of Australia prompted the BFU to initiate an investigation.

Cooperation with the TSB

At the beginning of the investigation, the B-747 had already gone back to Australia and that meant that neither the crew nor FDR or CVR data were available.

The B-747 crew was interviewed by an accident investigator of the TSB of Australia. The BFU secured and evaluated all data from the responsible ATC provider.

The following actual flight status was reconstructed based on the evaluated data:

03:18 UTC: B-747 reports to Langen Radar NR 4: Cleared GEDERN FL 110

03:24 UTC: Radar NR 4: Fly one holding pattern overhead GEDERN, reduce speed

03:28 UTC: Transfer to Frankfurt Arrival

03:34 UTC: B-747: Frankfurt, can you update the weather of the field;

TR 1: I'll call you back

03:37 UTC: B-747: B-747 fuel critical, we require immediate deviation to Munich

03:37 UTC: TR 1: for your info: Nobody approaching here because of the weather

03:41 UTC: Transfer to Langen Radar OR 1

03:51 UTC: Transfer to Munich Radar

03:52 UTC: B-747: **Pan Pan**: Fuel critical direct to OM 08L

03:56 UTC: B-747: Require priority and still clearance 08L OM

NR I: Confirmed and priority is copied

03:59 UTC: Transfer to MUC Arrival 128.02

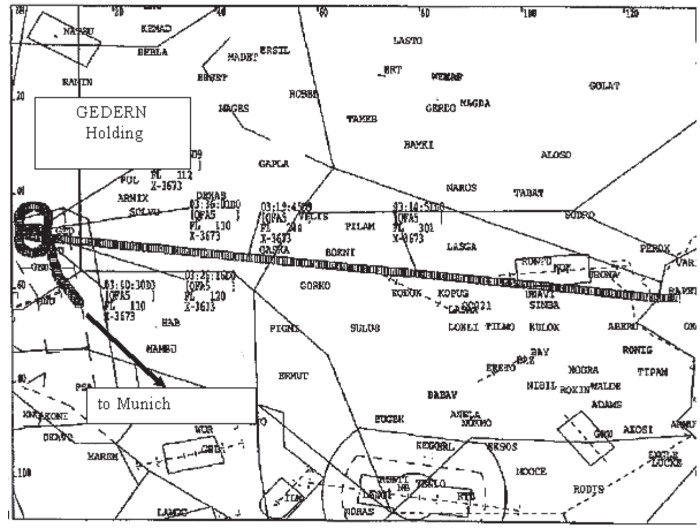

Figure 1. Flightpath of the B-747.

04:01 UTC: ARR: Request POB and DG

04:03 UTC: Transfer to MUC Director 118.42

04:07 UTC: DIR: B-747 on requested HDG clear to ILS 08L

04:08 UTC: Transfer to MUC TWR 118.7

04:09 UTC: TWR: clear to land

04:10 UTC: Landing in MUC

At 04:10 UTC the aircraft landed in Munich. Nobody was injured, and the aircraft was not damaged. Fuel remaining was 3.5 t (total) and 4.3 t (FMC calc).

During the interview, the crew made some remarks that could be of significance to the assessment of the incident.

• The weather information was not up-to-date.

• Other air crews and ATC controllers were talking in German on the radio frequencies.

• The alternate airport Cologne-Bonn was not acceptable due to the prevailing weather.

• After "PAN PAN" was used, ATC did not provide any preferential treatment.

• The support provided by ATC during the approach to Munich was good.

Weather situation

All relevant weather data available to the crew for their flight planning were secured during the investigation into the serious incident. The written documentation of the prevailing weather at the time of the incident was also secured.

During their flight planning in Singapore, the following TAFs and actuals of the destination airport were available to the crew:

• TAF EDDF 280000Z 280110 17005KT CAVOK

• TAF EDDF 280300Z 2

• METAR EDDF 280220Z 01005KT CAVOK 21/19 Q 1010 NOSIG= 80413 20008KT CAVOK

• METAR EDDF 280250Z 3504KT CAVOK 21/19 Q 1011 NOSIG=

• METAR EDDF 280320Z 26009KT 240V300 9999 – TSRA SCT040CB SCT090 BKN280 21/19 Q1012 BECMG NSW=

The B-747 crew was able to listen to ATIS Frankfurt during their approach to Frankfurt Airport. ATIS broadcast the following weather information:

ATIS July 28 03:00:12:
-ATIS EDDF C METAR 280250 SR: 0350 SS: 1915 CTR:VMC
-ILS 25L

-35004kt WIND 18: 31003G04KT/270V340
-CAVOK
-1011
-NOSIG
-Lightning TS SW PART

ATIS July 28 03:09:05:
-ATIS EDDF C SPECI 280305 SR: 0350 SS: 1915 CTR:VMC
-ILS 25L

-33005kt WIND 18: 30004G08KT/260V340 9999
-TS FEW040CB SCT090 BKN 280
-21/19
-1011
-NOSIG

The weather report of the DWD's (German Meteorological Service) meteorological office at Frankfurt Airport stated that the prevailing sky cover incorporated individual showers and thunderstorm cells whose meteorological activity in the area of Frankfurt Airport was rather low. At 03:20 UTC the meteorological office Frankfurt (EDDF) reported thunderstorms with light rain (-TSRA). Horizontal ground visibility was more than 10 km and the cloud base (SCT CB) in 4,000 ft AGL. Between 03:20 UTC and 04:20 UTC, surface wind came from changing directions. Mean wind speeds were almost 10 kt (03:20 UTC). The landing weather forecast (TREND) reported no significant weather.

At 03:30 UTC and 03:45 UTC radar images of the meteorological office Frankfurt showed significant thunderstorm activities in the holding area GEDERN (about 100 km northeast of Frankfurt).

Air traffic control

The ATC provider DFS (German Air Navigation Service) stated that between 03:15 UTC and 03:55 UTC approaches to Frankfurt Airport had to be reduced due to thunderstorms. Between 03:55 UTC and 04:15 UTC, approaches were not possible at all. Between 04:15 UTC and 04:45 UTC 35 approaches were possible.

Fuel planning

The fuel uplift for the flight to Frankfurt was in accordance with the operator's Civil Aviation Safety Authority (CASA) of Australia-approved fuel policy.

Analysis

After landing in Munich, the fuel remaining was below the fuel quantity required by the operator. With a remaining fuel quantity of 3.5 t a go-around at Munich Airport would not have been safely accomplishable. A further delay during the approach to Munich could also have resulted in a critical situation. The increased consumption was a result of the longer flightpath.

The crew decided to abort the initiated approach to Frankfurt due to the weather situation because a landing delay was foreseeable. The alternate airport (Cologne-Bonn), according to the flight planning, was not considered to be an alternative equally due to the weather situation indicated by the onboard weather radar.

The B-747 crew was not informed of the prevailing weather in the terminal area of Frankfurt Airport. According to the broadcast weather information (TAF, METAR, ATIS), the crew could expect CAVOK conditions.

The crew based their decision to abort the approach to Frankfurt on their onboard weather radar, which showed thunderstorm cells and excerpts of other crews' radio communications with ATC, which were mostly held in German.

Weather situation and transmission of prevailing weather

Greater Frankfurt had weather conditions with individual thunderstorms or cumulonimbus clouds which were issued through GAMET and AIRMET.

Between 03:20 UTC and 04:20 UTC, the effect of the weather activity in the direct vicinity of Frankfurt Airport was rather low. According to the report of the meteorological office Frankfurt, which showed thunderstorms with light rain, ground visibility of more than 10 km and a cloud base (SCT CB) in 4,000 ft, the airport was perfectly available for takeoffs and landings.

Distinctive weather activities (thunderstorms) were, however, occurring in the holding area GEDERN. Other aircraft in the holding area GEDERN talked among themselves and with ATC about these weather activities via radio communication.

TAFs and METARs available to the B-747 crew did not contain any information on special weather conditions that would have made an approach to Frankfurt Airport impossible. Even the last ATIS broadcast, which the crew listen to, reported CAVOK. Only the ATIS broadcast after that reported thunderstorm activities (TS FEW040CB SCT090 BKN 280). The crew, however, did not listen to that one anymore.

The weather situation issued through METARs corresponded to the prevailing weather in the direct vicinity of the airport. ICAO Annex 3 states that for METAR and SPECI, the present weather information should be representative of conditions at the aerodrome and, for certain specified present weather phenomena, in its vicinity. The distance between Frankfurt Airport and the holding area GEDERN was more than 40 nm. The weather was significantly worse in the holding area GEDERN.

Communication

The DWD uses weather radar to observe and record the weather in Germany. This radar image clearly depicted the weather situation in the holding area GEDERN.

The radar image was available to the weather information at Frankfurt Airport but not at the ATC controllers' workstations. A weather briefing had informed the controllers of the general weather situation but not of the particular situation in the approach zone.

Had the ATC workstations been equipped with weather radar, the controllers could have informed the B-747 crew (and others for that matter) of the current weather in the approach zone and the holding area at the entry of German airspace. An early deci-

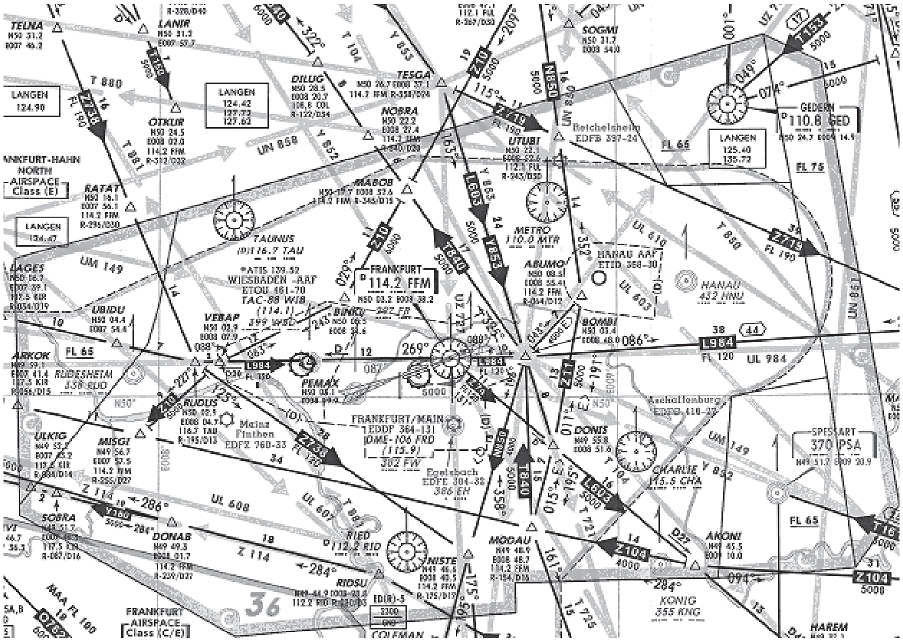

Figure 2. TMA Frankfurt.

sion to divert to Munich Airport could have saved about 60 minutes' flight time. Without a weather radar image, the controllers depended on weather information coming from flight crews via radio communication. This communication did take place but mostly in German. The result was that the B-747 crew was not able to gather all up-to-date weather information.

ATC support

The workload for Langen Radar's controllers of the respective sectors was high because of the approach delays for Frankfurt Airport.

The controllers did not give any weather information to the B-747 crew. The B-747 crew asked ATC for weather information shortly before they decided to divert to Munich. ATC's answer was, "I'll call you back." The crew decided to divert to Munich before they received an answer to their request.

The B-747 crew used "PAN PAN" after their decision to divert to Munich and not "MAYDAY MAYDAY." By definition, "PAN PAN" indicates that the crew has an urgent message to transmit but is not in an emergency situation and, therefore, ATC does not have to give them priority.

Crew decision

The B-747 crew was under pressure to come up with a decision. The crew had gathered information of the difficult weather situation and the possibly resulting delays shortly before they decided to divert to Munich.

The B-747 crew could have reached the alternate airport Cologne-Bonn faster but the thunderstorm cells indicated on the onboard weather radar and the altogether unclear weather situation justified the crew's decision. Any distance to Nuremberg, Stuttgart, or Hanover airports would have been shorter, and the prevailing weather at the respective destination would have permitted a landing.

Conclusions

The investigation of this incident shows that

- a low-fuel situation may arise in spite of the adherence to the required fuel policy,
- the reasons for a low-fuel situation can be very complex,
- the pressure to come up with a decision can be very high in a low-fuel situation,
- the weather information must be up-to-date,
- by definition, TAFs, METARs, and SPECIs report weather information of airports and certain specified present weather phenomena in their vicinity,
- enroute and approach weather information must be transmitted to flight crews,
- ATC support with up-to-date weather information can be crucial,
- an exchange of weather information between aircraft in the same airspace and between aircraft and ATC can be important, and
- radio communications should be in English.

Moreover, this case shows that

- the investigation of a serious incident can provide vital information for flight safety,
- the investigation of a serious incident can be time consuming, and
- an investigation done by an operator can only be incomprehensive because, for example, access to data from ATC or other involved organizations is limited. ◆

Breaking the Chain: An Empirical Analysis of Accident Causal Factors by Human Factors Analysis and Classification System (HFACS)

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Abstract

This research analyzed 523 accidents in the ROC. Air Force between 1978 and 2002 using the Human Factors Analysis and Classification System (HFACS) framework described by Wiegmann and Shappell (2003). This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher levels in the organization result in operational errors and accidents. Suggestions are made about intervention strategies focusing on the categories at higher levels of HFACS. Specific targets for remedial safety actions should be aimed in the areas that share the strongest and greatest number of significant associations with "organizational influences" (for example, "organizational process," "inadequate supervision," and "crew resource management"). The greatest gains in safety benefit could be achieved by targeting these areas. Furthermore, this study also demonstrates that the HFACS framework is a useful tool for guiding accident investigations and for targeting potentially cost-effective remedial safety actions for breaking the chain of accidents.

Introduction

In accident investigation, it is easier to identify the cause with factual proof for hardware failures than for human failure. The role of human error in aircraft accidents is a topic of much scientific debate. There are a number of perspectives for describing and analyzing human errors, each based on different assumptions about their nature and the underlying causal factors of the human contribution in the sequence of events leading up to an accident. Accidents, especially those involving human errors, normally are associated with a chain of events—a series of problems that degrade the performance of the equipment, the crewman, or both until accidents are inevitable (Diehl 1989). Feggetter (1991) suggested that the role of psychologists who investigate accidents is to collect and make a detailed examination of the large amounts of information associated with human errors and to gain a complete understanding of the surrounding circumstances. By examining and correlating information across a number of accidents, predictors may be identified that may then be applied to individual crews or situations in order to develop the effective prevention strategies for breaking the chain leading to accidents.

Helmreich (1994) suggested that despite impressive technological advances, aircraft accidents continue to happen, and it is now suggested that humans, primarily the aircraft pilot and crew, are the weak link in the aviation safety chain. In general aviation, pilots are assessed as being the cause of accidents in more than 80% of cases and that more than half of these accidents are the result of poor pilot judgment (Trollip and Jensen, 1991). As aircraft have become increasingly more reliable, human performance has played a proportionately increasing role in the cause of accidents. As a result, many human factors accident analysis frameworks, taxonomies and analysis strategies have been devised over the years (e.g., Diehl 1989, Harle 1995, Hollnagel 1998, Hunter and Baker 2000). The Human Factors Analysis and Classification System (HFACS) developed by Wiegmann and Shappell (2003) is the most commonly used and is the one used herein as a basis for the current work.

HFACS is a generic human error framework originally developed for U.S. military aviation as a tool for the analysis of the human factors aspects of accidents. It is based on Reason's (1990) systemwide model of human error in which active failures are associated with the performance of front-line operators in complex systems, and latent failures are characterized as inadequacies or mis-specifications that might lie dormant within a system for a long time and are only triggered when combined with other factors to breach the system's defenses. These latent failures are spawned in the upper management levels of the organization. As

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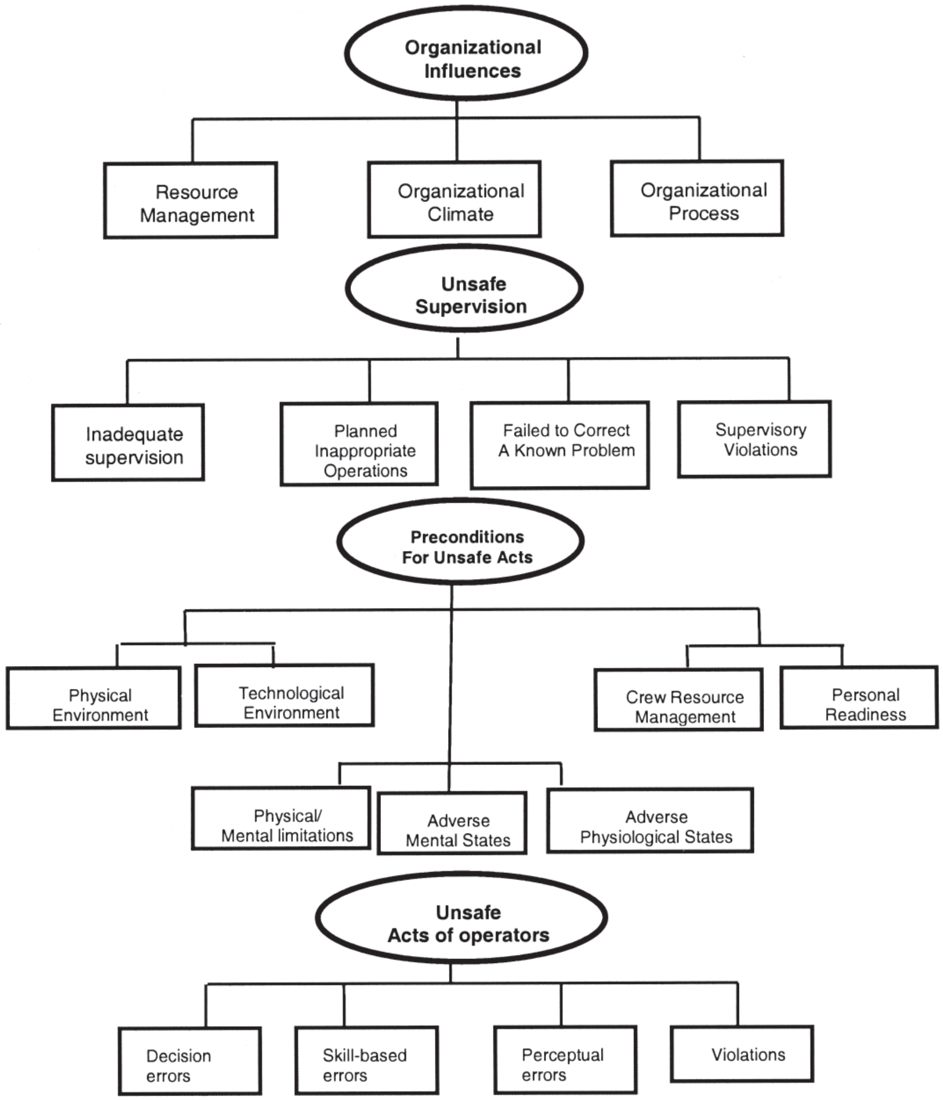

Figure 1. The HFACS framework—each upper level would affect a downward level, proposed by Wiegmann and Shappell (2003).

Reason (1997) noted, complex systems are designed, operated, maintained, and managed by human beings, so it is not surprising that human decisions and actions are implicated in all organizational accidents. Reason's model revolutionized the manner in which the role of human error in aviation accidents was viewed, but it did not provide a detailed method for the analysis of aviation accidents and mishaps. However, Wiegmann and Shappell developed the HFACS to fulfill such a need. The development of HFACS is described in a series of books and papers (e.g., Shappell and Wiegmann 2001, 2003, and 2004, and Wiegmann and Shappell 1997, 2001a, 2001b, 2001c, and 2003). Wiegmann and Shappell (2001b) suggest that the HFACS framework bridges the gap between theory and practice by providing safety professionals with a theoretically based tool for identifying and classifying human errors. The tool focuses on both latent and active failures and their interrelationships, and it facilitates the identification of the underlying causes of human error. However, as aviation accidents are often the result of a number of causes, the challenge for accident investigators is how best to identify and mitigate the causal sequence of events leading up to an accident.

HFACS examines human error at four levels. Each higher level is assumed to affect the next downward level in the HFACS framework (see Figure 1).

- Level 1—"Unsafe acts of operators": This level is where the majority of causes of accidents are focused. Such causes can be classified into the two basic categories of errors and violations.
- Level 2—"Preconditions for unsafe acts": This level addresses the latent failures within the causal sequence of events as well as more obvious active failures. It also describes the context of substandard conditions of operators and the substandard practices they adopt.
- Level 3—"Unsafe supervision": This level traces the causal chain of events producing unsafe acts up to the front-line supervisors.
- Level 4—"Organizational influences": This level encompasses the most elusive of these latent failures—fallible decisions of upper-level management, which directly affect supervisory practices, as well as the conditions and actions of front-line operators.

Wiegmann and Shappell (2001a) reported that the framework as a whole had an inter-rater reliability figure (using Cohen's Kappa) of 0.71, indicating substantial agreement; however, no figures were reported for the individual HFACS categories. Li and Harris (2005) conducted further research and found the inter-rater reliabilities for the individual categories in the HFACS framework (assessed using Cohen's Kappa) ranged between 0.440 and 0.826, a range of values spanning between moderate agreement and substantial agreement. Fourteen HFACS categories exceeded a Kappa of 0.60, which indicates substantial agreement. Four categories had Kappa values between 0.40 and 0.59, indicating only moderate levels of agreement (Landis and Koch 1977).

Maurino, Reason, Johnston, and Lee (1995) suggested that it is important to understand how decisions made by people at the sharp end (in this case, pilot) are influenced by the actions of the people at the blunt end of their operating worlds, the higher levels in their organizations. However, there is little empirical work formally describing the hypothesized relationship between organizational structures, psychological precursors of accidents, and the actual errors committed by pilots. This research investigated 523 accidents in the ROC Air Force occurring between 1978 and 2002 through the application of the HFACS. The objective was to provide probabilities for the co-occurrence of categories across adjacent levels of the HFACS to establish how factors in the upper (organizational) levels in the framework affect categories in lower (operational) levels. Once the significant paths in the framework have been identified, the development of accident intervention strategies should proceed more rapidly and effectively for breaking the chain leading to accidents.

