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Air Safety Through Investigation

Proceedings of the 41st Annual International Seminar

'Investigating ASIA in Mind–Accurate, Speedy, Independent, and Authentic'

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ISASI 2010 SAPPORO

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PREFACE
ISASI 2010: *Konichiwah*

By Frank Del Gandio, President

Konichiwah, good morning, and welcome to ISASI 2010, and welcome to Sapporo. I hope everyone had a pleasant trip to Japan and this beautiful city. I will start by thanking our hosts, Japan's Transportation Safety Board, and especially Dr. Yuki Kakimoto, who co-chaired the Technical Committee. Dr. Kakimoto showed great patience when dealing with us from 8,000 miles away. She is a talented and gracious person.

This is ISASI's first seminar in Japan, but it is the third seminar since 2002 in Asia and our fourth in the Asia-Pacific region. Our Japanese colleagues have selected a beautiful setting for this seminar. It is a city known for its parks and its mountains. Those mountains explain Sapporo's status as an Olympic city, having hosted the 1972 Winter Games. The same mountains explain why Sapporo is the home of a world famous Snow Festival, or "Yuki Matsuri." If you are not familiar with the Snow Festival, I suggest you search the Internet because you will see that the snow sculptures at this festival are truly stunning.

Sapporo also is the home of the Nippon Ham Fighters of Japan's Pacific League. The bad news for visiting baseball fans is that you will have to travel to the Seibu Dome near Tokyo or to the Yahoo Dome in Kyushu in southern Japan if you wish to see the Ham Fighters play baseball this week.

Instead of baseball, you will be treated to a seminar that is full of high-quality presentations. Each year the technical program at our annual seminar gets better and better. ISASI Sapporo will be no exception. By the close of the seminar on Thursday, I think you will agree that this year's technical program was very strong.

The theme that our Japanese hosts selected for the seminar does a very nice job of defining basic objectives for any accident investigation: Accurate, Speedy, Independent, and Authentic, or ASIA. Investigations indeed need to be technically sound and accurate. They also need to be accomplished as quickly as possible, but without threatening the technical integrity of the investigation.

Integrity also requires that investigations remain independent of political pressure and free of criminalization if they are to be credible and if the knowledge gained from the investigation is to help prevent future accidents.

ISASI has always advocated for the independence of accident investigations. We recently emphasized this by issuing our first formal endorsement of a public policy. In that endorsement, we joined several other international aviation organizations to advocate for the universal decriminalization of aviation accidents. Criminalization of accidents or, for that matter, overt political influence in an investigation damages our ability to prevent future accidents and therefore is not in the public interest.

Finally, investigations need to be authentic. They need to be

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more than accurate; they need to be thorough, with all possibly pertinent issues examined, and with the use of all techniques necessary to ensure that we fully understand an accident. This is a good prescription for the standards by which we can judge the quality of investigations. You will hear multiple presentations this week that directly address those requirements.

For example, several presentations will address recovery technologies and innovative tools and techniques for understanding what happened and why. Other papers will explore the analysis of operational data and confidential reporting systems that apply the knowledge gained in order to prevent future accidents. Other papers will focus more narrowly on aviation issues, trends, and challenges in Asia. I am confident that you will not be disappointed in the topics nor in the quality of the presentations.

In my description of the presentations and the theme of ISASI 2010, I mentioned the idea of prevention several times. Prevention obviously is the reason we investigate accidents. Otherwise, our investigations would have no point. We will never reach a level of zero risk and we know that although the system continues to get safer year after year in most of the world, recent experience tells us that we still have work to do.

Actually, the recent accident record has been somewhat mixed. In 2009, the world aviation community had the fewest hull losses, by far, in the history of civil aviation. Measured by hull losses, the world accident rate in 2009 was 30 percent lower than the previously best year on record. Yet fatal hull losses rose slightly in 2009, and the number of fatalities increased significantly compared to 2008. So, when measured by hull loss rates, 2009 was the safest year ever. Yet, we had more fatal hull losses in 2009 than in 2008, and the number of fatalities exceeded 2008 by more than 200.