Method

Data

The data were derived from the narrative descriptions of accidents occurring in the ROC Air Force between 1978 and 2002. The data set comprised of 523 accidents occurring during this 25-year period. For each accident, the 24-hour on-call investigator-in-charge follows a standard procedure for conducting the investigation. The initial stage collects relevant information for further analysis including the accident classification, identification details, pilots' information, personnel involved, aircraft information, mission and flight details, history of flight, impact and post-impact information, meteorological information, radar information, and transmissions to and from tactical air traffic control. The wreckage of the aircraft is then recovered for investigation by the engineering teams. The final report details the causal factors of the accident and contains recommendations for accident prevention.

Classification framework

This study used the version of the HFACS framework described in Wiegmann and Shappell (2003). The first (operational) level of HFACS categorizes events under the general heading of "unsafe acts of operators" that can lead to an accident. This comprises of four subcategories of "decision errors," "skill-based errors," "perceptual errors," and "violations." The second level of HFACS concerns "preconditions for unsafe acts," which has seven further subcategories: "adverse mental states," "adverse physiological states," "physical/mental limitations," "crew resource management," "personal readiness," "physical environment," and "technological environment." The third level of HFACS is "unsafe supervision," which includes "inadequate supervision," "planned inappropriate operation," "failure to correct known problem," and "supervisory violation." The fourth and highest level of HFACS is "organizational influences" and comprises of the subcategories of "resource management," "organizational climate," and "organizational process." HFACS is described diagrammatically in Figure 1.

Coding process

Each accident report was coded independently by two investigators, an instructor pilot and an aviation psychologist. These investigators were trained on the use of the HFACS framework together for 10 hours to ensure that they achieved a detailed and accurate understanding of its categories. The presence or absence of each HFACS category was assessed in each narrative report. To avoid over-representation from any single accident, each HFACS category was counted a maximum of only once per accident.

Statistical analysis

Chi-square (χ^2) analyses of the cross-tabulations to measure the statistical strength of association between the categories in the higher and lower levels of the HFACS were used. As the χ^2 test is a simple test of association these analyses were supplemented with further analyses using Goodman and Kruskall's lambda (λ), which was used to calculate the proportional reduction in error (PRE). Goodman and Kruskall's lambda has the advantage of being a directional statistic. The lower-level categories in the HFACS were designated as being dependent upon the categories at the immediately higher level in the framework, which is congruent with the theoretical assumptions underlying HFACS. The value for lambda indicates the strength of the relationship, with the higher levels in the HFACS being deemed to influence (cause) changes at the lower organizational levels, thus going beyond what may be deemed a simple test of co-occurrence between categories. Finally, odds ratios were also calculated, which provided an estimate of the likelihood of the presence of a contributory factor in one HFACS category being associated concomitantly with the presence of a factor in another category. However, it must be noted that as odds ratios are an asymmetric measure, they are only really theoretically meaningful when associated with a non-zero value for lambda. From a theoretical standpoint, lower levels in the HFACS cannot adversely affect higher levels.

HFACS Category		Frequency	Percentage
Level 4 Organizational Influences	Organizational process	76	14.5
	Organizational climate	4	0.8
	Resource management	184	35.2
Level 3 Unsafe Supervision	Supervisory violation	8	1.5
	Failed to correct a known problem	12	2.3
	Planned inadequate operations	24	4.6
	Inadequate supervision	177	33.8
Level 2 Preconditions for Unsafe Acts	Technology environment	44	8.4
	Physical environment	74	14.1
	Personal readiness	29	5.5
	Crew resource management	146	27.9
	Physical/mental limitation	73	14.0
	Adverse physiological states	2	0.4
	Adverse mental states	184	35.2
Level 1 Unsafe Acts of Operators	Violations	160	30.6
	Perceptual errors	116	22.2
	Skilled-based errors	226	43.2
	Decision errors	223	42.6

Table 1. Frequency and percentage counts for each HFACS category for all 523 accidents.

Results

The frequency of occurrence the individual causal factors coded in the analysis of the 523 accidents is given in Table 1. In these accidents, 1,762 instances of human error were recorded within the HFACS framework. Initial results found that acts at the level of "unsafe acts of operators" were involved in 725 (41.1%) of instances, the "preconditions for unsafe acts" level was as a causal factor in 552 (31.3%) of instances; the "unsafe supervision" level was involved in 221 (12.5%) of instances, and the "organizational influences" level in the HFACS model was involved as a factor in 264 (15%) of instances. Relatively few categories had exceptionally low counts. Only the categories of "organizational climate" (Level 4); "supervisory violation" (Level 3) and "adverse physiological state" (Level 2) failed to achieve double figures.

Analysis of the strength of association between categories at HFACS Level 4 "organizational influences" and HFACS Level 3 "unsafe supervision" found that out of a possible 12 relationships there were eight pairs of significant associations between categories at adjacent levels. "Organizational process" was significantly associated with all four supervisory factors at Level 3: "inadequate supervision," "planned inappropriate operations," "failed to cor-

Organizational Influence *With* Unsafe Supervision	Pearson Chi-square			Lambda		Odds Ratio
	Value	df	p	Value	P	
Resource Management * Inadequate Supervision	13.525	1	<.001	.000	ns	0.473
Organizational climate * Inadequate Supervision	7.562	1	<.006	.023	<.045	nc
Organizational climate * Failed to correct known problem	39.753	1	<.001	.000	ns	49.500
Organizational climate * Supervisory violation	61.121	1	<.001	.000	ns	83.167
Organizational process * Inadequate Supervision	91.208	1	<.001	.282	<.001	13.561
Organizational process * Planned inappropriate operations	14.174	1	<.001	.000	ns	4.535
Organizational process *Failed to correct a known problem	11.899	1	<.001	.000	ns	6.100
Organizational process * Supervisory violation	46.307	1	<.001	.000	ns	nc

ns: *not significant*
nc: *not computed due to a zero frequency in one cell of the contingency table*

Table 2. Chi-square test of association and Goodman and Kruskall's lambda and odds ratios summarizing significant associations between categories at the level of "organizational influences" and "unsafe supervision."

rect a known problem," and "supervisory violations." "Organizational climate" was significantly associated with "inadequate supervision," "failed to correct a known problem," and "supervisory violations." "Resource management" was significantly associated with only one category at Level 3, "inadequate supervision." Further examination of the directional PRE showed two significant associations between categories at Level 4 and Level 3; "organizational climate" with "inadequate supervision" and "organizational process" with "inadequate supervision." It should be noted, though, that only four instances were observed in which "organizational climate" was implicated as a contributory factor. As a result, any associations involving this category should be treated with extreme caution. The association between "organizational process" with "inadequate supervision" also had a high odds ratio, suggesting that poor supervisory practices were more than 13 times more likely to occur when associated with poor higher level managerial processes in the air force. These statistically significant relationships are summarized in Table 2 and are described diagrammatically in Figure 2.

Analysis of the strength of association between categories at HFACS Level 3 "unsafe supervision" and HFACS Level 2 "preconditions for unsafe acts" showed that out of a total number of 28 possible comparisons, a further eight pairs of significant associations between categories at adjacent levels were found. "Inadequate supervision" showed significant statistical associations with five categories, "adverse mental states," "physical/mental limitations," "crew resource management," "personal readiness," and "physical environment." "Planned inappropriate operations" had significant relationships with two Level 2 categories, "adverse mental states" and "crew resource management." "Failed to correct a known problem" was significantly associated with the lower-level category of "adverse mental states." These significant associations are summarized in Table 3 and in Figure 2. Further examination of the directional PRE found that there was a significant association between the Level 3 and Level 2 categories of "inadequate supervision" and "crew resource management." This relationship also had a high odds ratio, suggesting that poor su-

Unsafe Supervision *With* Preconditions for Unsafe Acts	Pearson Chi-square			Lambda		Odds ratio
	Value	df	P	Value	p	
Inadequate Supervision * Adverse mental states	29.545	1	<.001	.038	ns	2.824
Inadequate Supervision *Physical/mental limitation	7.945	1	<.005	.000	ns	2.036
Inadequate Supervision * CRM	143.573	1	<.001	.281	<.002	12.780
Inadequate Supervision * Personal readiness	10.101	1	<.001	.000	ns	3.304
Inadequate Supervision * Physical environment	6.604	1	<.010	.000	ns	0.469
Planned inappropriate operations *Adverse mental states	5.730	1	<.020	.022	ns	2.594
Planned inappropriate operations *CRM	10.824	1	<.001	.027	ns	3.744
Failed to correct a known problem * Adverse mental states	6.958	1	<.008	.000	ns	nc

ns: *not significant*
nc: *not computed due to a zero frequency in one cell of the contingency table*

Table 3. Chi-square test of association and Goodman and Kruskall's lambda and odds ratios summarizing significant associations between categories at the level of "unsafe supervision" and "precondition for unsafe acts."

Precondition for Unsafe Acts With *Unsafe Acts of Operators*	Pearson Chi-square			Lambda		Odds ratio
	Value	df	p	Value	P	
Adverse mental state * Decision errors	59.226	1	<.001	.269	<.001	4.364
Adverse mental states * Skill-based errors	61.701	1	<.001	.283	<.001	4.518
Adverse mental states * Perceptual errors	43.730	1	<.001	.000	ns	4.106
Adverse mental states * Violations	13.025	1	<.001	.000	ns	2.019
Physical/mental limitation * Decision errors	50.996	1	<.001	.211	<.001	7.730
Physical/mental limitation * Skill-based errors	33.051	1	<.001	.164	<.001	4.735
Physical/mental limitation * Perceptual errors	27.401	1	<.001	.000	ns	3.764
CRM * Decision errors	42.578	1	<.001	.215	<.001	3.724
CRM * Skill-based errors	35.423	1	<.001	.195	<.001	3.299
CRM * Perceptual errors	62.086	1	<.001	.000	ns	5.435
CRM * Violations	19.850	1	<.001	.000	ns	2.462
Personal readiness * Decision errors	10.220	1	<.001	.058	<.015	3.613
Personal readiness * Skill-based errors	15.181	1	<.001	.075	<.001	5.231
Technology environment * Decision errors	3.982	1	<.046	.000	ns	0.509
Technology environment * Skill-based errors	5.724	1	<.017	.000	ns	0.440
Technology environment * Perceptual errors	6.982	1	<.008	.000	ns	0.228

ns: *not significant*
nc: *not computed due to a zero frequency in one cell of the contingency table*

Table 4. Chi-square test of association and Goodman and Kruskall's lambda and odds ratios summarizing significant associations between categories at the level of "precondition for unsafe acts" and "unsafe acts of operators."

pervisory practices were almost 13 times more likely to subsequently result in poor CRM.

Analysis of the strength of association between categories at HFACS Level 2 "preconditions for unsafe acts" and HFACS Level 1 "unsafe acts of operators" showed a further 16 pairs of significant associations out of a possible 28. The Level 2 category of "adverse mental states" exhibited significant statistical associations with four Level 1 categories, "decision errors," "skill-based errors," "perceptual errors," and "violations." "Crew resource management" was also associated with four lower-level catego-

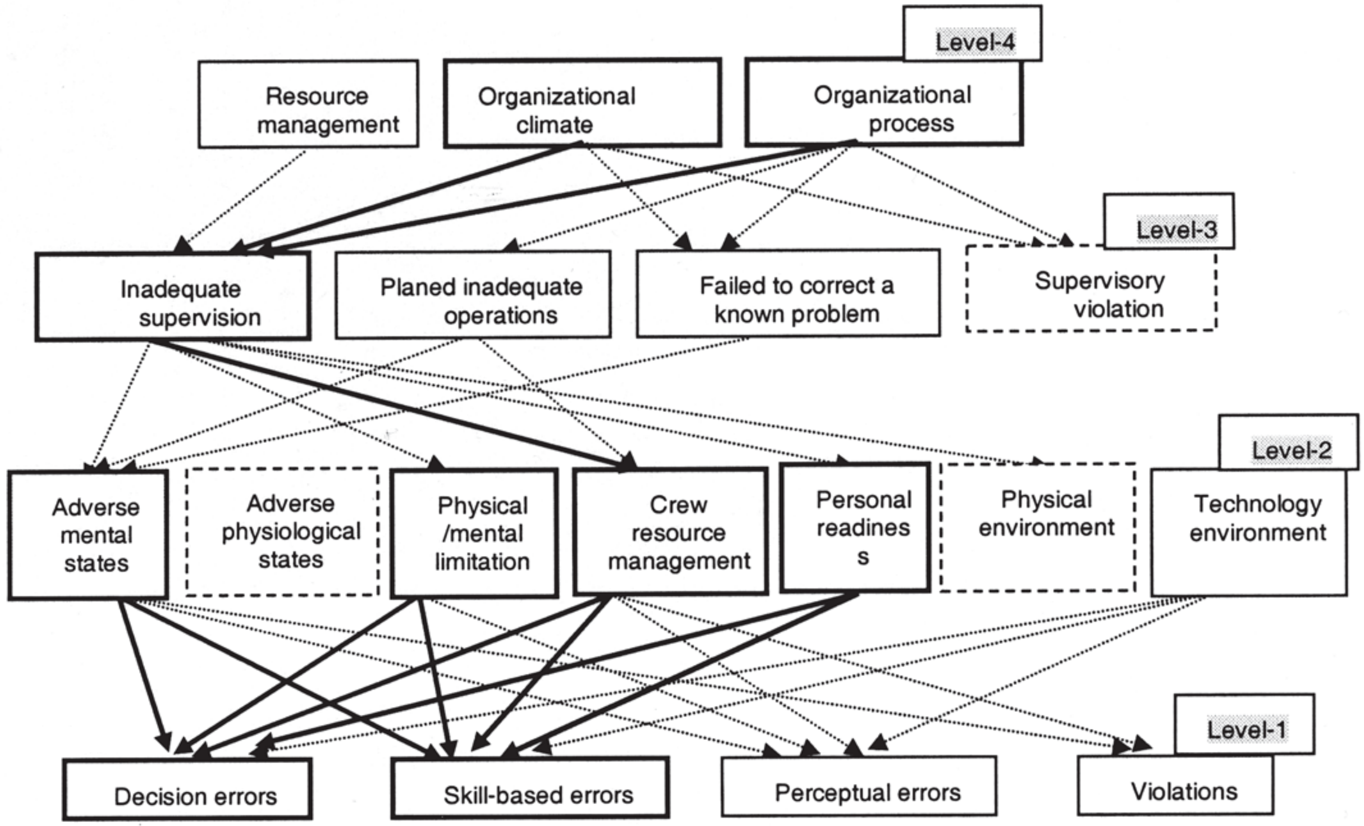

Figure 2. Paths between categories at the four levels in the HFACS framework showing the significant associations using chi-square ($\chi 2$) and lambda (λ). [dashed box] Means the category has no significant association with downward level categories – – – – – – ►Means Chi-square significant ————►Means both chi-square and lambda significant

ries in the HFACS framework, "decision errors," "skill-based errors," "perceptual errors," and "violations." "Physical/mental limitations" was associated with three categories, "decision errors," "skill-based errors," and "perceptual errors." The "technology environment" was also statistically associated with a further three Level 1 categories, "decision errors," "skill-based errors," and "perceptual errors." Finally, "personal readiness" was associated with "decision errors" and "skill-based errors." Further examination of the directional PRE found that there were eight significant associations between Level 2 and Level 1 categories. These were "adverse mental states" with "decision errors" and "skill-based errors," "physical/mental limitations" with "decision errors" and "skill-based errors," "crew resource management" with "decision errors" and "skill-based errors," and "personal readiness" with the categories of "decision errors" and "skill-based errors." These significant statistical relationships are summarized in Table 4 and are described diagrammatically in Figure 2. All these significant associations were associated with high odds ratios, suggesting that inadequate performance in the higher level HFACS categories was associated with much increased likelihood of poor performance at the lower levels.

Discussion

It can be seen from the data presented in Table 1 that the vast majority of HFACS categories had large numbers of instances of occurrence in the data set, which allows reasonable confidence in the results of the statistical analyses and the pattern of results obtained. Reason (1990 and 1997) has suggested that there is a "many to one" mapping of the psychological precursors of unsafe acts and the actual errors themselves, making it difficult to predict which actual errors will occur as a result of which preconditions. This research, using the HFACS framework developed by Wiegmann and Shappell (2003) goes some way to supporting this assertion. There are statistically significant associations between causal factors at higher organizational levels, the psychological contributory factors, and the errors committed by pilots (see Tables 2-4 and Figure 2). However, some care needs to be taken when interpreting the statistical relationships presented within HFACS. In a few categories (noted earlier) the frequency counts are small. Furthermore, the frequency counts within categories were all derived from accidents. It is unknown (and unknowable) how often instances within the various HFACS categories have occurred in day-to-day operations that have not resulted in an accident. Thus, the relationships between HFACS levels and categories should not be interpreted outside the accident causal sequence. It should also be noted that only in those cases where a significant χ^2 test of association is accompanied by a significant value for lambda can it be assumed that the categories in the lower levels of the HFACS framework were dependent upon the higher-level categories, as is congruent with the underpinning theory.

Orasanu and Connolly (1993) have suggested that decision-making occurs in an organizational context and that the organization influences decisions directly by stipulating standard operating procedures, and indirectly through the organization's norms and culture. Reason (1990) proposed that latent conditions are present in all systems and that they are an inevitable part of organizational life. For example, resources are normally distributed unequally in organizations. The original decision on how to allocate resources may have been based on sound commercial arguments, but such inequities may create reliability or safety problems for someone somewhere in the system at some later point. This analysis showed that at HFACS Level 4, "organizational influences," all the categories had some association with causal factors at Level 3 ("unsafe supervision"). However, the category of "organizational process" is the key factor at this highest organizational level. Poor "organizational processes" were associated with inadequacies in all categories at the level of "unsafe supervision" and hence indirectly were ultimately at the root of many operational errors resulting in accidents. Well-developed "organizational processes" that are consistently adhered to are key to all safety management systems. The commitment to safety must come from the very highest levels of the organization if it is to be successful in this respect (Reason 1997). Both Reason (1990) and Wiegmann and Shappell (2003) hypothesized that inappropriate decision-making by upper-level management can adversely influence the personnel and practices at the supervisory level, which in turn affects the psychological preconditions and hence the subsequent actions of the front-line operators. This study provides statistical support for this hypothesized relationship. Furthermore, the odds ratios associated with "supervisory failures" were more than 13 times more likely to occur in the presence of a concomitant failure in the category of "organizational process" (see Table 2).

Wojcik (1989) proposed that some conditions are studied by psychologists and are reasonably well understood, such as work schedules that allow adequate sleep. However, other conditions related to management and organizational factors are more difficult to observe and quantify. At present, the accident causal factors cited by investigation authorities usually, though not always, emphasize technology, the physical environment and the more immediate human factors, an emphasis partly due to the "stop rules" of investigators when searching for accident causes (Rasmussen, 1988). The category of "inadequate supervision" was the key factor at HFACS Level 3. It had many, significant statistical associations with categories in Level 2, however, there was only one significant "causal" relationship observed, which was with the Level 2 category of "crew resource management." The failure of senior officers in a supervisory position to provide guidance and operational doctrine to pilots was associated with many forms of psychological precursor that subsequently resulted in active, operational failures. Again, the values for the odds ratios associated with "supervisory failures" and several Level 2 categories strongly suggest that this is a key area for breaking the chain leading to accidents. This suggests that accident investigations should be pursued further back into the organization than is often the case at present.

Reason (1990) suggested that human behavior is governed by the interplay between psychological and situational factors. The preconditions for unsafe acts (Level 2) show a number of strong statistical relationships with the active failures of the operators at Level 1. In many cases the relationships uncovered in the data suggest a strong "causal" influence of the higher-level HFACS categories on the Level 1 errors. These Level 2 factors show Reason's classic "many to one" mapping of psychological precursors to active failures in all of the Level 1 categories with the exception of "violations" which is only closely related to two higher level categories suggesting that a completely different mechanism is at play here to cause such failures (see Figure 2).

Some aspects, however, are almost out of the control of even the higher levels of the organization. It is interesting to note that the Level 2 category of the "technological environment" (which is essentially concerned with such factors as the quality of cockpit interfaces) is not at all influenced by the higher managerial levels. However, it has a significant association with several HFACS Level 1 categories. This is probably a result of the higher levels in the ROC Air Force chain of command having little or no influence on the cockpit design of their aircraft. Indeed, it is often the case in the military that those responsible for the design and/or procurement of large pieces of equipment are in entirely different organizations to the operators of these systems. Those responsible for the technology environment are not actually in the same management hierarchy as the people using it.

It will be noted from the results presented in tables 2-4 (and in Figure 2) that even though there were a considerable number of statistically significant associations between HFACS categories at adjacent organizational levels, there were relatively few "causal" relationships, where the lower-level categories were statistically dependent upon higher-level categories. This may lead to the suggestion that unlike the proposition expounded in the HFACS model (and in its associated underlying theory), organizational influences are not always unidirectional. People at lower levels in the organization may, in some circumstances, adversely influence behavior at higher managerial levels. It is conceivable that pilots exhibiting "poor personal readiness," an "adverse mental state," or who had "physical or mental limitations" could cause problems that resulted in "inadequate supervision." On the other hand, though, it is difficult to see how "decision errors" could cause an "adverse mental state." The results obtained suggest that the HFACS framework needs to be modified slightly to encompass a more dynamic view of organizations.

The results suggest that interventions at HFACS Levels 1 and 2 would only have limited effect in improving overall safety. As an example, improving CRM practices alone is unlikely to have a major impact on safety unless the supervisory processes (Level 3) and organizational processes (Level 4) are in place to provide facilities, oversee CRM training, monitor its effectiveness, and respond to any further changes required in the training program. All of these activities require organizational commitment and capacity, which can only be provided from the highest levels of management. Furthermore, on a "dollar-for-dollar" basis, interventions at higher levels are also likely to be more cost effective in terms of the net safety benefits they realize. Specific targets for remedial safety action should be aimed in the areas that share the strongest and greatest number of significant associations with lower levels in the organization (for example, "organizational process," "inadequate supervision," and "crew resource management." All of these categories are also at the root of paths of association with other HFACS categories that have very high values for the odds ratios associated with them, which further suggests that the greatest gains in safety benefit could be achieved by targeting these areas.

Conclusions

There is a growing awareness of the role of management and organizational factors in aviation accidents (Orasanu and Connolly

1993). There is an explicit relationship between organizational conditions and the individual psychological factors affecting safety performance. It is important to understand how the errors committed by pilots are influenced by the actions of management at the higher levels in their organizations (Maurino et al. 1995). If the aviation industry wants to achieve the goal of significantly reducing the aviation accident rate, these organizational and human factors must be addressed. Before research efforts can be systematically refocused, a comprehensive analysis of existing databases needs to be conducted to determine the most prevalent underlying organizational factors, as well as the more immediate human factors responsible for aviation accidents and incidents. Furthermore, if these efforts are to be sustained, appropriate human factors investigation methods and techniques will need to be developed so that data gathered during human factors accident investigations can be improved, and analysis of the underlying causes of human error facilitated (Wiegmann and Shappell 2001c). This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher levels in the organization promulgate throughout the ROC Air Force to result in operational errors and accidents. There are clearly defined, statistically-described paths that relate errors at Level 1 (the operational level) with inadequacies at both the immediately adjacent and higher levels in the organization. The accidents and incidents analyzed all occurred in the ROC Air Force, thus the patterns of interrelationships reported may be culturally specific. However, there is no reason why this analytical methodology cannot be employed on other data sets to establish if the patterns observed hold good in other cultures, thereby providing further empirical evidence to support the HFACS methodology. This research draws a clear picture that supports Reason's (1990) model of active failures resulting from latent conditions in the organization. Furthermore, the HFACS framework has been proven to be a useful tool for guiding accident investigations and for targeting potentially cost-effective remedial safety actions for breaking accidents chain. ◆

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Major Investigation Management

By Nick Stoss, Director, Air Investigations Branch, Transportation Safety Board of Canada

Background

As the director of the second-largest national aviation safety investigation authority, I frequently have been asked for how the Air Branch of the Transportation Safety Board of Canada (TSB) plans for and conducts major investigations. The catalysts for such a request from another national aviation accident investigation authority (AAIA) are valid concerns that the AAIA may not have the required resources and expertise to capably respond to a major accident, and that the AAIA may not have the knowledge and experience to manage and conduct a major investigation. The basic challenge is "Will the AAIA be able to do it competently and professionally the first/next time it happens?"

I routinely have three responses to these questions. The first is that "managing a major investigation is not rocket science"; the second is that "a successful major investigation does rely on comprehensive readiness and sound management"; and the third is "that, rather than starting from 'scratch' [i.e., reinventing the wheel], one can learn much of what is required through consultation with other AAIAs and a careful review of their documented processes."

In this paper, I first will present my views on "organizational readiness," "major occurrence response," and "managing major occurrence investigations." Then, I will touch on some TSB recent experiences in conducting major investigations, including the management of the investigation into the Air France A340 runway-overrun accident at Toronto on Aug. 2, 2005.

This paper is not designed to provide all the answers to the complexities of conducting a successful major investigation; instead, I will be highlighting some important issues that the TSB believes should be the basis for an AAIA to examine/evaluate its readiness and ability to take on such an important task.

Organizational readiness

I know that all AAIAs would agree that organizational readiness is the cornerstone to being able to handle day-to-day responsibilities. At the same time, AAIAs would acknowledge that their ability to meet these responsibilities can be affected by limited financial budgets, human resources, and investigation expertise and experience. It is for these reasons that I suggest that the cornerstone to an AAIA's organizational readiness to respond to any accident, but in particular to a major accident that will stretch resources and that will probably exceed in-house capabilities, is a comprehensive Major Occurrence Response Plan (MORP) and related checklists.

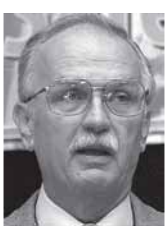
An AAIA's plan is not just a document solely based on intuition. It is a document that should be based on in-depth consideration of the following factors:

1. the AAIA's legislation, policies, and standards that support all the elements of the response and investigation plans;
2. the AAIA's investigation procedures and checklists to meet the requirements of all types of investigations, taking into the account the possible ranges of size and complexity;
3. the AAIA personnel's level of expertise, experience, and knowledge;
4. the AAIA's financial and equipment resources;
5. the AAIA's management structure and authorities, as well as its decision-making process(es);
6. the AAIA's readiness and ability to acquire additional financial, human, and equipment resources;
7. the entitlements, responsibilities, and procedures of other national and international agencies and departments that would become involved in the AAIA investigations; and
8. industry stakeholder[1] readiness and abilities to support an AAIA investigation.

The first four factors above are fundamental to day-to-day investigation operations and already should be well understood by all AAIAs. Although careful consideration of each of these points is required to ensure the integrity of an AAIA's MORP, for the purposes of this section of my paper I will limit myself to the discussion of the last four points, which are based on lessons learned by the TSB during our recent major investigations.

Management of a major investigation (command and control)

Managing a major investigation is like managing any important project. The investigator-in-charge (IIC) is the project manager who has been assigned a project [the safety investigation] with a clear objective [advancing transportation safety] that will be realized with the production of an investigation report and safety recommendations. The IIC is provided with specific financial, personnel, and equipment resources to complete the project. The IIC is accountable to the tasking authority [the Director of Investigations (DOI)] for conducting the investigation in accordance with the AAIA's legislation, policies, standards, and procedures. Finally, the IIC must keep the DOI informed as to the project status and the project plan, in particular when the assigned resources are inadequate and when additional support is required. The DOI, on the other hand, is responsible for ensuring that the



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investigation team is provided with the proper level of resources required to complete the investigation and, if this is not possible, to modify the project objectives or scope accordingly.

The above paragraph is a simple portrayal of the responsibilities of two levels of management in a major investigation. The reality is that there may be other levels of authority within an AAIA that have a role to play in support of a major occurrence investigation. The MORP should document the involvement and roles of those management levels to ensure everyone involved understands the chains of authority and scope of responsibilities. The following paragraphs provide some example perspectives of this issue.

For example, from an AAIA's perspective, the highest level of authority [chairperson, board, or commissioner] is vested with the responsibility for legislation, policy, inter-department liaison, and memoranda of understanding. The next level [executives, directors, and senior managers] is responsible for standards, guidelines, procedures, within-agency liaison, and resource allocation. Next, the IIC is responsible for adhering to the legislation, policy, standards and guidelines and for following established procedures. Finally, the group chairpersons of the investigation team members are responsible for following the investigation plan and checklists.

At the TSB of Canada, we, in part, document these divisions of responsibility for management and team members in the TSB Air Investigations Branch, Major Occurrence Investigation Checklist (MOIC).

For example, regarding the investigation and reporting in the context of an aviation occurrence—

- the IIC is accountable to the DOI for the management, conduct, and control of the investigation.
- the DOI has exclusive authority to direct the conduct of investigation on behalf of the Board. The DOI shall report to the Board with respect to investigations and shall conduct further investigation as required by the Board. This authority must be exercised in accordance with provisions of the Canadian Transportation Accident Investigation and Safety Board Act, and in accordance with TSB policies.
- the Board reviews transportation occurrence reports, makes findings as to causes and contributing factors, identifies safety deficiencies, makes safety recommendations, and issues public reports on its findings. The Board is also responsible for establishing policies that govern the classes of occurrences to be investigated and the conduct of investigations.

In the context of communications during an investigation, the TSB MOIC, in part, states that

- the investigator-in-charge is the TSB official spokesperson throughout the investigation regarding the progress of the investigation, release of factual information, investigation plans, and the TSB Investigation process. If approved by the DOI, the IIC may also be the TSB official spokesperson on the release of TSB safety communications and the TSB final investigation report.
- the director of Air Investigations, throughout the investigation, is the TSB executive responsible for communicating on TSB investigation legislation, policy, process, standards and procedures; and, on released Aviation Safety Advisories and Aviation Safety Information Letters. The DOI may also respond to inquiries on released TSB Board recommendations, and if approved by the chairman, the DOI may also be the TSB official spokesperson on the release of TSB Board recommendations, safety concerns, and the TSB final investigation report.
- the chairman, throughout the investigation, could communicate on TSB investigation legislation, policy, and process and on TSB Board recommendations, concerns, and final investigation reports. Questions on on-going investigations and on technical issues would normally be deferred to the IIC or the DOI.
- communication staff may be appointed as the TSB spokesperson on the TSB investigation process and previously released TSB communications.

There is not just one model for the management of major investigations. The important issue is that proper documentation of the process and individual responsibilities will play a significant part in the efficient management of the investigation. In addition, such documentation will add transparency of the process to all those involved in the investigation, not only AAIA members, but also the non-AAIA entities [other government departments, foreign states and agencies, accredited representatives, manufacturers, operators, associations].

AAIA observer legislation policies and procedures

Based on the concept that outside expertise will be required, AAIA legislation, policies, and procedures must include provisions for the use of non-AAIA personnel and resources. These provisions would be based on the requirement of the AAIA to maintain its independence and to maintain absolute control of the investigation. Equally important would be the requirement for all those involved in the safety investigation to maintain their independence from all other responsibilities [such as litigation, product liability, and discipline], and to conduct themselves in a manner that avoids all actual and potential conflicts of interest. Finally, the AAIA must take into account ICAO Annex 13 standards and recommended practices regarding the entitlements of accredited representatives and advisors.

Use of stakeholders/safety partners

No AAIA is staffed to the level where it has all the required in-house expertise and resources to respond to a major occurrence. To augment its capabilities, the AAIA will have to use persons from outside the agency to competently and credibly conduct a major investigation.

To establish readiness for a major investigation, the AAIA must determine what types of expertise are not available within the AAIA and then search for sources of that expertise to fill shortfalls. This search could include other national resources [government agencies, airlines operators, maintenance and technical organizations, and associations] as well as foreign resources [other AAIAs, manufacturers, regulators, etc.]. It is very important to note that an AAIA cannot afford to wait until the accident happens to do this analysis of resource requirements. Although you will never be able to plan for every circumstance, establishing "safety partnerships" will provide the framework required to rapidly expand resources.

These partnerships can be formalized using memoranda of understanding or working arrangements, or they can be established by less formal means. Notwithstanding, the term "partnership" implies cooperation on the subject matter of mutual interest; and in the context of an AAIA investigation, the mutual interest would be "advancing safety." A "safety partnership" does not imply collaboration, complicity, or compromise on safety issues, nor does it include any activity that is not directly linked to advancing safety. Any safety partnership agreement must clearly state the conditions and limits of the partnership.

Fundamental to the readiness to use non-AAIA personnel are the following:

- The AAIA rules and guidelines on and the conditions for use of these "safety partnerships" must be well documented.
- The AAIA personnel must be knowledgeable about these rules and conditions,
- The AAIA personnel must be knowledgeable about the safety interests and aware of the potential conflicting interests of the non-AAIA entities that may become involved in an AAIA investigation.
- Not only must all non-AAIA personnel be familiar with the AAIA's rules and guidelines on and conditions for the use of these "safety partnerships," but they must be knowledgeable about AAIA's investigation mission, methodology, policies, standards, and procedures.

Finally, to ensure the readiness of potential safety partners, the AAIA may have to conduct training for them. Such training could include involving non-AAIA personnel in AAIA investigation response exercises and having them participate as observers on AAIA investigations. Equally important for AAIA personnel is that they participate in the emergency response exercises conducted by other agencies that have disaster response responsibilities.

TSB observer policy and procedures

Here is how the TSB handles some of the safety-partner/observer[2] issues.

- First, TSB legislation makes it very clear that it is solely the TSB's discretion to accept observers. It also directs that observers will only be appointed if they have expertise required by the TSB.
- The TSB is also very clear that, no matter what organization the observer normally works for, while working on a TSB investigation, observers work directly for the IIC.
- Another area of concern is the inadvertent release of investigation information. In this regard, two conditions for a person being granted "observer status" on a TSB investigation are that the TSB IIC is the sole person entitled to release investigation information and that no release or use of investigation data is permitted without the specific approval of the IIC. For the TSB, this is a two-way street: the IIC would routinely provide advance notice to stakeholders about information that will be released, and the observer must request permission to pass any investigation information to the parent organization, prior to any use of that information.
- The TSB lives up to the information sharing requirements contained in ICAO Annex 13 information provisions but restricts the release and use of the information as stated above.

TSB roles of observers/participants

In addition to the provisions within Annex 13 regarding the rights of accredited representatives and advisors, the TSB has a broader view of the roles of observers on a TSB investigation. Specifically, observers and participants are expected to

- contribute their expertise where required by the TSB.
- be the point of liaison between the TSB and their parent organization or agency.
- assist in the validation of investigation data.
- contribute to investigation planning.
- assist in areas of analysis.
- assist in determining safety significant events and underlying factors.
- assist in assessing risks, defenses, and risk control options.
- assist in validating safety deficiencies.

The following are those who the TSB normally invites and accepts as observers:

- Accredited representatives from the AAIAs of involved states;
- Advisors to accredited representatives as appointed by the foreign states;
- Transport Canada, by legislation, is permitted to appoint a Minister's observer, but this observer's participation is limited to observing;
- Airline safety department investigators of the involved airline;
- Manufacturer safety department investigators of the involved manufacturer;
- Safety staff of other involved organizations—we do not accept lawyers or managers and staff who may be implicated in the investigation;
- Association safety department investigators of the association whose members are involved; and
- Foreign AAIA investigators for both training purposes and for specific expertise.

TSB observer/safety partner readiness

The TSB spends significant effort at establishing and maintaining relationships with key foreign states, companies, departments, organizations, and associations to ensure that these are ready to participate in TSB investigations.

- *State AAIAs:* TSB investigators are frequently in contact with foreign investigation agencies when they become involved as accredited representative representing Canadian safety interests in foreign investigations. The TSB also conducts liaison visits, exchanges training opportunities, and shares experiences with these agencies. The TSB also consults other agencies when establishing and revising investigation policies, standards and procedures.
- *Manufacturers:* The TSB maintains relationships with the safety departments of Canadian manufacturers of aeronautical products to ensure response readiness for Canadian and foreign investigations involving these products. The TSB does likewise with foreign manufactures whose products are used in Canada.
- *Airlines:* The TSB maintains relationships with the safety departments of all Canadian and some foreign airlines to ensure response readiness and effectiveness for Canadian and foreign investigations.
- *Police Forces:* TSB regional offices maintain close contact with provincial and municipal police forces during day-to-day investigations operations. These relationships are further enhanced by joint disaster response exercises, routine meetings, and briefings to ensure clear understanding of each other's mandates and procedures. The TSB also has memoranda of understanding with some police forces to ensure proper handling of evidence, security for accident sites, immediate access to accident sites for TSB investigators, and procedures for resolving conflicting interests and priorities.
- *Coroners:* TSB regional offices maintain close contact with provincial coroners during day-to-day investigations operations, and

the TSB and coroners exchange services, such as coroner autopsies for TSB investigations and TSB technical assessments of accident scenes for the coroner inquiries. The TSB also has memoranda of understanding with the coroners of all our provinces.

• *Other Canadian Government Organizations:* The TSB maintains close liaison with other Canadian government departments involved in responding to major accidents. The TSB established and maintains working arrangements with Transport Canada, Foreign Affairs Canada, emergency measures organizations, Department of Health, Treasury Board, National Defence, etc. The TSB also participates in meetings and exercises with most of them.

• *Insurance Adjusters:* TSB regional offices work with insurance adjusters to share efforts in recovering wreckage.

• *News Media:* The TSB liaises with news media organizations to understand their requirements and to educate them on our mandates and procedures. The TSB's current communications posture, procedures, and products have been formulated based on mutual knowledge of the media's and the TSB's requirements.

Major occurrence response

Activate the major investigation response plan

Each AAIA should have a plan for reacting to accidents. The factors in the plan would normally include the following: the collection and assessment of the occurrence information to determine the type and scope of the AAIA response required; the call out of required investigators and support personnel; the notification of national authorities, including regulators, air traffic service providers, police, etc.; the notification of involved airlines, manufacturers, etc.; and the notification of foreign states as required by ICAO Annex 13. The only difference for this aspect in a major investigation situation would be the requirement to notify and increased number of investigators, support staff, and non-AAIA entities.

The next step would be to establish the composition of the major investigation team. Based on the profile and type of occurrence, the location of the occurrence, the type of operation and aircraft, the number of persons on board, the damage to property, etc., the AAIA would have to determine the type and depth of investigation expertise, resources, and equipment required. These factors would also influence the selection of the investigator-in-charge (IIC) and group chairmen, and the provision of personnel and other resources to the investigation team, if need be from non-AAIB sources.

Another important factor that will result in a successful response to a major accident is that the AAIA should concentrate on managing the existing initial response plan. This would not be the time for making changes to your plan—doing so will probably result in uncertainty and like cause confusion. Specifically, resist the temptation to second-guess your preparations, and go with your plan and rely on the readiness and training of your staff. Effectively, the AAIA response plan and the major occurrence checklists in most situations are, in fact, the AAIA's Day #1 and Day #2 investigation plan.

An important element in the TSB's response plan is that the initial response to the accident site is conducted by the same small regional team that would react on a day-to-day basis to routine accidents. This team remains in control until the major investigation team arrives on site. This practice allows more time to organize and deploy the major investigation team to the accident location.

Role of AAIA management/executive

The AAIA's MORP should document the roles and involvement of its management team and executives, the command and control structure, and the communication requirements between the IIC and the management team. Specifically, once the major investigation team is established and the day-to-day management of the investigation has been passed to the IIC, the AAIA senior management role should become one of ensuring support to the IIC and the investigation team. The AAIA management should also monitor strategic planning issues, such as acquiring additional financial, technical, and human resources for the investigation.

As mentioned earlier in this paper, the TSB Air Investigations Branch, Major Occurrence Investigation Checklist (MOIC) documents the roles of TSB managers from the investigation team perspective. However, in addition and based on our experiences over the last five major investigations, additional plans and checklists have been put in place across the TSB to ensure that all parts of the organization are ready to manage and provide support to the major occurrence investigation teams.

Management of the major investigation

Managing—general

The most critical aspect of a successful major accident investigation is the IIC's management of the project. Effectively, the IIC, who probably is very comfortable in applying his technical and operational investigation expertise, now has to rely on the expertise of his group chairmen and investigators to do this work. To be successful, a major accident investigation IIC must

• concentrate on managing the investigation: An IIC should be monitoring the progress of the investigation, looking forward, and planning ahead.

• use the Major Occurrence Investigation Checklist: It is the basis for monitoring the progress of the investigation and planning future investigation activities. This is not to suggest that the IIC should blindly follow the Checklist. The IIC's monitoring of the Checklist is the best way to determine if the Checklist is effective in all areas of the investigation and to determine if the Checklist needs to be revised.

• manage investigation team resources: Throughout the investigation, the IIC must ensure that the major investigation team has the investigation expertise required, that the personnel provided to the investigation are assigned to investigation groups, and that future needs of the investigation team are determined. This type of planning is critical in setting out work requirements and schedules. In reality, the IIC may have to do more with fewer investigators, may have to do with fewer resources, may have to delay some aspects of the investigation until resources become available, and in some circumstances may even have to set aside some non-critical investigation tasks.

Tracking major investigation issues

As stated earlier, an IIC cannot be expected to do all the work and to know every aspect of an unfolding investigation, in particular during the first few days of the investigation. To be successful, the IIC needs to concentrate on the validated factual information and significant safety issues identified by the investigation team, on the status of the overall investigation plan, on the plans of all the investigation groups, and on the outstanding investigation requirements.

In the TSB context, the MOIC allows flexibility in the organization and structure of the major investigation team and provides specific checklists[3] for these investigation management areas.

Managing investigation schedules

One of the most valuable resources that an IIC has is his or her assigned personnel, and the IIC must ensure that they maintain their physical and mental health and that their work areas are safe. If investigators are left to do their own work scheduling, the work pressures and their own enthusiasm can easily cause most of them to try to work 24 hours a day, 7 days a week. The only time-critical investigation task that exists is ensuring that perishable evidence is not compromised or lost. Once this task is completed, the IIC must not only manage the team work schedule, but also his or her schedule as well. This aspect of management must be done to not only ensure that the IIC and the group chairmen have the time available to meet their investigation management responsibilities, but also to ensure that the investigators are not over worked. Needless to say, overtime costs may also have an influence on scheduling.

IIC meetings

Team meetings are vital to the IIC's ability to competently manage the investigation. IIC meetings should be held daily during the first few weeks of an investigation and then as required as the investigation progresses. The following are some factors that should be considered when planning team meetings:

- An IIC should plan investigation meeting times that will establish a limit to the work day for all investigation team members; establishing firm times and mandatory attendance for meetings will help in that regard. Other factors to be considered are the potential loss of perishable evidence, daylight hours, travel time, briefings, interviews, etc. At the TSB, investigation progress meetings are scheduled at about 1900 hours and at 0800 hours.
- IICs must have a concise, consistent, and specific plan for all meetings and should follow the plan. Doing so will enhance the IIC's credibility and will be the catalyst to effective participation by others. For the most part, attendees at the meeting should be limited to the active participants in the investigation.
- The focus of the team meetings should be on group chairman presentations on the following points: the completed elements of the investigation plan, the significant facts determined, the safety issues under consideration, the proposed adjustments to short-term and long-term group investigation plans, the resource requirements and implications, and any assumptions and analysis—but only if they are required to support of safety issues and changes to the group investigation plans.

The objectives of these of investigation team meetings are the proper assessments of the progress of the investigation, and the validation of the team, and group investigation plans for the following day(s). In this regard, the success in managing the investigation will hinge on the IIC's decisions made as the result of these meetings.

A factor that will play an important role in the effectiveness of the IIC team meetings is the effectiveness of communications within and between the investigation groups. The IIC should encourage that investigation group meetings, as well as intergroup liaison and communications, take place regularly before investigation team meetings.

Communications, communications, communications

The AAIA major investigation plan should document the responsibility for communication between the investigation team and senior management, and within the AAIA executive. In this regard, the IIC would be the logical link between the investigation team and management. At the TSB, the IIC is required to communicate internally with the DOI on a daily basis and whenever a significant issue arises that requires higher level advice or support.