At this point, 2010 appears to be developing with a similar story. We can expect the number and rate of hull losses to be even lower than in 2009. However the number of fatal hull losses and the number of fatalities both are likely to be higher than in 2009. By the end of August, we already had Ethiopian Airlines in Beirut with 82 fatalities, Afriqiyah in Libya with 103 fatalities, Pamir Airways in Afghanistan with 44 Fatalities, Air India Express with 158 fatalities, 12 fatalities on an Antonov 24 in Russia, Airblue near Islamabad with 152 fatalities, 42 fatalities in the recent Henan Airlines accident in northeastern China, plus several fatal cargo hull losses that killed almost 20 crewmembers.

We also had a non-fatal hull loss in late July at Riyadh that illustrates why everyone in aviation safety needs to be cautious about preliminary information. The early information we received at FAA on this accident included the following:

- The airplane was a Boeing 747.
- The flight was a scheduled passenger service.
- The aircraft had suffered a severe inflight fire.
- The flight crew had declared an emergency.
- The ensuing crash led to "multiple passenger fatalities."

All of this, of course, was wrong. The aircraft was an MD-11, not a 747; it was a cargo flight with just two pilots onboard, not a passenger flight; it involved a hard and bounced landing with no inflight fire; no emergency was declared; and, finally, rather than "multiple passenger fatalities," the only injury was a non-life-threatening injury to the first officer.

Though this accident produced an unusual amount of misinformation early on, we often receive wildly inaccurate information immediately after an accident, whether the accident occurred in the United States or elsewhere.

Prevention obviously is the reason we investigate accidents. Otherwise, our investigations would have no point. We will never reach a level of zero risk, and we know that although the system continues to get safer year after year in most of the world recent experience tells us that we still have work to do.

The fatal accidents I mentioned here, plus the non-fatal case in Riyadh, make two simple points that I always note at ISASI seminars: again, accident investigators still have work to do, and we need to remain professional, with open minds that are not biased in any way by early reports. This seminar will help all of us here to do our jobs just a little bit better.

I will close with my usual recommendation. Please take advantage of all the knowledge that is in this room. We have real expertise from all over the world on all kinds of aviation and investigative issues. If you want a better understanding of some aircraft system, of an operational issue, of some safety process, or a particular accident, someone in this room can help you. If you cannot find the person, we can try to help to find the right person to answer your question. Please take advantage of the knowledge that is all around you, and please share your own knowledge with others in this room.

Finally, enjoy yourself while you are in Sapporo. It really is a beautiful city in a beautiful part of Japan. Find some time to walk around the city and consider staying for an extra day or two so you can see some of the mountains and parks and so you can enjoy the city.

Again, my thanks to our Japanese hosts, and I hope and expect that each of you will help to make this seminar a success.

Thank you. ◆

KEYNOTE ADDRESS
A Japan Transport Safety Board Air Safety View

By Norihiro Goto, Chairman, JTSB

(Remarks presented by Chairman Norihiro Goto in his keynote opening address to the ISASI 2010 air accident investigation seminar delegates on September 7 in Sapporo, Japan.—Editor)

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Author Norihiro Goto, chairman, JTSB, and keynote speaker at ISASI 2010.

Good morning everyone. It is my honor to be able to deliver a keynote address to our colleagues, ISASI members.

It is well known that ISASI is ever pursuing air safety through accident investigation. And together with this objective of ISASI, the Japan Transport Safety Board JTSB) is aiming to prevent the recurrence of an accident or a serious incident and is also aiming to mitigate damage caused by an accident even if it unfortunately recurs. These preventions and mitigations are addressed based on the found causes of an accident or a serious incident.

The JTSB

The JTSB was established on Oct. 1, 2008. It originated from the Aircraft Accidents Investigation Commission (AAIC), which was established in 1974. This establishment of the AAIC was urged then because more than a couple of very serious aircraft accidents, including a midair collision, occurred during the several years before 1974. Meanwhile, railway accidents continued to occur. And two serious railway accidents in 1991 and 2000 motivated the then AAIC to include the investigation of railway accidents and serious incidents, and the AAIC eventually became the Aircraft and Railway Accidents Investigation Commission (ARAIC) in October 2001.

In January 2010, the International Maritime Organization adopted the Casualty Investigation Code, which prescribes separating the cause finding and the disciplinary function, into the Safety of Life at Sea (SOLAS) Convention. The ARAIC was reorganized by merging with the Cause Finding Portion of the then Japan Marine Accident Inquiry Agency, which was established in 1949, into the current system, the JTSB.