The plan should document who within the AAIA will be responsible for external communications with involved organizations and people with a direct interest in the investigation, such as crew, passengers, next-of-kin, and the news media. In the Canadian context, the IIC is the spokesperson on investigation matters. Although a public relations coordinator and families liaison coordinator may be assigned to the investigation team, the IIC must consider and must make time available for external communications tasks.

In particular, during the first week(s) of a major investigation, the external communications tasks have the potential to be overwhelming, and resources outside of the AAIA, including media specialists, may be needed.

Expect surprises

There will always be some surprises during an investigation so the IIC and management should expect them. When surprises happen, IICs must remain calm and not jump to judgment or conclusions quickly. Also IICs must not take on tasks that are beyond their responsibilities or beyond the capabilities of the investigation team.

Managing critical issues

The IIC of a major investigation will frequently encounter critical issues that need prompt handling. Good management principles suggest that establishing a separate project team may be best way to handle this "unplanned for" event. The disposition of the issue should be based on whether the issue is critical to the safety investigation and whether the existing investigation team can take on the issue without adversely affecting the progress of the investigation.

The AAIA's MORP and MOIC should include guidelines to assist in decision-making for this type of event. In some cases, the best solution may be to assign a separate project leader reporting to someone other than the IIC.

Managing investigation creep

Throughout the investigation, the scope and depth of the investigation will have to be re-evaluated, in particular when a lack of resources will dictate that the investigation team cannot investigate all deficiencies or ambiguities discovered during the investigation. In such situations, hard decisions will have to be made. Important criteria for these decisions should be the relationship of the potential investigation area with the identified safety significant events of the occurrence, as well as on the potential of the additional investigation work to result in significant enhancements to aviation safety.

Possible decisions include the following: aggressively pursuing the proposed area of investigation, with the probable consequence of limiting other aspects of the investigation or delaying the overall investigation; setting aside the proposed area of investigation; or delaying the decision. There also will be situations wherein the investigation has already reached positive conclusions and validated a safety deficiency, to the point that a recommendation to conduct further technical or operational analysis can be passed on to the responsible authority[4].

The pressures for an investigation team to investigate everything and the concern that not doing so may put the AAIA's reputation at risk will always be present on a major investigation. Consequently, the AAIA should plan for this problem area and have a decision-making process that includes documenting the decisions made and the supporting rationale.

Conducting lessons learned

Another important part of enhancing the readiness of an AAIA to conduct major investigations is having a process to learn from past experience. In this regard, the TSB conducts a post-investigation wrap-up meeting to review of the lessons learned during the investigation. This review evaluates the adequacy of investigation standards and procedures; evaluates the effectiveness of the investigation team organization, planning, procedures, and processes; reexamines the problems encountered and the effectiveness of the actions taken to resolve the issues; and evaluates the safety actions taken by the AAIA, regulators, and industry as a result of the investigation and its report. The review is expected to result in recommendations for improvements for future investigations.

To enhance the effectiveness of this review, investigation team members are encouraged throughout the investigation to record both positive and negative lessons learned and ideas for improvements. This review includes all parts of the AAIA that supported the investigation, and rather than waiting for the end of the investigation, corrective action is taken on all significant issues as soon as they are recognized.

Air France A340 runway-overrun investigation experience

On Aug. 2, 2005, the crew of Air France Flight 358 (AF358), an Airbus 340-313, French registration F-GLZQ, Serial Number 289, conducted an approach to Runway 24L at the Toronto/Lester B. Pearson International Airport (LBPIA), Ontario, Canada. At 1602 eastern daylight time, the aircraft landed long, overran the end of the runway, and came to rest in a ravine just outside the airport perimeter. There were no reported dangerous goods on board the aircraft. An ensuing fire destroyed the aircraft. Two crew members and nine passengers received serious injuries. The Transportation Safety Board of Canada (TSB) was notified within minutes of the accident by air traffic control (ATC) services provided by NAV CANADA at LBPIA. The TSB Ontario regional office responded immediately by notifying the head office and by sending investigators to the site.

Based on the profile of the accident, the decision was made to establish a major occurrence investigation team. The immediate decision was to assess the types of investigation expertise required and the level of expertise available within the TSB and then determine the types of expertise required and the sources from which that expertise could be acquired. For example, although the TSB had investigated a number of occurrences involving Airbus products and large passenger aircraft, it did not have any specific operational or technical expertise on the A340 aircraft. To fill this requirement, the TSB used the expertise of Airbus, Air France, and the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) of France. Another example is that although the TSB had one cabin safety specialist investigator, it was readily apparent that additional resources would be required. In addition to the expertise that would be available from Airbus and Air France, the TSB requested additional support from the National Transportation Safety Board (NTSB). Another example of another source from which expertise was acquired was the Aircraft Accident Investigation Branch (AAIB), which, in response to a TSB request, supplied expertise for the Engines Group and the Weather Group.

The TSB deployed a major occurrence investigation team to the site within 12 hours of the accident. The team for the field phase of the investigation comprised 35 TSB investigators, supported by accredited representatives from the BEA and the NTSB, and 43 observers from the following entities: Transport Canada, the Federal Aviation Administration (FAA) of the United States, NAV CANADA, Air France, Airbus, General Electric, the UK AAIB, Goodrich Corporation, the Peel Regional Police, and the Greater Toronto Airport Authority (GTAA). The field phase of this investigation was completed in 14 days. On August 16, control of the site and Runway 24L was returned to the airport authority.

The lessons already learned from this portion of the investigation were significant in a number of areas. First, there was no question that having previously established relations with the airport authority, local police, and NAV CANADA, and having participated with these entities in disaster response exercises greatly enhanced the initial responses by the TSB and the other agencies. Also, knowing each others' requirements greatly facilitated cooperation and coordination of activities at the accident site. Second, having work experience and close relationships with BEA, NTSB and the AAIB and in-depth knowledge of each others' legislation, investigation procedures, and expertise resulted in ensuring that needed expertise and support were immediately made available to this investigation.

The TSB has also learned lessons as the result of problems encountered during the field phase of the investigation. The first problem area that came to light was related to site security and site safety[5]. In this regard, within weeks following the completion of the field phase, the TSB examined the problem areas, and in part, determined that the there were weaknesses in the delineation of responsibilities for both site security and site safety. In addition, the responsibility for the applicable checklist had been assigned as a secondary duty to an individual who was heavily tasked with the management of other technical areas of the investigation. The resolution of this problem area, in part, has resulted in separating these two areas of responsibility and the establishment of a new checklist, procedures, and forms for formally transferring the control of accident site between the TSB and other authorities.

Conclusion summary

As I mentioned at the start of this paper, managing a major investigation is not rocket science. Notwithstanding, being able to competently conduct a major investigation requires comprehensive planning. Competent investigation management is the corner stone to a successful and effective investigation. Unfortunately, I could not cover all aspects of investigation management in this paper; doing so would have resulted in a very large document. Consequently, I highlighted organization readiness, the importance of documented major occurrence response plan and checklists, and the need for AAIAs to augment their resources using non-AAIA personnel. I particularly emphasized the need for the AAIA to plan the involvement of safety partners in its major investigations and to prepare its staff and potential safety partners for such an engagement.

This paper also covered some important aspects regarding the response to a major occurrence, concentrating on an AAIA's initial response, on selected aspects of managing the field investigation, and on the importance of having a process to learn from both the successes and difficulties encountered during the investigation.

The last element of my paper dealt with TSB's recent experience during its response to the Air France 358, Airbus A340-313, runway-overrun accident that occurred in Toronto, Canada, on Aug. 2, 2005. Although this event challenged the TSB, our success confirmed the importance of our readiness, plans, checklists, procedures, and approach to investigation management.

I hope that this paper will be of benefit to other state accident investigation authorities, as well as any other entities that may become involved in a major aircraft accident investigation.

As a final note, if you require additional information on managing major investigations, do not hesitate to contact me directly: phone: 613-994-3813, cellular: 613-286-4348, facsimile: 613-953-9586. Alternatively, you can go to the TSB website (http://www.tsb.gc.ca), where additional information on TSB legislation, policies, investigation process, occurrence reports, recommendations, subscription services, and statistics is readily available. TSB manuals are also available on request. ◆

Endnotes

1 The terms "stakeholder" and "safety partners" in this paper represent the various states and organizations that have a safety interest in the investigation and have the expertise necessary to contribute to the AAIA's mandate to advance aviation safety.

2 In the *Canadian Transportation Accident Investigation and Safety Board Act*, the term "observer" is defined in part as "a person" who "is invited by the Board to attend as an observer because, in the opinion of the Board, the person has a direct interest in the subject matter of the investigation *and* will contribute to achieving the Board's object." (Other wording in the Act recognizes accredited representative entitlements contained in ICAO Annex 13.)

3 Although all the specific positions listed in the MOIC may not be staffed for every investigation, the checklists established for the deputy IIC, operations lead, technical lead, safety analysis (safety action) coordinator, family liaison coordinator, and investigation team administration office facilitate the monitoring and management of those functions associated with the investigation.

4 For example, as part of the ongoing TSB investigation (A04F0047) into the March 6, 2005, Air Transat Flight 961 A310-300 loss-of-rudder event, the Board determined that the current inspection program for Airbus composite rudders might not ensure the timely detection of defects, and that delamination could grow undetected and the increasing age of the composite rudders suggest that increased attention is warranted. As a result, the Board issued recommendations A06-06 and A06-06 for authorities to continue to research the problem area.
... that the Department of Transport and the European Aviation Safety Agency, in coordination with other involved regulatory authorities and industry, urgently develop and implement an inspection program that will allow early and consistent detection of damage to the rudder assembly of aircraft equipped with this type of rudder.

5 At the time of the accident, in the TSB MOIC, these two areas of responsibility were assigned to the "site coordinator/safety officer."

A Safety Issue Investigation into Small Aircraft Accidents Resulting in Post-Impact Fire: The Experience, Techniques, and Lessons Learned

By William R. (Bill) Kemp, Senior Technical Investigator, TSB Canada

1.0 Introduction

1.1 Safety issue investigation

A safety issue investigation examines multiple transportation occurrences that are indicative of significant unsafe situations or conditions in order to confirm a particular safety concern, make recommendations to mitigate the concern, and advance transportation safety. The Air Branch of the Transportation Safety Board of Canada (TSB) recently undertook a safety issue investigation (SII A05-01) into 521 aviation accidents that occurred in Canada between 1976 and 2002, inclusive and involved aircraft weighing 5,700 kilograms or less, which resulted in post-impact fire (PIF). The overall significance of small aircraft PIF would not have become apparent through individual occurrence investigations, and the conclusions and recommendations could not have been supported by any other investigative means. While the investigation identified that PIF continues to present a great risk to occupants of small aircraft and that there is evidence to support safety action, the results were limited by weaknesses in the quantity and quality of supplemental accident data in aircraft accident files and databases.

This conference paper will describe the methodology used for this safety issue investigation, identify the data deficiencies that were encountered, discuss factors that may contribute to data deficiencies, and propose options for improvement. The experience, techniques, and lessons learned from this investigation could benefit future small and large aircraft safety issue investigations.

The safety issue investigation report (SII A05-01), titled *"Post-Impact Fires Resulting from Small Aircraft Accidents,"* including recommendations, is expected to be public and available on the TSB website at http://www.tsb.gc.ca/ before the International Society of Air Safety Investigators (ISASI) conference in September 2006.

Bill Kemp is a senior technical investigator with the Transportation Safety Board of Canada (TSBC). He began his aviation career in 1971 and worked as a flight instructor, a fixed-wing charter pilot, and an aircraft maintenance engineer prior to joining the Canadian Aviation Safety Board in 1988. He is experienced in all categories of fixed-wing and helicopter accident investigations. Bill holds a BA with distinction in anthropology, with a psychology minor, from the University of Alberta and has a specific interest in aircraft crash survival. He works out of the TSBC Western Region Office, in Edmonton, Alberta.

1.2 History of events leading to the investigation

On May 30, 2000, a Cessna 177B Cardinal, being operated VFR under CARs 703 air taxi rules, struck trees and crashed following takeoff from the Calling Lake, Alberta, aerodrome (reference report A00W0109). An intense fuel-fed, post-impact fire ensued, which destroyed the aircraft. The pilot sustained fatal injuries due to the thermal effect of fire, and the passenger sustained fractures and serious burns. The accident demonstrated that PIF continues to pose a risk to small aircraft occupants, and the investigation identified the lack of fuel system crashworthiness standards as a small aircraft safety deficiency.

During the investigation into this accident, the TSB Aviation Safety Information System (ASIS) database was queried to determine the number of similar small aircraft PIF accidents that had occurred in Canada. ASIS is the electronic repository for all Air Branch accident and incident data. It is an Oracle-based system that comprises both data fields and free-text fields. Information can be retrieved from the database by searching the data fields with ASIS Query tools, and information in the free-text fields can be searched with text search tools such as Fulcrum.

In year 2000, ASIS contained records of approximately 14,000 small aircraft accidents, going back to 1976. The initial query of the events (fire) and phases (post-impact) fields of ASIS revealed 43 PIF accidents. This number was unexpectedly low, which indicated that PIF had not been entered as an event and phase for all PIF accidents. A higher-level query identified 86 PIF accidents, which, based on corporate knowledge, was still very low. As a follow-up, all ASIS initial notification summaries and all electronically formatted small aircraft accident reports were searched for words like “burn,” “fire,” “flame,” and “explosion.” This search isolated approximately 800 accidents. The initial notifications and final reports for these occurrences were reviewed one by one to confirm that PIF had occurred. Accidents involving inflight fire were excluded, as were non-PIF accidents that had been identified through use of words like “back fire” and “exhaust flame.” Ultimately 521 Canadian accidents involving 523 small aircraft were identified as having resulted in PIF. This was over tenfold the number that had been recovered from ASIS during the initial query.

In light of that finding, the Board identified a need to determine the extent to which safety deficiencies contribute to the risks associated with PIF in otherwise survivable accidents and the risk control options available to mitigate those risks.

2.0 Methodology

2.1 Literature review

The initial phase of the investigation consisted of a literature review to determine the extent to which PIF had been addressed by accident investigation agencies and regulators in the past, to evaluate the success of previous efforts, and, in short, start where other people left off. The literature review uncovered a chronicle of efforts by accident investigation agencies, regulators, and academics to identify the risks associated with PIF and to reduce that risk. The record included special studies, reports, recommendations, and notices of proposed rulemaking.

As far back as 1971, the Flight Safety Foundation had identified the small aircraft crash fire hazard as one of the critical problems in flight safety. The study established that if an accident resulted in fire, there are almost two chances out of three of a fatality, while without fire the chance of fatality dropped to one in ten. The report concluded that elimination of fire would substantially improve safety (Hoekstra and Huang 1971).

Between February 1976 and June 1977, the United States Federal Aviation Administration (FAA) sponsored a project to demonstrate the crash performance of light-weight, flexible, crash-resistant fuel cells in combination with frangible fuel-line couplings in fixed-wing aircraft. Three full-scale crash tests were performed by catapulting Piper Navajo airframes into an earthen hill. The report concluded that light-weight, flexible, crash-resistant fuel cells used with self-sealing frangible fuel-line couplings could effectively reduce post-crash fuel fires in general aviation aircraft equipped with wing tanks (Perella, W.M. 1978).

The United States National Transportation Safety Board (NTSB) published a special study in 1980 titled *General Aviation Accidents: Postcrash Fires and How to Prevent or Control Them* (NTSB-AAS-80-2). The study revealed that PIF occurred in approximately 8% of general aviation accidents. The final report included six recommendations (A-80-90 to A-80-95) aimed at reducing the incidence of PIF. The recommendations called for changes in airworthiness regulations, funding for further research and development, and assessment of the feasibility of retrofitting existing aircraft.

The General Aviation Safety Panel, a committee of knowledgeable volunteers from the general aviation community that was formed in the early 1980s, had also submitted recommendations to the FAA. The recommendations proposed requirements to reduce fuel spillage in specified areas of aircraft and for tanks in defined locations to meet specific crashworthiness criteria. The recommendations also proposed that the FAA investigate additional means to reduce fuel spillage from tanks in general and prepare an advisory circular to identify acceptable means for compliance with regulations pertaining to fire-resistant fuel systems.

Small aircraft PIF had also been addressed in a number of studies by individuals and non-governmental groups. Jennings and Mohier (1988) had described how progressive improvements in crash protection technology, including fuel tank placement and the use of internal rubber fuel bladders, had reduced the incidence of PIF in Indianapolis Motor Speedway accidents, and proposed that many of the crashworthiness technological advances were directly transferable to aircraft. Li et al. (1996) had studied the epidemiology of aircraft fire in commuter and air taxi crashes and had concluded that aircraft fire was most likely when a crash occurred at night, in a non-airport location, and in instrument meteorological conditions, which often thwarted rescue and firefighting efforts. Li et al. (1999) had noted that general aviation accounts for the majority of aviation crashes and casualties in the United States and that better occupant protection equipment, such as air bag and crashworthy fuel systems, were needed for general aviation aircraft. Bensyl et al. (2001) had concluded that post-impact fire was the strongest predictor of fatality for pilots involved in work-related aircraft crashes in Alaska between 1990 and 1999, and that fuel systems that could more effectively withstand impact forces and keep from igniting in crash conditions would lessen the number of PIF accidents.

2.2 Previous notices of proposed rulemaking

In 1985, the FAA had announced its intent to incorporate airworthiness standards for crash-resistant fuel systems into FAR 23 aircraft in an advanced notice of proposed rulemaking (ANPRM). The purpose of the ANPRM was to solicit public comment regarding needed regulatory changes and their costs. In a response to the ANPRM, the NTSB reported that about 14% of the fatally injured occupants in fire accidents could have survived had there been no fire and that about 26% of the seriously injured occupants in accidents with fire could have been injured less severely had there been no fire.

The FAA had issued NPRM No. 85-7A, titled 14 *CFR Part 23, Airworthiness Standards; Crash-Resistant Fuel Systems* in February 1990. The NPRM had proposed changes to FAA Part 23 airworthiness standards to enhance fuel system crash resistance in normal, utility, acrobatic, and commuter-category aircraft. The NPRM focussed on fuel containment during crash conditions and did not address elimination of crash-induced ignition sources. The NPRM was withdrawn in December 1999 following review of comments received from 17 respondents. The withdrawal notice stated that the FAA had completed a revised economic evaluation of the safety recommendations as a result of the comments received and concluded that the costs of the proposed changes were not justified by the potential benefits. The withdrawal notice also discussed the concerns expressed in the comments received, including the need for a definition of a "survivable" crash, the reliability of self-closing devices in fuel lines, the preference for an objective test for fuel tanks rather than mandating the use of flexible bladder tanks, and the inability to apply selective standards based on aircraft types. Since the withdrawal of NPRM 85-7A in 1999, there had been no tangible action by regulators to address the issue of crashworthiness as it related to PIF in small production fixed-wing aircraft through certification change.

In contrast, NPRM 90-24, *Airworthiness Standards; Crash Resistant Fuel Systems in Normal and Transport Category Rotorcraft*, was issued in 1990. This was essentially the helicopter version of NPRM 85-7A. NPRM 90-24 proposed to add crash resistant fuel system (CRFS) design and test criteria to the airworthiness standards for FAR 27 (normal category) and FAR 29 (transport category) helicopters. In 1994, after approximately 4 years of deliberation, the FAA issued the final rule for NPRM 90-24, which mandated CRFS standards for newly certified helicopters. This was one of the most significant certification improvements in the history of civilian helicopter development. Fuel systems in helicopters certified subsequent to 1994 were required to meet drop-test criteria and specific load factors, and required design features such as self-sealing breakaway couplings and frangible or deformable structural attachments. Fuel was required to be located as far as practicable from occupied areas and from potential ignition sources, and rigid or semi-rigid fuel tank or bladder walls are required to be impact and tear resistant. NPRM 90-24 did not address retrofitting of previously certified helicopters.

The literature review confirmed that small aircraft PIF was a continuing safety concern and that the risks were well-known. While the helicopter industry had addressed the problem in a practical way in newly certified models, past actions by the NTSB and FAA to promote tenable change in small aeroplanes had been unsuccessful, due to negative cost-benefit analysis (CBA).

2.3 Examination of available injury and pathology data

The next phase of the investigation consisted of examination of injury and pathology records to identify accidents where fire had contributed to injury and fatality. Requests were submitted to access archived paper files; in a small number of cases the occurrence file could not be found.

Tombstone data, including the numbers of serious injuries and fatalities, had been recorded in all cases; however, many files were incomplete, omitting burn vs. impact injury and pathology data, most notably due to missing victim autopsy reports, registrations of death, or detailed injury descriptions. Passenger data were more incomplete than flight crew data. In addition to the general lack of reference to injury detail, the names of passengers often had not been recorded. In these cases, newspaper archives were searched to recover the missing names to facilitate requests to medical examiners and coroners. Medical examiner and coroner records could only be recovered by reference to a correctly spelled name, not by accident date or location. Where necessary, requests were forwarded to chief medical examiners and chief coroners across Canada for historical pathological records that were missing from the occurrence files.

The review of these records required a lot of good, old-fashioned manual detective work. The extent to which fire contributed to fatalities was determined solely by reference to cause-of-death statements on available autopsy reports, coroner investigation statements, and/or registrations of death. Fire-related serious injuries were identified by a review of occurrence summaries, survivor interviews, investigator notes, newspaper clippings, and/or final reports. For each accident, the injuries and fatalities were recorded as impact related or fire related on an Excel spreadsheet, to differentiate the accidents that were impact survivable from those that were not.

Collectively, the 521 PIF accidents had resulted in 728 fatalities and 231 serious injuries. Cause of death was undetermined for 129 of the 728 fatalities. Fire or smoke inhalation was identified as either partly or solely the cause of death or serious injury in 128 of these accidents. These 128 impact survivable accidents had accounted for, at minimum, 205 fire-related fatalities (nearly 30% of the 728 fatalities) and 80 fire-related serious injuries (nearly 35% of the 231 serious injuries).

2.4 Identification of unsafe conditions that contributed to PIF

Core accident data for the impact survivable PIF subset were captured by means of file-by-file examination and entered into a 28,000-cell Excel spreadsheet to identify the common unsafe conditions that had contributed to the fire-related injuries and fatalities. The unsafe conditions contributed or likely contributed to at least one fatality or one serious injury in the associated accident, as evidenced by the corresponding occurrence file, database or occurrence report. One hundred ten potentially unsafe conditions were grouped under four broad categories on the spreadsheet: "IGNITION," "COMBUSTIBLE MATERIALS THAT BURNED," "EGRESS," and "FIRE SUPPRESSION." A "0" was entered in the appropriate cell where an unsafe condition was deemed not to have contributed, a "1" was entered where an unsafe condition contributed, and the cell was left blank if it was unknown if an unsafe condition contributed. The data on the unsafe conditions spreadsheet were gathered entirely from a review of the files, and no accidents were reinvestigated. The unsafe conditions were not mutually exclusive; for example, a file may have indicated several possible ignition sources or several possible combustibles.

During the process of reviewing the subset files to record common unsafe conditions, it became clear that in many cases the data necessary to identify safety deficiencies that contribute to PIF in impact-survivable small aircraft accidents had not been adequately documented or addressed. Accident characteristics such as speed and angle of impact had not been recorded in sufficient detail to be of any use. As well, during recent years, many small aircraft occurrences had been recorded as Class 5 occurrences. By definition, Class 5 occurrences are not investigated; however, data are recorded "in suitable scope and detail for possible safety analysis, statistical reporting, or archival purposes." Overall, the PIF data for Class 5 occurrences was extremely limited.

2.5 Review of the cost-benefit analysis for NPRM 85-7A

In light of the finding that NPRM 85-7A had been withdrawn due to negative CBA, two University of Alberta Transportation economists were contracted to examine the current process of aviation economic analysis, including CBA, and to assess the effect of that process on decision-making in the application of risk control options that are available to mitigate PIF risks. Their report was titled "*A Review of the Process of Economic Analysis into Risk Control Options for Mitigation of Post-impact Fire Risks for Aircraft with a Maximum Certified Takeoff Weight of 5,670 Kilograms or Less*." The report reviewed the process of economic analysis followed in the United States to assess aviation safety measures and offered a preliminary analysis of the potential benefits of post-impact fire risk control measures (PIFRCMs) in terms of lives saved in Canada.

The report concluded that the U.S. guidelines on economic analysis generally, and cost-benefit analysis specifically, are commendable. The only apparent defect is that $3 million for value of a statistical life (VSL) is low by about a factor of two relative to recent empirical estimates. The report also concluded that a detailed cost-benefit analysis may be warranted for specific PIFRSMs, using the new and comprehensive TSB database of small aircraft post-impact fires.

2.6 Preparation of final report and Board process

In all of the 128 accidents where PIF contributed to serious injuries or fatalities, the aircraft occupants were in close proximity to fire or smoke for some time following the impact. The investigation identified four essential conditions that had to be in place for this to occur—

1. There was an ignition source in proximity to a combustible material, such as fuel.
2. There was combustible material in close proximity to the occupants.
3. Occupant egress was compromised.
4. The fire was not suppressed in time to prevent fire-related injuries or fatalities.

A confidential draft report was prepared and forwarded to major interested parties whose interests may be affected by the report, for comment, and all comments were considered prior to final Board approval of the report.

3.0 Databases

3.1 Data and information

The terms "data" and "information" are often used interchangeably; however, database designers assign them distinctly different meanings. Data are characteristically defined as raw, unsummerized, and unanalyzed facts, while information is data that have been processed into meaningful knowledge. In the context of safety issue investigations, data from multiple occurrences are the raw material for the investigation and information is the product, in the form of a report and recommendations. Accident databases capture both quantitative data, which are represented mostly by variables recorded numerically, and qualitative data, which are represented mostly by variables recorded in text or imaging form.

3.2 Other references to data deficiencies in aircraft accident databases

The literature review turned up numerous references to data deficiencies limiting the results of aviation safety studies. The 1971 Flight Safety Foundation report noted that while a considerable effort had been devoted to studies of crashworthiness, there was very little specific information in the reports of fatal accidents in general aviation as to the cause of death. The report suggested that more complete and concise reporting would aid in developing design changes and improved standards (Hoekstra and Huang 1971).

In 1987, the FAA published a report titled *"Study of General Aviation Fire Accidents (1974-1983)."* The report described patterns of post-impact and inflight fire accidents involving general aviation aircraft and documented the application of various interior materials used in those aircraft. The primary source of accident information for the study was the computerized accident data system of the NTSB. The report concluded

"Overall, data regarding general aviation fires was found to be scarce and often inaccurate. Recent changes in the investigation program of the FAA and NTSB promise to improve the collection of data on fires; however, improved computer handling and access processes need to be developed to ensure the data is not modified during entry and that it is more easily and flexibly accessible."

In 1997, Li and Baker (1997) reported that injuries sustained from aviation crashes have not been well documented at a national level and concluded that the full importance of PIF may be underestimated.

Formal and informal communication with NTSB aviation accident investigators during the course of the PIF safety issue investigation identified similar deficiencies in the investigation and documentation of small aircraft PIF accidents in the United States. A request was forwarded to the NTSB for statistics relating to small aircraft PIF rates and to the number of fatalities where fire contributed to death in the United States during the most recent 10 or more years. Five years of limited data was provided. Between Jan. 1, 1998, and Dec. 31, 2002, there were 1,368 fatal accidents involving small aircraft in the United States. The number of PIF accidents was not identified, and the number of fire-related fatalities could not be fully determined because database files pertaining to PIF accidents had to be researched individually to determine the cause of death, and in many cases no cause of death information had been recorded. To the extent that the available data was examined, 9 fatal accidents where fire had caused or contributed to fatalities were identified, and the total number of fatalities in those 9 accidents was 16, including one individual who was on the ground near the impact site at the time of the accident. These results are considered highly conservative, due to incomplete data.

As recent as 2005, Haden et al. (2005) reported the primary limitation in their study into the effectiveness of crash-resistant fuel systems in civil helicopter accidents was the lack of information in the NTSB database to determine severity of impact. The authors reported that the NTSB database contained little or no specific data on injuries sustained by occupants, a lack of data related to the performance of personal protective systems such as seats and restraint systems, and virtually no data related to the type of fuel system or its performance in a crash.

Concerns regarding injury and fatality data deficiencies have been expressed in large aircraft safety studies as well. In 1996 the European Transport Safety Council (ETSC) published a report that examined ways to improve occupant survivability in accidents involving large aircraft, through improvements in occupant protection, fire survivability, and evacuation. The report stated that improving survivability would necessitate comprehensive review of all promising options available to regulators and industry. The report also stated

"A fundamental limitation to this process, however, is the lack of adequate accident information from a sufficient number of accidents to allow a full cost benefit analysis to be performed. The absence in many accident investigations of detailed information on injury mechanisms and cause of death makes the precise estimation of the potential benefits of any one measure very difficult."

In 2002, Robertson et al. (2002) reported on the results of a study, funded by the FAA, of transport airplane crash-resistant fuel system (CRFS) technology, and on the efforts that have let to the highly successful military CRFS, which has saved many lives and reduced the costs of accidents. The following quotation is an excerpt from the Executive summary of the report:

"*A review of the available accident data is of little help in establishing the level of current fuel system crash performance. Although the occurrence of fire is reported in accident reports, the number of fatalities caused by fire, as opposed to impact, is often not available or is unreliable. The effect of the crash on the fuel system and its components is not reported. Similarly, the reports on structural damage are inadequate to establish crash vectors, crash forces, structural displacements, and other necessary struc-*

tural behavior patterns. The inadequacy of current available crash data underscores the need for the training of field investigators in specific crashworthiness technology and data collection."

3.3 Challenges to accident database design

The greatest challenge to accident/incident database design and management is determining what raw data need to be stored. A fundamental question is "Why are we collecting data?" The answer to this question defines immediate and long-term data management goals and identifies what facts have to be systematically gathered and stored in order to meet those goals. The answer may be influenced by a number of variables, including the agency's mandate as defined by governing acts and regulations, the investigation methodologies used by the agency, and the organizational culture. With regard to long-term planning, the answer is complicated by a circular dilemma: the data you need to collect for future use depend on the questions you expect to have to answer in the future, and no one knows what the questions will be 10 years down the road. Data are essentially inert until you have a question. Data are expensive to acquire and store, and storing large amounts of data for no eventual benefit wastes resources. As well, while it is a given that governments like to collect volumes of data, there is little value in duplicating the storage of data already available in other databases. Basic tombstone-type data that are identical to data recorded in other databases, such as those maintained by regulators and ATC agencies, are unlikely to be of any significant value in future safety issue investigations.

An excerpt from a Flight Safety Digest report on Continuing Airworthiness Risk Evaluation (CARE) (1999) provides a straightforward perspective on data management—

"Ideally, a database should be designed only to collect the data that are needed for the task at hand. The resulting database is less expensive to maintain and encourages higher-quality data. Such a database can be gradually expanded or adjusted if needed; thus, adaptability should be considered in database design."

A second challenge is maintaining a high standard of data quality in order to preserve confidence in the data. Data for scientific research must be gathered systematically, in a consistent manner, and recorded accurately. Qualitative data such as events and phases must be captured and recorded uniformly by different investigators. Accuracy, reliability and convenience are enhanced by the use of a common, internationally recognized taxonomy.

3.4 A common taxonomy

Most accident investigation agencies maintain their own independent databases, and there are probably as many different taxonomies for recording data as there are databases. The current International Civil Aviation Organization (ICAO) taxonomy standard is ADREP 2000. While it is unlikely that more than a few databases are entirely ADREP 2000 compliant, the data in non-compliant databases can often be translated into the ADREP format to meet the ICAO accident/incident reporting (ADREP) requirements.

The use of a common taxonomy like ADREP 2000 allows accident and incident data to be recorded in a consistent way and shared worldwide through the web. Other benefits include consolidation of resources, simplified search capabilities, and ultimately a better understanding of representative key issues. The European Coordination Centre for Aviation Incident Reporting Systems (ECCAIRS) recently adopted the ADREP 2000 taxonomy for incident reporting.

ADREP 2000 contains more than 600 data fields that can be filled in either by manual entry or from a predefined list. Each field is assigned an identification number. The structure of ADREP 2000 allows a comprehensive reconstruction of an accident, including events, phases, explanatory and descriptive factors, and human factors. While the classification process with ADREP 2000 has been criticized as being complex and cumbersome to complete, especially for the part relative to human factors, and the risk of generating inappropriate coding remains quite high (European Commission, 2000), the system offers a respectable opportunity to record basic data relative to PIF. By requiring certain supplemental fields to be completed in every case of PIF, using a standard taxonomy such as ADREP 2000, it would be possible to accumulate a credible record of basic PIF statistical data, without a significant outlay of resources. Quantitative data such as the number of injuries and fatalities due to burns, and qualitative data such as potential ignition sources and fire locations, are easily recorded. One minor shortcoming of ADREP 2000 is that it has no taxonomy standard to record injury details such as types and locations of fractures and soft tissue injuries. This could be easily improved by incorporating a recognized medical taxonomy, such as the International Statistical Classification of Diseases and Related Health Problems (ICD), into the system.

Examples of fields in ADREP 2000 that can be used to record data relevant to PIF are provided in Table 1.

3.5 Factors that contribute to injury and PIF data deficits

Several factors contribute to crashworthiness and injury data deficits in small aircraft accident databases. One key factor may be the basic philosophy of accident investigation. ICAO Annex 13 provides guidelines for aircraft accident and incident investigation. Chapter 3 paragraph 3.1 of Annex 13 states

"The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents."

A possible drawback in this logic is that it disregards the potential to improve safety through investigation of post-crash factors such as vehicle crashworthiness and PIF. This induces the mindset of "prevent the accident and you prevent the fire and injury, so let's reduce the risk of PIF through accident prevention." This concept only works up to the point of the next PIF accident. In fact, aviation accidents are expected to occur. Regulators require aircraft to carry ELTs, survival gear, and first aid kits, and to be fitted with robust passenger and cargo restraint systems. There are requirements to file flight plans, to have aircraft rescue and firefighting services (ARFF) available at large airports, and to carry trained flight attendants on large aircraft. These defenses are necessary because accidents are anticipated. Yet, despite the understanding that accidents will occur, there is a strong bureaucratic reluctance to mandating comprehensive engineering improvements to reduce the risk of events like PIF. It is far more effective to prevent PIF than to rely on potential fire

EXAMPLES OF PIF RELEVANT FIELDS IN ADREP 2000

SECTION	ID. #	DESCRIPTION	ENTRY
Fuel	126	Type of fuel used	Manual
Fuel	234	Quantity of fuel on board	Predefined
Information related to the conditions under which a fire started	124	Fire fuel source	Predefined
Information related to the conditions under which a fire started	143	Ignition source of the fire	Predefined
Information related to the conditions under which a fire started	144	Initial location of the fire	Predefined
Rescue fire services aerodrome	52	Aerodrome rescue fire service (ARFS) availability	Predefined
Rescue fire services aerodrome	238	Reasons why the ARFS ineffective	Predefined
Autopsy	218	Categories of persons on whom autopsies have been performed	Predefined
Injury types	101	Fatal injuries caused by burns	Manual
Injury types	103	Fatal injuries caused by fumes or gasses	Manual
Injury types	104	Fatal injuries caused by impact	Manual
Injury types	199	Non-fatal injuries caused by burns	Manual
Injury Types	201	Non-fatal injuries caused by fumes or gasses	Manual
Injury types	202	Non-fatal injuries caused by impact	Manual
Injury types	302	Unspecified injuries caused by burns	Manual
Note	426	Note	Manual
Evacuation	98	Escape time in the evacuation from aircraft	Manual
Evacuation	135	Evacuation hampered by	Predefined
Survivability	284	Survivability in the aircraft	Predefined

Table 1

and rescue services when fire occurs. Clearly accident prevention takes precedent over any other safety initiative; however, in a dedicated effort to investigate and make findings solely to prevent re-occurrence, the investigation community may inadvertently minimize or exclude consideration toward investigating post-accident survivability issues such as PIF to the extent necessary to bring about change.

The second challenge is convincing investigators to obtain and enter supplemental data, such as survival and PIF data, into a database. The traditional standard for small aircraft crashworthiness investigation is to examine the use of restraints, and report if a shoulder harness was or was not available and was or was not used. Inflight fires are investigated to the extent possible; PIF on the other hand is accepted as a fact of life. Data entry above and beyond the minimum required to support an individual occurrence investigation is often perceived as a clerical job, not an accident investigation job. The priority is writing an individual occurrence report that will pass the various levels of review. With the "cradle to grave" approach to small aircraft accident investigation, whereby the investigators themselves are responsible for the investigation, the safety analysis, the report writing, and the safety action, investigator workload for individual occurrence investigations had increased significantly. One result is that investigators are likely to collect more information but tend to input less data into the database.

Ease of data entry will also influence data input. A complex, user unfriendly database that requires significant training, frequent reference to policy manuals, and constant use to maintain data entry skills will be underutilized due to investigator frustration. The easier it is to enter supplemental data, the more likely supplemental data will be entered. As well, investigators need to be convinced of the long-term benefit to collecting and entering non-essential and non-cause-related data, such as types and mechanisms of injury, in order to buy in. If investigators see little or no connection between the reports they are working on and the data they are expected to enter, in other words the data does not contribute to the reports, they will not be motivated to complete the work. Another factor is that managers, junior investigators, and seasoned investigators all tend to see things differently, which leads to different attitudes and values regarding data entry requirements.

Investigators and agencies tend to avoid including details regarding cause of death and injury in final reports due to the sensitive and personal nature of the information. As well, while cause of death data is readily available to investigators in the form of autopsy reports and registrations of death, survivor injuries may be difficult to document properly. While the survivors themselves may be able to describe their injuries in general terms, physicians prefer not to discuss or release details, due to doctor/patient privilege and privacy concerns. Descriptions and discussions of survivable burn, disfigurement, and amputation injuries in public reports may be particularly upsetting to families of survivors. In some countries it may be illegal to include injury details in public reports without consent by the survivor. When injury information is obtained, it can be technically deidentified by not naming the individual concerned; however, if there were only one or two people on the aircraft, it is easy to connect the injury to a specific occupant. Crashworthiness recommendations are weakened without injury details. Because of these complexities, investigators often take the positions that if the injury and fatality information will not be included in the final report, why bother to collect and record it in a database.

One of the reasons for the data deficiencies pertinent to the PIF safety issue investigation may have been that no one recognized the importance of collecting PIF information to the degree necessary to support a safety issue investigation, at the time of the individual occurrences were investigated. Other factors may include a lack of crashworthiness training for investigators and mediocre knowledge of medical terminology.

3.6 Sources of bias in the data analysis of SII A05-01

In addition to the full contribution of PIF to fatalities and serious injuries likely being underestimated in SI A05-01, several sources of bias likely distorted the record of unsafe conditions associated with the accidents in the impact survivable PIF data subset. One potential source of bias relates to the dynamics of PIF. In cases of extreme fire damage, it is difficult to determine where the fire started and how it progressed, due to loss of evidence; hence the unsafe conditions that were easiest to detect or identify would be more prevalent, possibly inflating their importance.

As well, the reference to "did not contribute as an unsafe condition" in the common unsafe condition Excel spreadsheet varied across unsafe conditions so that the frequencies of "did not contribute" could not be directly compared to the frequencies of "contributed." For example, if hydraulic fluid was not the "primary combustible," should spillage or consumption by fire be designated "contributed" or "did not contribute"? As well, because the impact survivable data set had been assembled from many accident records complied over many years by investigators, the absence of data regarding an unsafe condition may have indicated that its contribution was unknown or that it was not applicable.

A third potential source of bias is the former practice of using a paper report form to record basic data vs. the current practice of recording data only on a computer. Prior to 1991, Canadian Aviation Safety Board (CASB) air accident investigators systematically recorded core accident data on paper forms and attached the completed forms to the occurrence file. The report form contained unsafe condition check boxes and text boxes based on International Civil Aviation Organization (ICAO) definitions. The greatest sources of data specific to PIF, in occurrence files assembled prior to 1991, were the pages dedicated to survival data (page 14) and fire data (page 15) in the ICAO forms. Survival data fields documented the number of fatalities from burns and toxic fumes, the effectiveness of evacuation assistance by ground rescue groups, and the evacuation time. Fire data fields documented the extent of fire damage, the identification of combustible materials and probable ignition sources, fire suppression information, distance occupants had to move to clear the fire area, and distance from nearest available fire fighting equipment. ASIS computer screens replaced these forms in the early 1990s, and the extent to which these types of data were recorded declined significantly. Consequently, unsafe conditions associated with PIF, particularly those related to ignition sources, were more extensively reported before 1991. Data prior to 1991 may reflect an overrepresentation of these unsafe conditions due to priming of investigators by the reporting form, or data subsequent to 1991 may underrepresent unsafe conditions as investigators were not cued to check for additional unsafe conditions that may have been present. For many accidents, more than one unsafe conditions from each family (ignition sources in particular) were recorded as contributory and ascribed equal causal likelihood in the occurrence, thereby inflating the apparent prevalence of the less likely unsafe condition.

Finally, the available data were not collected in a consistent manner. As noted above, the original data were recorded by many different investigators over a considerable period of time, within the context of their own perceptions of salient unsafe conditions. That context was unavailable to the safety issue investigation team, and it was not possible to reinvestigate any of the individual occurrences in the data set. Furthermore, seasoned investigators are known to see things differently than junior investigators and all investigators are occasionally guided more by intuition than by science, all of which can result in the identification of different unsafe conditions.

3.7 Initiatives to improve data collection and recording

Computers provide nearly unlimited power to collect data, which has resulted in an explosive growth in data. There are currently a number of initiatives under way that are intended to improve data collection and management within and among various accident investigation agencies and affiliates. Agencies currently making changes include the European Coordination Centre for Aviation Incident System (ECCAIRS), the Commercial Aviation Safety Team (CAST), the NTSB, and the TSB. The TSB initiative is known as the Transportation Investigation Information Management System (TIIMS). This project aims to modernize and improve information management products, services, and productivity tools within the agency. TIIMS will meet the administrative requirements for record keeping within the federal government and will make data retrieval for such things as access to information requests much easier. It will not necessarily improve the input of raw quantitative and qualitative accident data, however, as the modal accident investigation databases remain unchanged. They are simply linked to TIIMS. The supplemental data necessary to support future safety issue investigations will still need to be prioritized, gathered, and entered. If the requirement to enter specific supplemental data for use in safety issue investigations is not identified or justified, or if a data entry process is not user friendly, the there will be little improvement in data collection.

4.0 Discussion

4.1 Safety issue investigation methodology

The approach to this safety issue investigation was to systematically review, record and analyze previously acquired accident data. This approach is entirely retrospective in nature; hence there was no opportunity to revisit accident sites or reinvestigate past occurrences to answer questions that come up during the file review. The safety impact of a safety issue investigation that has followed this methodology, including acceptance of the report and any accompanying recommendations by regulators, is entirely dependent on the type, quality and quality of available data.

An alternative approach is to identify a potential safety issue based on analysis of previously acquired data, place that safety issue on a key issues list, and then investigate that issue thoroughly during future individual occurrence investigations. This allows specified data to be gathered in a consistent manner, over a defined period of time, by the application of an investigation standard specific to each individual safety issue. Following this methodology should result in a high degree of confidence in the collected data; this will result in stronger safety action. The disadvantage is that the number of occurrences in the multiple occurrence data sets will be smaller, compared to the number in the historical database, due to the shorter period of data collection.

The ideal methodology may be a combination of the two.

4.2 Suggestions for improvement

The greatest opportunity for improvement in data collection rests with the need to decide what data needs to be collected to meet defined goals. It is impossible to fill out all 600 fields in a database system like ADREP 2000 for every accident. There is a need for accident investigation agencies, both nationally and internationally, to examine ways to prioritize what basic and supplemental data needs to be collected to support future safety issue investigations and to set priorities on the collection of that data. There is also a need to standardize methods to systematically collect the required data and to implement quality assurance procedures, to maintain a high level of confidence in the data. One significant challenge is predicting what questions will need to be addressed in the future, to best identify relevant data.