The JTSB deals with three modes—aviation, railway, and marine. Figure 1 shows a recent accident example in each mode. We have eight regional offices across Japan: from north to south at Hakodate, Sendai, Yokohama, Kobe, Hiroshima, Moji, Nagasaki, and Naha as seen in Figure 2. These regional offices treat marine accidents and incidents, but they also have the responsibility to offer help, such as logistic supply, to investigations in other modes.

The JTSB

1. conducts investigations to determine the causes of aircraft, railway, and marine accidents/serious incidents and damage caused by the accidents.
2. provides recommendations or opinions, based on the findings of the investigations, to relevant ministers or parties involved concerning the measures to be taken to prevent the recurrence of accidents/incidents and to mitigate damage caused by accidents.
3. conducts research and studies to fulfill the above-mentioned duties.

Regarding these three duties, everyone here understands what they mean, and can correlate them with what each one is working for. There is one problem, though, among these three duties. That is with regard to the third duty. Each investigation board or committee or commission has a number of investigators with a number of specialties. However, there are various accidents, and there may be some that present investigators find quite difficult to handle in terms of specialty and field. A particular

Figure 1. Recent accidents in Japan in three modes.

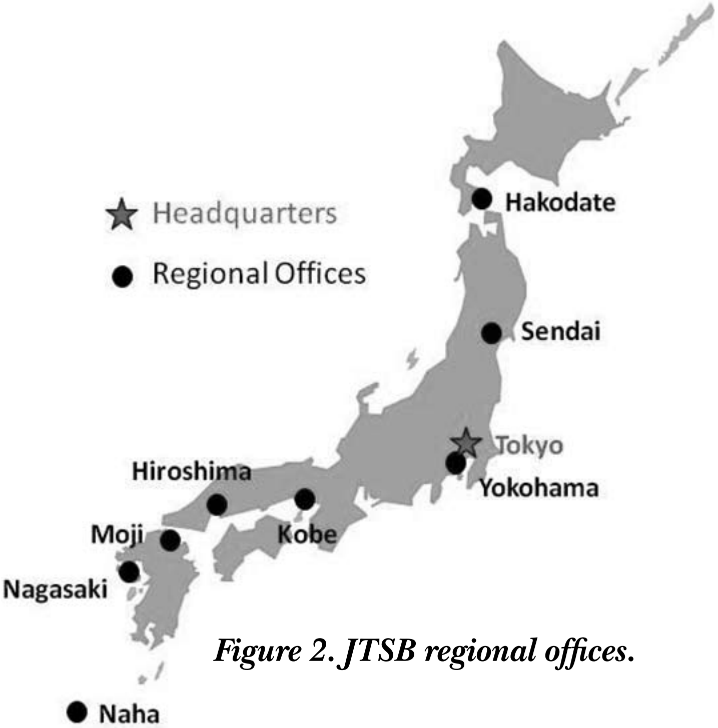


Figure 2. JTSB regional offices.

Figure 4. Domestic accident rates in Japan.

specialty is needed sometimes, and at other times especially deep professionalism is required to look into the cause of an accident. Every once in a while, we do not find appropriate investigators, or we do not have research facilities capable of a particular analysis. For such a case, we have to rely on the cooperation of research institutes and/or universities. In our case, the cooperation of national research institutes is encouraged by law in the phase of tests and research.

In addition, we have to pay attention to the attributes that accompany a so-called public investigation in order to carry out those duties. As the NTSB chairman mentioned at the previous ISASI meeting in Orlando, Fla., there are three critical attributes: transparency, accountability, and integrity. We want to raise the bar in all three of these important areas. But we also have to consider the extent to which the bar could be raised, depending on the boundaries that each country has. This is a very complicated problem, which continues to be addressed in terms of culture and the judicial system of a country. I hope discussion will take place here regarding this issue.

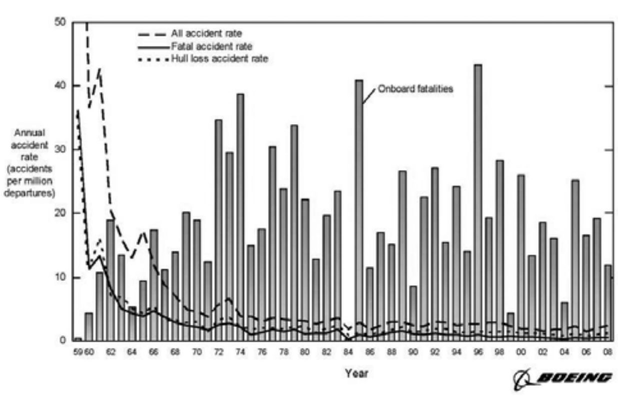


Figure 3. Worldwide accident rates (http://www.boeing.com/aboutus/govt_ops/reports_white_papers/commercial_jet_airplane_accidents_statistical_summary.pdf).

CAUSES OF ACCIDENTS

1.1 Pilot Error
Includes pilot incapacitation

1.2 Pilot Error (weather related)
Pilot error brought about by weather-related phenomena

1.3 Pilot Error (mechanical related)
Pilot error brought about by some type of mechanical failure

1.4 Other Human Error
Includes air traffic controller errors, improper loading of aircraft, fuel contamination, fuel starvation, and improper maintenance procedure

2 Weather
Includes lightning

3 Mechanical Failure
Includes design flaws and cargo hold/cabin fires

4 Sabotage
Includes explosive devices, shoot downs, and hijackings

5 Other Causes

Figure 5. Causes of accidents.

Tasks for the future

Figure 3 shows the accident rates of the worldwide commercial jet fleet from 1959 through 2008. Boeing compiled these statistics for jet aircraft heavier than 60,000 pounds, and they do not include non-fatal injuries resulting from atmospheric turbulence. You can see that the annual accident rate, accidents per million departures, is converging to a certain constant. On the other hand, Figure

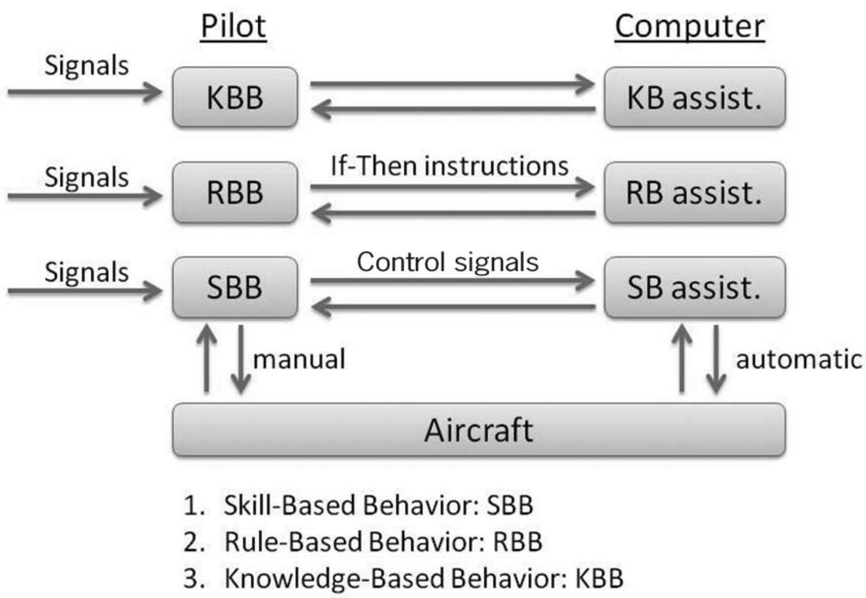


Figure 6. Hierarchical pilot behavioral model (J. Rasmussen, 1986).

4 shows the domestic Japanese statistics for 1974 through 2008. These statistics are for commercial aircraft heavier than 12,700 pounds and include non-fatal injuries resulting from atmospheric turbulence.

As far as Japanese domestic statistics are concerned, there have not been any fatalities since 1986 for the commercial aircraft included in Figure 4. It should be emphasized that we have been very fortunate because we've had serious accidents during this period, including the belly landing accident of a Bombardier-8-402 at Kochi Airport on March 13, 2007, and the aircraft fire accident of a Boeing 737-800 at Naha Airport on August 20, 2007. These accidents fortunately resulted in no fatalities because of the crews' and passengers' calm and composed handling of the situations.

Although these Japanese statistics looks quite bumpy because of a different treatment of the population, the average trend for the past 20 years looks the same as the worldwide statistics: both are converging to certain constants. This points out that if we take into consideration the tendency for increases in annual departures the absolute number of accidents is increasing.