There may be benefits to developing database programs that are similar to income tax software programs, whereby data is filed in four easy steps: answer questions to fill out the appropriate fields, have the software review the inputs for errors, correct the errors, and file the data. A system like this provides a built-in quality control.

A third possibility for improving documentation and data collection, especially for secondary issues such as small aircraft PIF, may be to return to paper-based recording of certain supplemental data in the field, then scan the recorded data field into the electronic database using optical character recognition (OCR) software. The potential for improved data collection is evidenced by the fact that during this safety issue investigation, significantly more data was gathered from a review of the pre-1991 ICAO-based paper forms, compared to the post-1991 ASIS records. There are a number of advantages to utilizing hard-copy forms to collect core accident data. The use of a paper format makes life easier in the field. Paper documents are easily portable, they serve as a field checklist, and they provide a basis for consistency in data gathering. The use of a standardized format results in data being gathered in a consistent manner and with reference to a standard taxonomy. During the course of this investigation, it was determined that the ASIS screens containing fields for supplemental PIF data, for the majority of occurrences, had not been utilized sufficiently to provide any useful documentation in the PIF project. As a result, investigators required an inordinate amount of time to identify the accidents that had resulted in PIF to determine the number of fire-related injuries and fatalities and to identify the common unsafe conditions that contributed to those PIF accidents where fire-related injuries and fatalities occurred. The history of incomplete ASIS PIF data entries constituted a corporate safety deficiency.

Universal acceptance of the ADREP 2000 taxonomy system as the standard for database management would go a long way to improving data collection. A "most wanted fields" list, based on the safety issues of greatest importance, would help to prioritize and manage the data input workload and reduce the probability of accumulating insignificant data. Sharing of standardized databases via the Internet may also be easily facilitated by use of a standard taxonomy.

4.3 A straightforward approach to the documentation of PIF

Useful small aircraft PIF data can be collected and recorded with minimal outlay of resources. Documentation of PIF begins by entering PIF as a phase and event in the electronic database, and by stating in the initial notification summary and the final report that PIF occurred. Where PIF has occurred, it is necessary to determine if the accident was impact survivable. A PIF accident is clearly impact-survivable if there are survivors; in this case, record the extent of burn injuries. Where fatalities have occurred, it is important to communicate directly with the responsible coroner or medical examiner as pathologists are not necessarily aviation experts. A coroner or medical examiner will be required to determine the cause of death in every case of accidental or unexpected death. The pathologist's opinion of the medical cause of death is based on the pathological examination. Where PIF has occurred, a thorough post-mortem examination of all fatally injured occupants, to the level permitted by the nature of the remains, is necessary to differentiate fire-and impact-related deaths with certainty. A full autopsy may not required to determine cause of death; however, body X-rays should always be performed to identify patterns of skeletal trauma. In cases where the impact was clearly not survivable, the significance of further PIF investigation is diminished. If it is determined that the accident was impact survivable, then it is necessary to ascertain and document the unsafe conditions that contributed to PIF. Survivor and bystander testimony can be extremely helpful to identify the source and propagation pattern of the fire. Record the type and amount of fuel on board the aircraft, the location of fuel relative to the location of each occupant, potential sources of fuel spillage and ignition, the wind and temperature conditions, and the effectiveness of emergency response. As PIF occurs in approximately 4% of small aircraft accidents, this process to document PIF factors should be required in only about four percent of overall accidents.

5.0 Analysis

By examining multiple aviation occurrences that have similar characteristics, accident investigation agencies may identify combinations of safety deficiencies or unsafe conditions that would not be apparent through individual occurrence investigation and analysis. Whereas an individual occurrence investigation concentrates largely on gathering new data that is associated with the occurrence, a safety issue investigation depends largely on data that already exists. Safety issue investigations can provide strong support for recommendations that may not be otherwise possible and are a reliable source of data for cost-benefit analysis. There is a safety implication concerning the quality of data available for cost-benefit analysis: conservative or inferior data can negatively bias the result, which precludes safety action. No organizations are better suited to collect and record this data than accident investigation agencies that have complete and timely access to the data, and there is no better time to acquire the data than during investigations into individual occurrences.

The objectives of the PIF safety issue investigation were to determine the extent of fire-related injuries and fatalities in 521 PIF accidents, identify the common unsafe conditions that contribute to PIF, and identify the control options for mitigating the risks associated with this type of occurrence. The data that were essential for this investigation were data that pertained to post-impact aspects of the accident, rather than data that had been accumulated to make findings as to the cause and contributing factors. The data collected and analyzed indicated that there is a significant risk for PIF and fire-related injuries and fatalities in small aircraft accidents and that past attempts to change certification requirements had been unsuccessful. The fact that the NTSB had reported in 1980 that about 14% of the fatally injured occupants in fire accidents could have survived had there been no fire, and that about 26% of the seriously injured occupants in accidents with fire could have been injured less severely had there been no fire, while corresponding TSB figures are 30% and 35%, indicates a weakness in the earlier data. The data weakness may have contributed to the cost-benefit analysis (CBA) conclusions to disregard the safety action proposed in NPRM 85-7A.

There are at least three lessons to be learned from this safety issue investigation. Lesson one is that while tools are in place to record critical supplemental accident data, such as injury and survival data, that data had often not been recorded in sufficient quantity or quality, especially in the electronic database, to be of value. This concern has been raised in numerous other safety studies. Lesson two is that the safety deficiencies that contribute to PIF in otherwise survivable small aircraft accidents had also not been well recorded in the electronic database in the past. This indicates that the administrative defenses to limit, reduce, or prevent the problem of incomplete data entries either did not exist or were inadequate. Lesson number three is that there were several sources of data bias in the data analysis, which may have distorted the record of unsafe conditions associated with the impact-survivable PIF accident set. All of these lessons identify shortcomings to basing a safety issue investigation on limited, previously acquired data, and imply that there are advantages to following alternate methodologies.

Multiple occurrence data are the raw material for safety issue investigations; therefore, data quality and quantity are critical to the success of a safety issue investigation. At a time when it is becoming more and more difficult to convince regulators that further changes are necessary to improve aviation safety, especially in the area of engineering improvements to enhance survivability, it is more important than ever to collect and record the right high-quality data. The tools such as hardware, software, and taxonomy are available. Safety issues such as PIF have international implications; thus, there is a need for the international community to become involved in setting priorities for data collection, and to look at better ways to collect the right data. The specific nature of accident investigation makes it easy to collect too much of the wrong data, which wastes resources and diminishes the opportunity to advance safety.

The message for accident investigation agencies is clear: weak data is a data management problem, not a hardware or software technology problem. Computer technology is cheap; the manpower required to catalogue data is not. Data relevance is the key; more is not necessarily better. The specific nature of accident investigation makes it easy to collect insufficient amounts of data or too much of the wrong data; either way wastes resources at either the input or output end of the data spectrum and diminishes the opportunity to advance safety. The message for managers and investigators is also clear: data is only useful if it is available in a database and if it can be turned into helpful information. That data becomes important to others when they can use it to support their own investigations and safety recommendations.

As with all enterprises, aviation accident investigation is constantly evolving as new challenges and new technologies appear. We may have reached a point in that evolution where the benefits of individual occurrence investigations are diminishing and the benefits of multiple occurrence safety issue investigations need to be explored. In order to move away from the traditional mindset of identifying causes and contributing factors based only on individual occurrence investigations and dedicate more resources to safety issue investigations, we need the right data. Success in safety issue investigations can only be achieved through improved data management.

6.0 Conclusions

This PIF safety issue investigation exposed weaknesses in data quality in aircraft accident databases. The problem may be more widespread than currently recognized. Weak and incomplete supplemental accident data reduces the ability of accident investigation agencies to identify safety deficiencies and make recommendations and ultimately places the aviation community at greater risk for the recurrence of similar accidents. Deficiencies in supplemental injury and fatality data also compromise the ability of regulators to conduct accurate cost-benefit analyses. There is a need for the international community to examine ways to prioritize what basic and supplemental data needs to be collected, set priorities on collection of that data, and standardize a method of systematically collecting the data to effectively support future issue-based safety investigations at a collaborative international level. Additional analytical studies are necessary to identify the extent to which accident investigation database deficiencies are constraining overall safety improvement and to suggest practical improvements. The members of the International Society of Air Safety Investigators (ISASI) may be able to promote these initiatives. ◆

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Investigation into Turbulence-Related Accidents

By Gary R. Morphew, Director, Aircraft Accident Investigation, Southern California Safety Institute

Background

As an instructor and as an aircraft accident investigator, I have been trying to review all kinds of accident reports in order to improve my own knowledge and pass on meaningful investigation techniques to my students.

When I became an investigator, as a pilot, I understood fully the scrutiny that would be placed on the pilot flying the aircraft as well as the crew's interaction during the events that followed. By fully exploring the pilot's actions and inactions, we have, over the years, improved training, perceptions, and communication, and this has resulted in a reduction in the accident rate. We have moved far beyond "pilot error" and have found many factors that lead to the error in the first place.

Until I joined SCSI, however, I had not spent too much time looking into the role of the flight attendant other than as a valuable member of the crew during evacuations and emergencies. Now, with my association with the annual International Aircraft Cabin Safety Symposium, I have a different appreciation and, to be honest, some concerns over the analysis of the flight attendant's role in reported accidents.

In the summer of 2005, I was reading a synopsis of an NTSB investigation report involving an encounter with turbulence and a serious injury to the flight attendant on board. Nothing in particular was revealing in the synopsis until I got to the statement of probable cause. There I found a need to review the full report. The more I read, the more I became concerned that the point of the investigation had been missed by the NTSB investigator.

This concern was based on the following

- The aircraft's captain understood the potential for an encounter with turbulence severe enough to call the lead flight attendant and told her to expect turbulence on arrival. The discussion between them evolved into a decision to complete all the prelanding "final" cabin preparations early and to be seated.
- The lead flight attendant notified the other flight attendants, completed her portion of the prelanding preparation, and took her seat. The report indicated that the lead flight attendant was from this point "unaware" of the status of the flight attendants at the rear of the aircraft. One of these flight attendants reported he felt there was little or no sense of "urgency" in the warning.
- Ten minutes after the captain had warned the flight attendants, the aircraft encountered turbulence severe enough for the unrestrained flight attendant in the rear of the aircraft to be thrown down with sufficient force to break his leg.

By this time I was formulating my own findings, causes, and recommendations for the report (a practice I have for evaluating all investigations). Imagine my surprise when I read the following:

The NTSB probable cause was stated as "an inadvertent encounter with turbulence." Given the circumstances I have described, what was "inadvertent" about the encounter?

- The captain gave the warning in a timely manner.
- The lead flight attendant passed on at least the substance, if not the urgency, of the warning.
- The lead flight attendant was reportedly "unaware" of the status of the other flight attendants.

It was not "inadvertent," it was expected. The actions by the flight crew were appropriate, the actions in the cabin were suspect. There must be more to the story.

I continued reading the report looking for additional information about the flight attendants. I wanted to understand the experience of both the lead and the injured flight attendants. When I evaluate a pilot's role in an event, his or her experience overall and in the specific aircraft is critical to understanding the decisions and reactions to events. I was sorely disappointed. Nothing at all was listed.

Further, when I got to the part of the report that indicated who "assisted" in the investigation, only the legally required FAA representative was identified. I was surprised that the flight attendant union was not represented.

I immediately contacted some of my friends in the union. They put me in contact with the specific airline's flight attendant safety representative and we discussed the event. From the union, I understood that since this was a "tabletop" investigation, one not actually involving face-to-face cooperation between the investigators, the IIC determined that the union's participation was not required and denied their petition to participate. Not only that, I found out that in contrast to the NTSB report, the airline does not utilize a lead flight attendant as a designated, assigned, crew position! Apparently, airline management determined that if it designated a crewmember to have the specific responsibility as lead, it would necessarily have to compensate them for the additional responsibility.

To further my consternation, I learned that the senior flight attendants, who are able to pick their routes and assignments, choose not to occupy the lead position since they would not be compensated for it and they, therefore, did not want the responsibility. Consequently, the position fell to the more junior flight attendants who were left that "seat" to assume the communication and coordination responsibility.

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Data extraction/analysis

I decided to conduct my own research to discover whether this investigation was an aberration or just indicative of the "norm."

Using the NTSB accident database, I extracted all air carrier accident reports involving turbulence in the years 2000-2005. From this listing of some 86 reported accidents, I eliminated first all those reports that were in the preliminary investigation stage. In addition, I deleted those reports that had only the factual summary available as I decided I needed to evaluate the probable cause as part of my investigation. Finally, I culled out any reports that, after review, did not involve an encounter with turbulence as the primary event. There were several reports in which the database search found the word "turbulence," but I found the turbulence to be cursory to the accident itself.

This left some 60 accident investigation reports for the period. In these investigations, there were some 88 flight attendants reportedly injured. In 53 cases (88.3%) of the reports, their injuries were, in fact, the reason for the investigation as the aircraft was undamaged and there were few passenger injuries. In fact, in only 7 reports (11.7%) were there only passenger injuries.

I found that in most cases, (81.7%) the "seat belt" light was on indicating an anticipation of some degree of turbulence. However, we all recognize that there are many duties that flight attendants must accomplish during the normal operating periods when the passengers have been advised to remain seated with seat belts fastened.

In 28 accidents (46.7%), however, the flight deck has passed a warning for the FAs to be seated as the turbulence was expected to be beyond the normal cautionary levels. So what happens when the flight attendant receives the warning from the flight deck? In most of the cases (36.7%) where a warning was issued by the flight deck, the lead flight attendant passed on the warning to the other flight attendants, when they were present.

In the final analysis, in only four cases (6.7%) did the NTSB find that the actions or inactions of the injured flight attendant were deficient and described in the probable cause statement. I found this to be a very surprising number. Closer analysis, however, indicated when cause was attributed to the flight attendant, in three of these four cases, the injured flight attendant had determined on his or her own when to resume cabin duties. This is significant when you factor in that the air carrier policies normally do not include any communication from the flight deck as to when the perceived danger has passed.

Most significantly to my review was the fact that of the 60 reports, I found only two cases (3.3%) in which the flight attendant organization (or union) was listed as participating in the NTSB investigation. This lent credence to the informal observation I had received earlier that the inclusion of these potentially valuable members of the investigation had been excluded.

Now, I am not saying that the union did not care nor that it did not conduct its own investigation into the event. I believe the safety staff would have paid a great deal of attention to these on-the-job injuries. But without the formal identification of factors in the NTSB reports, it is increasingly difficult to share information and, eventually, change the conditions faced.

Even more surprising, I confirmed that the initial report that led me to this research was not an aberration. Three-quarters (45) of the reported accidents were attributed to the turbulence alone! In fact, in nearly one-half of these cases, the NTSB determined that the encounter with turbulence was "inadvertent, unexpected, or unforecast" and that this was the primary cause of the accident.

In one-fifth (12) of the cases, the NTSB found cause with the actions of the flight crew, either in the failure to issue a warning, or failure to deviate from known weather, or even their "inadvertent" entry into turbulence.

In two investigations, the NTSB found the probable cause rested with others—one a dispatcher, the other an air traffic controller—each of whom failed to relay hazardous weather information.

Again, the NTSB found only four accidents (6.7%) where the probable cause rested at least partially with one of flight attendants. In two, the injured flight attendant removed the seat belt to attend to a cabin duty, and in another, the flight attendant claimed the seat belt had not worked. In only one case was the probable cause shared with a lead FA's failure to warn the other FAs of the danger.

However, in my opinion, based on the narratives of all the investigations, at least 12 accidents (20%) were a direct result of flight attendant actions or inactions.

In these 12 cases, I felt the cause factors included

- The flight attendant who was injured or the lead flight attendant failed to understand the gravity of the expected turbulence;
- The lead flight attendant failed to communicate the warning adequately;
- The flight attendant heard and understood the warning, but continued routine cabin duties instead of securing themselves; and/or
- The flight attendant understood the danger but left their secure seat-belted position to attend a perceived anomaly in the cabin.

It really should be understood at this juncture, in keeping with our stated policy, that I am not putting "blame" on anyone. However, in my experience in aircraft accident investigation, human factors and crew resource management, the necessity to accurately identify the true cause factors is essential to the accident prevention process.

Investigation reports

Let me address my perceived inadequacy of the reports. I have no idea whether the investigator-in-charge actually evaluated the flight attendant actions or responsibilities. In some cases, I feel there probably was some consideration to it. It was interesting that in each investigation that actually had the flight attendant union participating, no cause or contributing factor ever surfaced. Further, there was never a discussion about training. I also found that none of the reports I reviewed had any discussion of the flight attendant procedures or the air carrier's corporate policies concerning turbulence avoidance or securing the cabin when warned of turbulence ahead.

Common terminology, such as the lead flight attendant, reflects nothing about the duties and responsibilities of the position. There is no discussion to define these. Do all airlines operate the same? I think not. In fact, in one report along in the probable cause statement, which identified the probable cause resting with the flight attendant, the NTSB referred to the this person as the "undetermined crewmember." Even after the investigation, the IIC did not know which flight attendant was injured?

Recommendations

So what do I feel must be done? First and foremost, the flight attendant unions must attempt to participate in every investigation involving an injury to one of their members. This may put a real burden on the safety staff, but the safety representatives associated with the airline can assist. If the NTSB denies participation, this fact must be documented and if it becomes a trend, a communication to the chairman of the NTSB regarding this must be made, and, if necessary, made public.

Next, the actions and inactions of all affected flight attendants must be evaluated. Even when the flightdeck crew's actions are not suspect, their flying time, years qualified as a pilot, and their duties as instructor, check airman, etc., are identified. The only time I saw a discussion regarding the flight attendants outside the aircraft referred only to where the flight attendants were domiciled! The duties and responsibilities of those placed in critical positions must be evaluated and deficiencies identified.

Additionally, if clear and unambiguous terms have not yet been developed, there should be a specific phraseology agreed upon that conveys the urgency and the danger of an anticipated encounter. If time is available, something to the effect of "Clean up the cabin then be seated" should be used. If insufficient time is available to clear the cabin, some phrase like "Sit Down, Now!" should be used. Also, there should be equally clear communication as to when the danger is down to an acceptable level; "All Clear or Resume Duties" comes to mind.

Finally, The role of the lead flight attendant should be clearly defined and experience should count! If air carriers have not yet decided that leadership extends to activities on the passenger side of the cockpit door, then they truly do not understand the lessons learned in more than 100 years of aviation. In any operation that deals with the safety of flight, experience and training translates into advances. Air carriers are in budgetary crisis and that is well understood. Savings based on compromise of safety will never be returned when occurrences turn into incidents, or incidents become accidents.

If there is a lead position, it should have expected responsibilities. If training and experience factor into the appointment of those assigned lead positions, then compensation must naturally follow.

I have been involved in aviation for more than 40 years and in aviation safety for nearly 30; I know that investigations must be thorough and accurate if any meaningful changes are to be made. We have got to move beyond the detailed documentation of just the flightdeck personnel. When the reporting forms call only for documenting the pilots, it is not surprising that this is all we get. If the investigation does document the experience and training of all crew members involved, but it is not reported, the aviation community which relies of the exchange of information in order to see trends and effect change is denied the opportunity to learn from other's accidents.

Of course, detailed investigation and reporting into the actions or inactions of flight attendants during turbulence events as well as other cabin-related safety duties will bring deficiencies to public notice. That being said, it is time for the cabin crew to experience the gains that full and accurate reporting has meant for the pilots—even when it is painful to have it identified. Positive changes will come about. It may be embarrassing, it may be difficult to accept at times, but the benefits will eventually come about.

Lastly, while my research dealt with only investigations conducted by the United States National Transportation Safety Board, I think an analysis of all governmental investigations would demonstrate that my observations are not unique to the NTSB or the United States. ◆

Polishing the Apple and the Investigator —Examining the Importance of Investigator Education Prior To an Investigation

By Dana Siewert, Director of Aviation Safety, UND Aerospace, University of North Dakota, and Corey Stephens, Senior Staff Engineer, Engineering & Accident Investigation Section, Air Line Pilots Association, Int'l

Introduction

I hear and I forget. I see and I remember. I do and I understand.
Confucius, *Chinese philosopher and reformer (551 BC-479 BC)*

In an ideal world we wouldn't have aircraft accidents or incidents; but, if there were one, everyone would show up completely prepared and properly trained. While most investigative agencies are able to keep their investigators trained and "current," it can be difficult for other parties that support an investigation to keep up that same level of training. Parties in the United States bring technical expertise to an investigation. The pilots' association brings someone who is type rated and current in the aircraft as well as being familiar with company policy and procedures. The manufacturer is the expert on design, systems, and performance. The airline brings knowledge of company maintenance practices, policies, procedures, and training. The list goes on for every party member. All of the parties bring important knowledge to the process, and the investigation is more complete with this input. While it is important to have a knowledgeable person as a representative, it is also important to have that person prepared to participate in an investigation.

In our experience working accidents and incidents, we have found four facts that can affect investigators: 1) training can become "stale" if not practiced regularly; 2) the field phase of an investigation can be overwhelming; 3) the party and investigative group system can be confusing; and 4) being a subject expert does not ensure success in the field. When confronted with these issues, it became apparent that our investigator training program needed to be modified. What we concluded was that a simulated accident site with multiple parties involved was an ideal training tool for not only accident, but also incident investigation. In this paper we will be looking at some of the problems investigators have encountered and how we are beginning to train for those problems. We will be looking at the Air Line Pilots Association, Int'l and the University of North Dakota's Advanced Accident Investigation Course as an example of such training.

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Corey Stephens is a senior staff engineer with the Engineering & Air Safety Department of the Air Line Pilots Association, International (ALPA). His current duties include participating in all of ALPA's accident investigation activity, and he is the staff lead for ALPA's advanced accident investigation course. Corey has been with ALPA for 9 years and has worked on accidents in the USA and Canada. He has also assisted the International Federation of Air Line Pilots Associations (IFALPA) with technical expertise on international accidents. Corey is the industry co-chair of the CAST/ICAO Common Taxonomy Team (CICTT), and he also serves as an ALPA representative to the Commercial Aviation Safety Team–Joint Implementation Monitoring Data Analysis Team (CAST–JIMDAT). Corey has also worked in the Safety Department of United Airlines and with the U.S. National Transportation Safety Board.