What we have to keep challenging should be the decrease in the absolute number of aircraft accidents. So we want to direct our interest to the causes of aircraft accidents.

Causes of accidents are diverse as seen in Figure 5. The broad category of human factors from 1.1 through 1.4 remains the leading cause of aircraft accidents.

As a result of J. Rasmussen's work, pilots' control behavior can be modeled and classified into three levels as seen in Figure 6.

The lowest level shows skill-based behavior (SBB). SBB is essentially represented by manual control, and is observed in the takeoff and landing phases or in the phase in which automatic flight control systems (AFCSs) are disengaged because of such effects as turbulence. But for freight cargo planes, for instance, pilots sometimes report in interviews that they at times disengage AFCSs intentionally and employ SBB for training in order to keep their manual control skills within a certain level.

It seems that there have been cases in which such manual control was not successful because of other effects such as turbulence and/or downdraft, which led to an accident at the approach, flare, and, landing phase.

As an upper level is rule-based behavior (RBB). If a pilot employs RBB correctly, together with engaging the AFCS, a commercial flight can be carried out smoothly. But note that the success of a flight with RBB relies on the normal operation of all the flight equipment, including computers and sensors on board.

If a pilot has trouble with flight systems or experiences unexpected changes in flight environments, knowledge-based behavior (KBB) is required. In a KBB situation in which a pilot cannot expect a flight management computer system to work normally, the pilot is required to behave more intellectually and creatively. Situational awareness is most important, and it is acquired with the help of crew resource management. Based on situational awareness, the pilot determines how to cope with the situation. One problem a pilot faces in such a situation is that if the AFCS is not working, then the AFCS counteracts the pilot's action to cope with the trouble. This conflict led to the idea of the so-called human-centered automation. An example of this is when a pilot exerts a control force greater than a certain amount to a control column or wheel, a relevant automatic control system in operation is disengaged so that the control is returned to the pilot's charge. But is this the only way to realize human-centered automation? Is there another way? This question might be one we'd like to discuss at ISASI.

Cooperation and coordination

Now I would like to move to a different topic that is very important to an accident investigation: cooperation and coordination, especially international cooperation and coordination of related countries to find out the causes of an accident. I'd like to use a real example to talk about this topic. Take a look at Figure 7.

Figure 7. An aircraft fire accident, Aug. 20, 2007, Naha, Okinawa, Japan.

This accident occurred on Aug. 20, 2007, at Naha Airport in Okinawa, Japan. China Airlines scheduled Flight 120, a Boeing 737-800, landed at Naha Airport (from Taiwan Taoyuan International Airport). Immediately after the engine shut down, fuel that was leaking from the right wing caught fire and the aircraft was engulfed in flames.

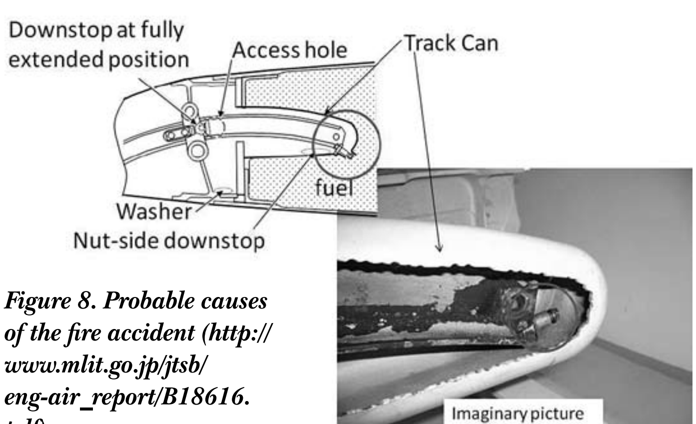


Figure 8. Probable causes of the fire accident (http://www.mlit.go.jp/jtsb/eng-air_report/B18616.pdf).

On board the aircraft were the captain, seven crewmembers, and 157 passengers, including two infants. All evacuated safely, and no one suffered fatal or serious injuries. However, the aircraft was consumed by fire leaving only a part of the airframe intact.

The fire started around the No. 2 engine, but because of the wind direction from right to left, the left side of the aircraft suffered the greatest damage.