Field investigation issues

As stated earlier, there are four facts that can affect an investigator—the first being than an investigator's training can become "stale" if not practiced regularly. Most investigative agencies have a core group of investigators who are trained and have built up experience working in the field. Unlike the investigative agency, parties that support an investigation normally don't participate in every investigation. Low accident rates over the last few years have kept most organizations "out of the field." Recently, most parties that support an investigation do much of their work by phone or e-mail, working smaller events that normally involve no fatalities. While the low accident rate is wonderful, it doesn't allow investigators to build up or maintain field experience. In busier years in the past, it was not uncommon for an investigator to complete initial training and work at least one accident or serious incident in the field. Some years, some carriers were a little busier and investigators could participate in two or three investigations. With improvements in safety and initiatives such as the Commercial Aviation Safety Team (CAST), air carrier accidents in North America are very infrequent. Without practice or regular review, an investigator's skills may become stale.

Another issue that we see in the field is that new investigators can become overwhelmed working on an accident. After an accident, an investigator is expected to "hit the ground running." If the wreckage is accessible, it is not uncommon to begin field work the day of or the day after an accident. For someone who works accidents regularly, there are a lot of familiar names and faces. For someone new, it can be daunting. You may have a long day in the field, having to work effectively and efficiently with a group whom you first met at breakfast. The investigators also find themselves working in a totally alien environment. Wreckage, fire, spilt fuel, firefighters, law enforcement, and the press all add to the sights and sounds and can be distractions. For pilots working in the field, they are looking at the wreckage of an aircraft that they fly regularly. Seeing an aircraft they have flown for some time and have learned to rely on, bent and broken in a field, can be disturbing. For pilots, flight attendants, mechanics, or other airline employees you are looking at an aircraft whose history you may know and have possibly flown several times. All of these thoughts can cause someone unfamiliar with an accident site to feel overwhelmed. While the person is still a valuable resource, he or she may not be as focused as need be.

Another issue is that the party and investigative group process can be confusing. While the Investigator-In-Charge (IIC) has the ultimate control on any site, the average participant will interface more with the investigative group chairman and the party coordinator. We have found that you can present the chain-of-command structure to new investigators in a classroom setting, but until they see the structure in place and at work, it doesn't really become clear to them. An investigator working an accident for the first time can easily be caught in procedural mistakes that lead to not only lost time but possibly evidence. It can take a couple of days for a new investigator to fully understand the information flow pattern from the investigative groups up to the IIC and then back out to the parties. If an investigator has a better grasp of the process and information flow earlier in the investigation, the more beneficial that investigator will be to his or her group and party.

Finally, being a subject matter expert does not guarantee success in a field investigation. A person can be a renowned expert in a particular area but lack the basic skills needed to be a successful investigative group member. An investigator must be ready to not only lend expertise, but also be able to function in the field. If the investigative group will be working on a crash site, then the group needs to have been trained in how to dress for the environment and the safety protocols to be used on site. No matter which group the investigators will be working with, they should have some basic knowledge of what that group is normally responsible for and what its end product will be. Investigators working on an investigative group owe it to the investigative agency, the group they will be participating on, and to their party to know what that group's purpose is and what is expected for a final product.

In cases where investigators have limited experience in the field, it can take some time for them to become acclimated. While working the wreckage of a CFIT accident several years ago, an investigative group was documenting impact marks in a wooded area. All group members but one were dressed appropriately. This member would have been highly valuable to the group, but he was forced to stand on the sidelines because he was not prepared to work in the environment. He had been chosen because he was a subject matter expert, but he had never received any training outside a classroom and had no field experience. This accident taught him some valuable lessons for the future. In another example from a different accident, a group member was accompanying his group to document switch positions in a cockpit. This member had limited accident experience but was assigned to this event because of previous experience as a pilot and in airline operations. While the group was preparing to enter the cockpit, this member began randomly flipping switches. The member was confronted and quickly admitted he didn't realize he had done anything wrong. It was unclear if he correctly recalled all the switches he had flipped. This investigator had limited field experience and had no clue as to the importance of protecting evidence. With these examples, it is easy to see that some initial training in a field environment is necessary.

Clearly, the stakes of any aircraft investigation are extremely high. Not only are there lessons to be learned, but the potential outcome can have a dramatic effect on companies, careers, and organizations for many, many years. Because of this, the quality of an investigation is of the utmost importance. In order to keep the quality of an investigation high, the investigators must be properly trained, well prepared, and focused.

Combined training

While there are countless books, brochures, and pamphlets on aircraft accident investigation techniques, they can not fully relate issues encountered in the field. There are many organizations and educational institutions that provide classroom courses and theory on the subject, however, little practical hands-on, "tinkicking" application. The ability to maintain pace with changing technology, commercial and general aviation glass cockpits, technically advanced aircraft (TAA), and very light jets (VLJs) is, and will continue to be, a current and expanding challenge for future accident investigators.

In addition to the National Transportation Safety Board, or any country's investigative agency, there are a multitude of "parties" that have expertise as well as an interest in the findings that result from an investigation. From air carriers to aircraft manufacturers, law enforcement, flight schools, and flight departments, all facets of aviation at some point in time may be called upon or may need to participate in the investigative process.

Unfortunately, many of those that may become, or have a willingness to become, a party to the investigation have limited guidance and low experience levels as investigators. Past experience shows that the efficiency of those investigating a major airline, general aviation, or military aircraft accident depends on each investigator's knowledge of the investigative process and techniques, how this "process" works, and the politics that may become apparent with a variety of federal and local agencies as well as personalities. However, as in any investigation, the primary purpose is to learn as much as possible by investigating all human, material, and environmental factors that directly or indirectly may have contributed to the accident. It's been said that each accident is an opportunity to learn, in an effort to define or reshape company culture or increase the level of aviation safety.

One method of preparing investigators for field investigations is through a realistic training program. An ideal program will bring together all of the facets of an investigation, from wreckage and environment to the investigative process and parties. This

Figure 1

combined training program would expose investigators to all of the sights, sounds, personalities, and confusion of an accident—but without the criticality and pressures faced at an actual site. The skills learned in this type of course would not only be of benefit for an accident investigation, but also for incident investigation. Both types of investigation involve some of the same personnel and procedural problems.

Recently, two organizations known internationally for their reputations in advancing aviation safety and education entered into a joint venture by pooling their resources and expertise to achieve a particular goal that would have been difficult, if not impossible, to accomplish individually. The Air Line Pilots Association, Int'l (ALPA) and the John D. Odegard School of Aerospace Science located at the University of North Dakota, in a cooperative effort, have joined forces to provide a stage that allows industry and education to come together, forming an educational team that focuses specifically on training the aircraft accident investigators of the future.

While not designed to solve aircraft accidents, the realistic course places participants in the logistics involved in accident response, participation, on-scene investigative groups, and investigative techniques. This cooperative effort by ALPA and the University of North Dakota has resulted in a lifelike, hands-on experience that provides participants an educational course on intricacies of aircraft accident investigation.

Because the field phase of an aircraft accident investigation can be confusing, chaotic, and labor intensive, this hands-on course using an actual aircraft wreckage and re-created aircraft accident site provides participants opportunities they could never experience in a classroom, learn from reading a book or experience watching a video or DVD. From site safety to site survey, the on-site examination demonstrates many of the activities and issues encountered in the field. Additionally, the course simulates a "contaminated" wreckage site, which trains applicants on the use of personal protective equipment, the hazards associated with hazardous debris, biohazard disposal, as well as jagged metal, pressure vessels, and environmental issues. Unlike a classroom, participants must plan and dress for the elements as outdoor modules are conducted rain or shine, hot or cold, and not always "bug free."

During the three, 10-hour-day schedule, participants are exposed to some of the same investigative groups used by the National Transportation Safety Board (NTSB), including Air Traffic Control (ATC), Cockpit Voice Recorders (CVR), Maintenance Records, Operations, Aircraft Structures and Survival Factors. Each 3-hour module allows participants on-the-spot, practical experience in each specific area. All modules are designed and conducted with the realism of an actual aircraft accident investigation. Students are exposed to normal group work, as well as to simulated issues that have been encountered in the field before. Students also gain exposure to topics such as cognitive interviewing and work with the latest technology being used in field investigations. As an example, during the structures module, participants will learn how to document the position of flight controls at the time of impact and look for any evidence of inflight failure prior to ground impact. Participants learn the differences between tension loads and compression loads, torque and transverse shear. They will learn how to document wreckage and ground scars using everything from stake lines to global positioning systems (GPS). Every training module provides the realities one would actually experience during a field investigation, including press briefings at the conclusion of each day. The course also includes high-altitude flights in an altitude chamber providing participants educational opportunities generally experienced by only those in the military. The opportunity to actually experience hypoxia, hyperventilation, trapped and evolved gases, cabin pressure emergencies, and rapid decompressions gives participants actual training and experience that can be applied during future accident investigations as well as increasing their personal safety and that of their passengers.

The synergy developed by ALPA and UND in this joint venture has been a successful mission to enhance aviation safety through accident investigation. Joint ventures are not new. However, the key to a successful partnership requires planning and cooperation. By combining the talents of two organizations, the results are increased resources, greater capacity, and increased technical expertise.

Conclusion

An investigation can be overwhelming, confusing, and if not properly prepared for, dangerous. While classroom instruction is good for passing on general knowledge, a simulated accident site acts as a practicum for this training. Both new and experienced investigators can learn from a simulated accident. New investigators are not only exposed to investigative processes and procedures, but also to long days and group dynamics. Experienced investigators are able to learn about new technology and procedures, while passing on some of their experience during the exercise. Also, by bringing together as many of the interested parties as possible, everyone gains respect for what these groups bring to an investigation. While every accident is an opportunity to learn, so is a simulated accident, and the lessons learned here can also be applied to incident investigation. If this leads to an improved incident investigation, the chain can be broken before it leads to an accident. ◆

Figure 2

Investigating a 'Minor' Incident Using Lessons Learned From a Major Accident

By Stéphane Corcos and Alain Agnesetti, BEA (Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile)

1. Introduction

Last summer was a terrible one for aviation safety, with several fatal accidents, in which more than 500 passengers died in just 2 months. Most investigations are still ongoing, but it is likely many of them will highlight shortcomings in the way various operators were overseen by their national authorities. The BEA has been involved in a number of them, to various extents, as the state of the manufacturer, the state having citizens among the victims, but also by assisting several countries in their investigations, including flight recorder readout.

Although most of these fatal accidents occurred outside the western hemisphere, any given citizen of a western country may one day be a passenger on a domestic flight in a less-developed country, or between two of them. Moreover, an investigation into an incident that occurred during takeoff from Paris CDG in July 2005 showed that it is not necessary to travel abroad to be at risk: in Europe, airlines from countries where safety oversight is weak can operate on a wet-lease basis for national flag carriers from EU states, where leasing conditions are somewhat overlooked. According to ICAO findings (the 35th assembly, September 2004), there are almost 30 states where safety deficiencies still prevail, where corrective actions have not been implemented. Rogue airlines know this situation and exploit these breaches, eventually making their way into western countries. "Virtual airlines," made up of parts that are often inconsistent, and which should actually be called "ticket sellers" rather than "airlines," are created there and then, like genuine toadstools, jeopardizing the safety and stability of the air transport industry.

The world aviation community has identified the problem, but implementation of solutions is very slow. ICAO has limited power, since its system is based on sovereignty. Many states commit themselves to implement ICAO standards but often have not taken appropriate action to enforce them through regulations, procedures, proper staffing—and above all, they lack political will to move forward. Instead, technical expertise is often superseded by political considerations for various reasons. Safety regulations are often seen as hindrances to the prosperous operation of an airline, and both authority and airline technical staff are under pressure from politics or financial managers. Safety is not attractive because it may, ultimately, confront you with the taboo of cancelling a flight. In aviation culture, especially in a fiercely competitive environment, cancelling a flight is seen as a failure. Consequently, safety personnel end up with being blamed for their actions, and are seen as "the bad guys."

Above all, it is our terrible experience in society that sometimes it seems that a price must be paid in blood before lessons are really accepted and the situation changed, before those concerned are convinced by the lessons derived from other occurrences, overcoming the inevitable costs and putting aside prestige considerations. When the aviation community says it will improve its level of safety, accident investigators are too often the "efficiency sensor," who demonstrate that the picture remains imperfect.

Traceability of airplanes can be impossible across borders, except with the help of private companies or individuals, whose website may include interesting information on a given situation. Thanks to Internet search engines, used more and more frequently in difficult investigations, some achievements are possible. But traceability of pilots, their initial and recurrent training, their ratings, and their actual experience is almost impossible, especially when, de facto, they act as mercenaries. They often move from airline to airline, and have no time to become familiar with the airline, the working environment, the standard operating procedures, the network—and they are not always in a position to perform at an acceptable safety level.

To illustrate this, we could reiterate the occurrence the BEA presented at ISASI 2005. The investigation into this incident in Nantes (approach flown well below and outside normal final ap-

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Alain Agnesetti is a former Air Force pilot instructor. As a flight safety officer and accident investigator in the French Air Force, he led various military accident investigations. A retired major with more than 6,000 flying hours, he joined the BEA in 1999 as a safety investigator. He has been an IIC on a number of national and foreign investigations and an accredited representative on major investigations abroad. Alain has a professional pilots license. He is a Chevalier de l'Ordre National du Mérite and holds the Médaille de l'Aéronautique.

proach path) had shown that the captain lacked knowledge on instrument approach procedures principles and limitations and on the autopilot of his airplane. This pilot, who held a Venezuelan license but flew with an Egyptian airline, was sacked before the investigation was completed. He, quite probably, has transferred now his inadequacies to another country, to another employer who has no reason to believe his knowledge is inadequate. No one has any way to know where he is now, even less to have him follow additional training.

Finally, traceability of airline managers, and even of airlines themselves, is no easier, while this is increasingly becoming a safety concern as well.

2. Safety oversight

Through safety oversight, a state ensures that national actors in the aviation industry (airmen, operators, maintenance organizations) perform their duty in a safe manner and meet the applicable requirements and standards.

The responsibilities and international obligations of states in relation to safety oversight are derived from the Convention of Dec. 7, 1944, on International Civil Aviation, known as the Chicago Convention, "in order that international civil aviation may be developed in a safe and orderly manner and that international air transport services may be established on the basis of equality of opportunity and operated soundly and economically." The Convention recognizes (Article 1) that "each state has complete and exclusive sovereignty over airspace above its territory."

Furthermore, it stipulates (Article 12) that states ensure that any aircraft flying over its territory or maneuvering thereon, as well as any aircraft with its registration mark, wherever it may be found, should be in conformity with the rules and regulations applicable in the place where the flight or the maneuver is taking place. The Convention also specifies (in Articles 31 and 32) that states of registry must issue certificates of airworthiness to aircraft undertaking international flights and certificates and licenses to their crews. However, Article 83b authorizes the partial or total transfer of these responsibilities, as well as those relating to Article 12, to the state of operator of the aircraft.

To ensure harmony between these various obligations, the Convention introduces, in Article 12, an obligation for national regulations to be in conformity with the rules established pursuant to the Convention and, in Article 33, the international recognition of documents issued by the state of registry insofar as they correspond to the standards.

This implies that each state commits itself to adopt a law or a civil aviation code, completed by the necessary rules of application, to put into place and apply the international standards. This also implies that each state may ascertain that other states are satisfactorily undertaking their commitments. Specifically, if the rules adopted by other states are inferior to international standards, Article 38 stipulates that these differences be notified to the Council.

Over the past 15 years, aviation has experienced rapid and steady growth and has always been ahead of global economic growth, which it has accompanied effectively, as a fundamental tool for development of exchanges. But this economic growth has been characterized by increased globalization, which has also affected aviation. The system has become so complex that in order to maintain an acceptable level of safety, increasing human, financial, organizational, and technological resources are required. Not all contracting states can cope with this challenge, and ICAO has noted that more and more contracting states are faced with difficulties in exercising their oversight function. This concern that all states keep up with their responsibilities has been shared by more and more states. In August 1992, the United States Federal Aviation Administration (FAA) established the IASA program. The foreign assessment program focuses on the ability of a country, rather than that of an individual air carrier, to adhere to international standards and recommended practices for aircraft operations and maintenance established by ICAO. It was recognized that in order to ensure that all foreign air carriers that operate to or from the United States were offering an acceptable level of safety, it was necessary to ascertain that safety oversight of these carriers was provided by a competent civil aviation authority (CAA) in accordance with ICAO standards.

In 1996, ICAO set up a voluntary program for safety assessment of national aviation authorities within contracting states. In 1998, this was replaced by a Universal Safety Oversight Audit Program (USAOP), adopted by resolution A32-11 of the 32nd Assembly.

These audits started in 1999 and covered airworthiness, personnel licensing, and operations. Their purpose was to assess whether a given contracting state was implementing critical elements of oversight in pertinent SARPs in an acceptable manner, following established procedures.

Meanwhile, in 1995, the BEA issued a safety recommendation requesting that the French DGAC play a lead role in the reinforcement of safety oversight of foreign states and carriers, both through ICAO and the European Conference for Civil Aviation (ECAC). The DGAC was designated coordinator of the new European SAFA program (Safety Assessment of Foreign Aircraft) that started in 1996, as a complement to USOAP audits. The Puerto Plata accident (a Boeing 757 operated by Birgenair, a Turkish operator with mostly German citizens on board) in 1996 accelerated this process.

Both the SAFA and USOAP programs are interrelated through a memorandum of understanding.

Although the SAFA inspections are limited and seldom thorough, they give a general overview of the foreign operator's safety. Furthermore, these inspections may lead to mandatory repairs, which contribute to safety on a given airplane. Finally, they foster cooperation between the inspecting state and the competent authority of the inspected operator to solve safety issues almost in real time.

3. Accident to a Boeing 727 operated by UTA in Cotonou

This oversight issue was significantly brought to light in the course of the investigation into an accident that occurred in Cotonou (Benin) on Dec. 25, 2003.

3.1. History of flight

A Boeing 727-223 registered 3X-GDO, operated by Guinean airline UTA (Union des Transports Africains), was on its second leg of its Conakry (Guinea)–Cotonou–Kufra (Lybia)–Beyrouth (Lebanon)–Dubai (United Arab Emirates) route. During the takeoff run, the airplane experienced a long, delayed, and shallow angle of lift off. It struck an ILS building located a hundred and eighteen meters past the runway end on the extended runway

UTA Boeing 727 accident Cotonou.

centerline and crashed onto the beach with most parts ending up in the ocean. There were at least 160 people on board, among whom 22 survived the accident, including the captain and the airline's general manager.

The Benin government delegated the investigation to the BEA.

3.2. Accident description

The investigation showed that the airplane weight was 7 to 8 tons above the maximum allowable weight and that the cargo compartments were loaded by poorly managed employees, in an anarchic way. The aircrew was unable to obtain precise data concerning passengers and luggage, nor for possible freight on board. Furthermore, they were lacking documentation to establish a precise load sheet: they were not informed that the forward cargo hold had been heavily loaded, which significantly displaced forward the center of gravity. Therefore, the crew took into account a weight of 78 tons with a standard loading, and a configuration of flaps 25°, trim setting 6¾, packs off, brakes release on takeoff thrust. At V1-VR callout, the airspeed was 137, which is in fact a V1-VR for 85.5 tons. On reaching this airspeed, the copilot (who was the pilot flying) pulled back on the column, but the airplane failed to pitch up. The airplane rotated slowly and lifted off in the very last meters of the runway. The main landing gear struck a 2.45-meter-high building containing the localizer system. The right main landing gear broke off and ripped off a part of the underwing flaps on the right wing. The airplane banked slightly to the right and crashed onto the beach. It broke into several pieces and ended up in the ocean.

3.3. Operational failings

The overall operation of the airplane, both at its base and at the various destinations it served, was not organized, undertaken, and overseen in an appropriate manner (this is an understatement).

In Cotonou, the station manager had no aeronautical knowledge. The resources (counters, vehicles, and staff) were rented from a company based at Cotonou airport, but this company was not tasked with any duty related to dispatch or handling, in particular providing the crew with performance data. Basic loading elements to the aircrew (number of passengers, estimated weight of luggage) were provided by a representative of the airline, flying on board the airplane.

At their main base in Conakry, apart from a rented check-in counter, the airline had two containers in which spares, drinking water, and the printed paperwork required for operations were stored.

It should also be noted that there was no competent technical management, that operational and maintenance activity were non-existent (no maintenance documents could be supplied to the investigators), and that no training was provided for ground crew.

3.4. History of operations

The airline, UTA, was initially based in Sierra Leone and operated under the name of West Coast Airlines. In 1997, its home base was transferred to Guinea under the name of UTA. It started operating rather light airplanes: a Let 410 and an Antonov 24. Both airplanes belonged to a Russian citizen, who was also the technical director of the airline. The airline was owned by a Lebanese citizen living in Guinea, several family members being among top managers of the airline, including the director general and the operations manager. When the airline added the Boeing 727 to its fleet, none of the technical staff had any knowledge of the airplane.

Until 2003, UTA performed local flights in western Africa. From April 2003, the airline wanted to extend its range of operations, and in June of the same year, long-distance flights to Lebanon and the UAE were organized with a Boeing 727. In April 2003, a request to open a Conakry–Abidjan–Cotonou–Beirut route was made to the authorities in the various countries concerned. On June 28, 2003, the route was opened between Conakry, Cotonou, and Beirut. In November, it was extended to Dubai.

The Boeing 727 was leased from FAG (Financial Advisory Group), formerly based in Miami (Florida), then allegedly based in the Virgin Islands, but for the airplane lease, the sole interface was through its office in Sharjah (United Arab Emirates). The leasing contract included the aircrew and technical maintenance of the airplane. It also stated that insurance and wages were to be paid by the airline. It should be noted that FAG did not hold an air operator certificate.

The airplane was first delivered to American Airlines (USA) in 1977. Until 2001, it had normal flying activity in the USA—

Between 2001 and 2003, stored in the Mojave desert; in 2003, became the property of a bank, still with a U.S. registration.

January 2003: operated by Ariana Afghan Airlines, Kabul (registered YA-FAK), owner based in Sharjah (UAE).

June 2003: operated by Alpha Omega airways, same owner, registered in Swaziland (3D-FAK).

July 2003: "operated by UTA," under wet lease from Alpha Omega, same registry.

October 2003: new lease to UTA, this time from FAG, same registration.

Two days later, transferred to Guinea registry, and became 3X-GDO.

From October 2003 till the day of the accident, it remained leased by FAG and operated by UTA as 3X-GDO on Guinea registry.

It should be noted that UTA operations actually begun with another B-727, registered 3X-GDM, also the property of FAG, which was grounded in Lebanon at its first flight for a number of major deficiencies. The airplane was then replaced by the 3D-FAK, and FAG got it back. The BEA deeply regrets that, due to time constraints and since this was not a part of the investigation, this airplane was not tracked after it returned under FAG responsibility.

3.5. Organizational failings

The investigation brought to light the inadequacy of both the airplane's and the airline's mandatory documentation. The airline's operations manual was a "cut and paste" job seemingly based on that of a Jordanian airline. It contained descriptions of systems, human resources, and equipment that the airline UTA did not possess. As the operator had no knowledge of the world of aviation, it could neither organize nor plan any operational follow up at all, even less ensure the safety of its flights.

The airline's only office was a ticket office in downtown Conakry. Overall, the airline was hardly more than a purely commercial structure.

3.6. Oversight

The airline oversight was exercised by the DNAC (Direction Nationale de l'Aviation Civile), the Civil Aviation Administration of Guinea. An air operator certificate was issued in November 2001. When the airline expanded with the leasing of a Boeing 727, the Guinea civil aviation authority stipulated that the airplane had to be maintained according to a program approved by the DNAC and in accordance with the manufacturer's maintenance manual.

The DNAC could not get information on the maintenance shop for the first of the two Boeing 727s. For the second, 3X-GDO, maintenance had been scheduled in Kabul, Afghanistan, in January 2004, a few weeks after the accident.

The Guinea CAA failed to exercise its normal duties, with almost no safety audit upon application to operate, no checks on operations, documentation, flight time limitation, crew or airplane activity follow up—in part under pressure from economic and employment issues.

During stopovers in Beirut, the Lebanese Civil Aviation Authority conducted ramp inspections on the 3X-GDM and 3D-FAK/3X-GDO. Although limited in time and depth, a ramp check showed such deficiencies that the 3X-GDM was banned from flying with passengers and was replaced by the 3D-FAK. On this second plane, the ramp check revealed 18 deficiencies. The plane was grounded in turn.

It took at least three iterations to the Lebanese CAA to have all deficiencies eventually corrected.

3.7. Causes

The direct cause of the accident was a forward CG, unknown to the crew.

The root causes of the accidents were

- the operator's lack of competence, organization, and regulatory documentation, which prevented them from appropriately organizing line operation and checking the airplane's loading.
- insufficient monitoring exercised by the Civil Aviation Administration of Guinea, and Swaziland prior to it, in the area of safety oversight.

Several contributory factors were noted, among which were a spread of responsibilities between the parties that made checks all the more difficult, as well as the failure to use proper dispatch or handling agents at the Cotonou station.

3.8. Safety recommendations

A first set of safety recommendations was addressed to civil aviation authorities, in particular of Guinea, so as to reorganize safety oversight and implementation of ICAO SARPs.

Another set was addressed to ICAO, recommending fostering a comprehensive enhancement of safety oversight within all member states, to include clarification of duties of the state of the operator, harmonization between scheduled and non-scheduled flights, identification of one operator so as to limit the spread of responsibilities, publication of guidelines to be used by Civil aviation authorities….

4. Incident to a Lockheed Tristar operated by StarJet-registered A6-BSM

In July 2005, almost as a precursor of the tragic summer, an incident occurred in Paris CDG.

Olympic Airlines was struggling to keep up with its maintenance and was short of airplanes. It contracted StarJet on a wet-lease basis through a broker to perform the scheduled flight OA202 from Paris to Athens.

The airplane was already late at the gate. When passengers boarded, loud bangs could be heard, produced by mechanics literally hammering on the cargo door to close it before flight. Several passengers panicked, some of them rebelled, and half of them left the airplane. It eventually left the gate 4 hours and 40 minutes late. On takeoff, just after gear retraction, loud thumps could be heard. The crew noticed turbine gas temperature rising above limits, along with vibrations from engine No. 3. In several cabin rows, passengers saw a flame behind the engine and panic spread. This was also seen from the ground by plane spotters.

The crew applied the appropriate procedure, shut the engine down, requested a visual approach and the airplane returned to Paris CDG, after an uneventful landing[1].

The news media splurge was amplified by residents neighbouring the airport. The BEA started an investigation to determine the facts.

Beyond a "mere" engine surge followed by exhaust pipe fire, numerous deficiencies were brought to light. Maintenance was not undertaken by an approved facility, and the lack of documentation made it impossible to conduct a proper follow up of maintenance operations. More generally, the investigation revealed several shortcomings in the operations as set up by StarJet: no logbook entries for several flights, several pieces of equipment were not airworthy, the documentation was not appropriate (OPS manual outdated and inadequate, MEL replaced by the MMEL, although this was agreed as an exemption by the CAA of the UAE).

The oversight from the United Arab Emirates, state of registry, and of the operator, revealed shortcomings in the area of operations. Although aware StarJet operations failed to meet the applicable safety standards, an exemption was granted so as they

StarJet Lockheed Tristar, registered A6-BSM, involved in an incident.

could fly for Olympic. The supervision and checks conducted by the civil aviation authority of Greece and Olympic Airlines could not prevent this airplane from being operated within the European Union.

The history of activity for the Boeing 727 3X-GDO and the Tristar L1011 A6-BSM are very similar. In both cases, the pattern of the geographical spread of the respective owners, operators, registry and oversight authorities, therefore, of responsibilities, is similar—

1981: BWIA (West Indies Airways), Trinidad

2003: stored in Port-of-Spain, then registered in Sierra Leone (9L-LED) with a 1-year validity certificate of airworthiness.

October 2004: bought by Star Air in Sierra Leone. The base was in Gibraltar and the headquarters in Amman (Jordan). The airplane was ferried to Amman.

October 2004: withdrawn from Trinidad registry.

June 2005: registered A6-BSM in the UAE. New owner : StarJet, company based in Sharjah. Same president as Star Air. No formal purchase or sale document formalized this transfer of property.

July 2005: StarJet was operating on a wet-lease basis for Olympic Airlines (Greece).

Although it was grounded most of the time, the airplane was, therefore, registered in more than one state between November 2003 and October 2004.

The above are only a few of the failings found, and the investigation is still ongoing; more details will be found in the final report.

5. Conclusion

The experience gained during the investigation into the Cotonou accident helped investigators operate more effectively and explore more precisely the apparent areas of deficiency, addressing in an even more pertinent way the root issues of failings in oversight.

The two investigations showed that aviation safety faces at least two challenges. The first one is a sound and organized implementation of international standards for operation of airplanes, and an appropriate level of supervision to ensure this standard. The second one is that western airlines, usually subject to a more stringent oversight from their authority, may delegate transport activity to operators who are subject to a much weaker monitoring activity. Action taken to guarantee an equivalent level of safety is not robust enough. Ultimately, fare-paying passengers may "legally" end up flying with a much lower degree of safety.

Among the challenges of the coming years, safety oversight is certainly one for which every country has a part to play, and should go beyond the concept of "black lists": strengthening of oversight, ramp checks extended as far as possible to areas such as aircrew training, cooperation between states, exchange of information, training, assistance to less-developed countries, and use of accident or incident investigation reports to be part of the safety assessment, to name but a few.

In this respect, satisfactory investigations are essential, since in some cases they consist now more of an audit on the safety structures than an identification of previously unknown safety weaknesses. This implies, of course, that confidence and cooperation be total between accident investigation authorities and that no one should be influenced, during an investigation, by economic, political, or image considerations. ◆

Endnote

[1] To date, the airplane is still grounded in Paris CDG. Several components were found to be not airworthy, as revealed by the first and subsequent inspections, and the owner has not mandated the repair.

Listening to the Specialists: How Pilot Self-Reporting Can Help Break the Accident Chain

By Sue Burdekin, Lecturer/Researcher-University of New South Wales, Australian Defence Force Academy

Abstract

Pilots are a group of aviation specialists with a vast amount of day-to-day operational knowledge that, to a large extent, is not fully utilized. Pilot self-reports of structured in-flight behavioral information can give management and operational staff visibility of not only what is happening in the field, but also why it is happening. It can give warning of issues arising and possible incidents developing. It can identify potential problem areas concerning air crew, cabin crew, air traffic management, airports, and ground staff so that a closer and more defined proactive investigation can be made. A carefully designed pilot self-reporting program based on sound operational research has the potential to provide evidence in the form of hard data, both quantitative and qualitative, for management to present a safety case for change and to provide direction and emphasis for in-house training programs. When tailored to suit a specific operation, pilot self-reporting has the ability to alert the organization to the development of adverse trends as well as monitor whether intervention actions are working in line operations. This paper describes a pilot self-report research study conducted at a low-cost carrier in Europe. It then discusses how this utilization of rich operational data from "front line" specialists can proactively identify and rectify safety deficiencies that could contribute to accidents and incidents, and make a valuable contribution to a safer aviation environment.

Introduction

Pilots are a highly trained group of individuals who spend their working lives at the coalface of aviation. Every working day pilots interact closely with the operational side of the aviation industry. They receive NOTAMS and weather from the relevant provider; they transit airport customs and security; they liaise with ground staff, maintainers, loadmasters, refuellers, baggage handlers, pushback, and surface movement coordinators; they fly into and out of a range of scheduled and occasionally non-scheduled network airports; they communicate with air traffic providers enroute, approach, and tower; and they work closely with other company employees both in flight and on the ground. Therefore, at any given time, pilots should be able to compose a comprehensive and reasonably accurate assessment of the level and quality of service and cooperation they receive in order to streamline the tasks they need to achieve. Importantly, pilots are in a position to be able to identify areas in need of attention and to be able to determine whether there are any safety implications associated with the operation of the flight from duty sign on to sign off. However, even though these highly trained specialists are informally gathering intelligence from every facet of the operation on a daily basis, they are rarely asked to provide formally structured feedback on the safety "health" of the system. When questioned about the possible use of pilot self-reports as a potentially valu-

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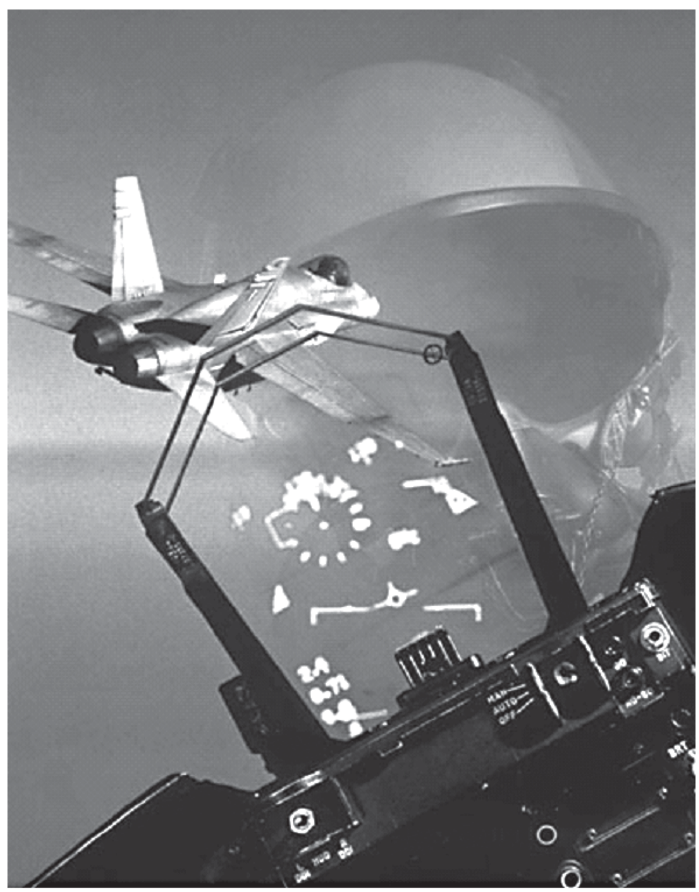

Photo 1. HUD display from the cockpit of the F/A-18 Hornet.

Photo 2. EasyJet pilot fills out self-report during turnaround.

able proactive safety measure, airline safety and accident investigation personnel often anecdotally reply that such reports would probably be unreliable because they would be biased.

Self-reporting research

Most of the self-report research that has been conducted has centered on the medical, educational, and workplace sectors. Self-report and self-assessment is common in these areas, and studies have shown that with practice these reports are generally critical and realistic (Drewes and Rundle 2002). Mabe and West (1982) proposed that if individuals understand the dimension in question, accept the dimension, and perceive that the assessment will not be used against them, self-assessments would be more accurate.

An Australian military pilot self-report study conducted by Burdekin (2003) found that after flying structured mission profiles in the simulator, F/A-18 Hornet pilots were able to recall and report on behavioral categories of their own performance, such as automation management, communication, and workload management, and that their self-reports were highly correlated with the ratings of the same behaviors made by an independent observer. This study was conducted in the simulator because many military aircraft do not have provision for an observer in the cockpit, and the Australian Defence Force (ADF) was interested in whether this kind of self-reported, structured and categorized behavioral information, as distinct from a normal mission debrief obtained from pilots after the mission would be reliable. Pilot reports were seen as useful in collecting operational data from front-line specialists as part of the overall ADF accident and incident prevention strategy. Such data also provide a means of evaluating the effectiveness of training programs such as CRM in normal operations and could be fed back into such training.

Testing airline pilot self-reporting in flight

On learning of the results from the ADF study, the Flight Operations Monitoring Group from Airbus was interested to determine whether pilot self-reporting would be a reliable means of gathering operational data from crews in a commercial airline environment. With the assistance of easyJet, one of their customer airlines, an airline pilot self-report study was conducted. Early in the planning stage, easyJet management and the research team made a presentation on the proposed research to the pilots' union to seek its cooperation. It was agreed that only volunteers were to be involved, no personal identification information was to be collected, and the primary researcher was to be the gatekeeper of the data.

The design of the study was developed in conjunction with easyJet pilots and Safety Department personnel. Although the protocols were influenced by the ADF study and the Airbus Line Operations Audit System, the nature of the information collected was designed and customized to be of use to the easyJet Safety Department in the early detection of safety-related issues. The reporting form asked pilots to assess their interaction with air traffic control, airports, ground support, and passengers. Pilots were also asked to rate their own performance across eight categories of behavior: briefing, contingency management, monitor/cross check, workload management, situational awareness, automation management, communication, and problem solving/decision-making. Each category of behavior was given a comprehensive descriptor. For example, the descriptor for the category "briefing" was

The required briefing was interactive and operationally thorough. Concise, not rushed, and met SOP requirements. Bottom lines were established. Roles and responsibilities were defined for normal and non-normal situations. Workload assignments were communicated and acknowledged.

In order for the pilots to make a more informed rating choice, a series of specific "word pictures" was given to each category of behavior ranging from a grading of 1 to 5 (refer to Table 1).

All data-collecting missions originated at easyJet's Geneva base and were flown in its fleet of A319 aircraft during normal revenue raising flights. At the time, the network of destinations was restricted to eight UK and European airports. In addition to reporting on their own individual performance during the flight, the captain and the first officer were asked to report on each other's performance using the structured questionnaires provided. The observers used the same questionnaires to report on both the captain and first officer. In an effort to be as unobtrusive to

1. Unsatisfactory briefing standard. • Briefing duration and crew interaction minimal. • Available company resources not utilized to a satisfactory standard. • SOPs not adhered to.
2. Basic briefing conducted with limited crew interaction. • Incomplete use of available resources, and workload allocation limited. • SOP briefing structure loosely adhered to.
3. Crew operates in accordance with SOP briefing structure. • Interactive briefing conducted in a timely manner, utilizing available resources to an adequate standard.
4. Effective crew briefing conducted utilizing all company/non-company information. • Proficient time and workload management with clear interaction and allocation of duties among crew.
5. Comprehensive and operationally thorough briefing conducted to a high standard. • Excellent crew interaction, participation, and understanding. • All available briefing resources utilized, and clear and concise • workload allocation among crew.

Table 1. Grading/word pictures for the behavioral category "briefing."

Rater	Mean	sd	N	r
OBS CPT	3.995 4.000	.36345 .58599	432	.344 **
OBS F/O	3.995 3.7394	.36345 .53281	376	.206 **
CPT F/O	4.0000 3.7394	.58599 .53281	376	.169 **

** Significant .001

Table 2: Ratings across all behavioral markers.

Behavioral Marker	OBS/CAPT	OBS/FO	CAPT/FO
Briefing	.630 **	.427 **	.275
Contingency mgt	.361 **	.056	.000
Monitor-x-check	.278 *	-.098	-.043
Workload mgt	.364 **	.164	.132
Situational awareness	.271 *	.368 *	.115
Automation mgt	.109	.301 *	.195
Communications	.457 **	.441 **	.335 *
Problem solve/decision-making	.265	-.232	-.116

* correlation is significant .005
** correlation is significant .001

Table 3: Correlations by behavioral category.

regular operations as possible, the pilot volunteers were not given a training program to explain the experimental study but rather a single page of explanatory notes before the flight in addition to a prior letter from management requesting their cooperation.

Sixty flight sectors were observed. The ratings of the observer/captain, observer/first officer, and captain/first officer were compared to measure the degree of correlation. The results were found to be statistically significant indicating that commercial airline pilots were able to reliably report on their own behavior across a range of structured categories when compared to the reports of an observer and each other (refer to Table 2).

The data were then compared by behavioral category in order to determine how individual behavioral markers contributed to the overall results (refer to Table 3).

This breakdown revealed that the marker selection appeared to be understood and rated consistently by the captain and the observer with the exception of "automation management" and "problem solve/decision-making." These markers would need to be reconsidered for future use. It may be found that they simply need a better definition. While the captains appeared to be very good at interpreting the markers and rating their own performance, the first officers seemed to have some difficulty. The observers and first officers found agreement on four of the eight markers but the captains and first officers only agreed with the ratings for the "communication" marker.

A closer inspection of the data indicated that the ratings of first officers were more discriminating. They did not seek to present their performance in an artificially inflated score, rather they were more severe on themselves. The most likely explanation for this result was suggested by airline check and training captains. When first officers complete their training they will have been trained to and assessed at a very high standard. Because first officers are not generally involved in the formal assessment of other pilots, the higher-than-average standard expected in a training environment may be the only exposure that they have had in rating operational performance. This may mean that if a pilot self-reporting system were to be introduced, comprehensive training would need to be an integral part of the package, as would be expected for any new program.

How can pilot self-reporting be applied?

One potentially valuable application of pilot self-reporting in the field of flight data monitoring (FDM) is supported by Reisinger et al (2005) who argue that the FDM system could be more efficient if it could be matched to a formal system of operational crew self-reports explaining the details of the flight. They propose that flight crews should conduct their own flight data analysis by being permitted access to the FDM data from their own flights thereby enabling them to add value to the flight data, such as potential threats and errors made, along with their personal coping methods and management strategies. The objective is to gain a greater insight into why certain decisions were made in flight. The researchers propose that if each pilot is aware of his personal statistics, he/she can tailor his/her future training accordingly.

Airbus has been thinking along similar lines with an option that it has made available on the A380. The new design allows the pilots to access and download from the cockpit a profile of the flight they have just completed prior to exiting the aircraft (Airbus 2005).

During the pilot self-reporting study at easyJet, the Safety Department requested that pilots provide open comments on topics such as, air traffic management, airports, and ground handling. Analysis of these comments provided consistent empirical data on a range of issues, such as separation problems due to traffic management at one particular airport, increasing problems with FOD at another airport, and a range of developing ground handling issues that with early intervention by the company at the management level could possibly be resolved before contributing to an accident or serious incident.

Bringing out the best in pilot self-reporting

To encourage active participation by line pilots and accurate data in the self-reporting process, it is recommended that the following points be recognized:

- The company should already have developed a mature safety culture where both management and pilots work together to achieve common goals in safety improvement.
- If a pilot self-report system is to be introduced, it must have the commitment and support of senior management and the unions. Agreement must be made in advance concerning issues of data security, participant anonymity, and for what purpose the data will be used.
- Emphasis needs to be placed on the fact that such a system is not looking at individuals. All data are combined and used in aggregate form only. There is no personal threat to any participant. The results of such a program should only be concerned with identifying safety trends across the organization.
- Great care should be taken in the design of the data-gathering system. Only information that can be, and will be used, to improve the safety of the operation should be collected.

Photo 4. Pilots were asked to comment on ground handling, ATC, airports, etc.

- The tasks required of the pilots should be well defined, with clear user directions, and any individual rating scale should be behaviorally based.
- The protocols should be intuitive and easy to work with, so that the introduction of an additional pilot requirement is undemanding and has a low impact.
- A focused training program should accompany the introduction of any new system. Promotion of the system is recommended by way of in-house magazines, posters, and other company-specific methods. The use of advocates and role models is extremely beneficial in order to ensure a smooth introduction to the program.
- Pilots need ongoing feedback if a self-reporting system is to remain "alive," viable, and dynamic. They must see evidence that problems they have identified are being acted upon.
- Any self-reporting system should be periodically reviewed and evaluated to ensure that the system is still achieving its aims.
- One advantage of such a system is that pilot self-report protocols can be easily altered for future data collection to reflect changing operational requirements.
- A pilot self-reporting program should be a component of an airline's integrated safety management system (Burdekin, in press).

With the adoption of a tailored design to suit individual airline operations, it is suggested that regular pilot reports on relevant safety issues could be adopted as an added component in the preventative accident and incident "toolkit." A structured program of pilot self-reports would enhance the factual information that is presently gathered from other sources, such as FDM, audits, and so on, to provide the explanation of "why it happened" to the "what happened" data.

Empirical evidence obtained from both civil and military pilots has shown that "listening" to highly trained and situationally aware pilots at the frontline of airline operations by introducing a structured pilot self-reporting system can provide an additional, and potentially very effective, tool to help break the accident chain by the early detection and rectification of problems in the aviation system. ◆

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