An investigation was started. Because the aircraft was manufactured in the U.S., the operator was Taiwanese, and the accident happened in Japan, the investigation team inevitably had an international make-up, just like many other aircraft accident investigations.

The Aviation Safety Council (ASC) of Taiwan investigators joined the on-site investigation on the second day, and the U.S. NTSB joined the investigation on the third day.

As the result of this international investigation, the cause of the accident was determined. A downstop assembly of the slat deployment mechanism escaped from the aft end of the main track, falling off to the base of the can. Due to the slat retraction, the assembly was pressed against the track can wall, which protruded into a wing fuel tank, eventually creating a hole through which fuel leaked. This fuel leak was finally ignited by the hot engine exhaust gas. Figure 8 illustrates the probable causes. Contributing to this finding were the knowledge and experience of each of the teams that consisted of the international investigation party. As shown in this example, international cooperation and coordination are very important factors in carrying out a successful investigation.

The JTSB is developing such international coordination by signing written agreements with the BEA (France), the ATSB (Australia), the KARAIB (Korea), the CAAC-AS (China), the ASC (Taiwan), and the AAIB (Singapore). We hope that the number of countries will increase in the future.

I hope that through this presentation air safety will be enhanced further. ◆

LEDERER AWARD

Mike Poole: 2010 Jerome F. Lederer Award Recipient

By Esperison Martinez, Editor, *ISASI Forum*

Michael Poole, right, accepts the ISASI 2010 Jerome F. Lederer Award from President Frank Del Gandio.

Presentation of the Lederer Award is a major highlight of the Society's annual seminar and the main event of the awards banquet marking the close of the seminar. And the ISASI 2010 Sapporo banquet was no exception. The evening was filled with gaiety, rekindling of tin-kicking friendships, and abundant peer respect. The elegantly served meal was a napkin dab away when President Frank Del Gandio said: "This is the time when we give away the coveted Jerry Lederer Award."

The Society presents its annual Jerome F. Lederer Award for outstanding lifetime contributions to technical excellence in furthering aviation accident investigation and achieving Society objectives. ISASI is an organization dedicated to enhancing aviation safety through the continuing development and improvement of air accident investigation techniques. Jerry, as he preferred to be called, joined ISASI in 1965 and was long recognized as the "Father of Aviation Safety." His aviation lore stretches back to the time of wooden wings and iron men and forward to NASA and manned space flight. He "flew west" at age 101 in 2004.

In calling ISASI member Michael Poole forward as this year's recipient of the Jerome F. Lederer Award, President Del Gandio recounted some Lederer lore. He said, "I'm sure many of you in this room don't know about Jerry and never met him. I can remember the time when some students attending a seminar got the chance to sit and talk to him. Later they said it was the most exciting point of their lives. Jerry had that effect on you.

"I know, because that's the way I was touched. Way back in '82 I heard the old guys, like I am now, talk about Jerry. I thought, "Just to shake his hand, that would be enough." In '86 I was Society secretary and the only Society officer at the Munich, Germany, seminar. I got to talk to him every day. It was an enduring and everlasting connection. He called me often. And if I didn't hear from him for a month, I called him to make sure he was still alive."

Del Gandio continued to regale the dinner group with "Jerry" stories, including the time when then FAA Administrator Marion Blakey, speaking at a Society seminar, presented Jerry a plaque, only to overhear the ever funster say, "I would rather have a kiss." She obliged.

Remembrances over, President Del Gandio said that the 2010 nominations garnered five entries for consideration by the 12-member Award Committee, chaired by Gail Braden. The review process ended with selection of Michael Poole, a member of the Canadian Society.

Del Gandio then turned to the recipient standing by his side and with a broad smile said, "It is my pleasure to introduce you to Michael Poole, our Lederer Award winner." He continued with Michael's background.

"Mike is a professional engineer with a current pilot's license and is recognized internationally as an expert in the field of flight data analysis. He started his career in the field of accident investigation in 1977 and worked for more than 20 years with the Transportation Safety Board of Canada. During his years at the Board, his accomplishments contributed to a better understanding of the issues involved with flight data analysis. For the last 15 years of his career at the TSB, he developed and was the head of the flight recorder and performance laboratory. He was the Flight Recorder Group chairman on behalf of the TSB on all major accidents in Canada, including Swissair 111 as well as several international accidents.

"Mike was the researcher and author of the light bulb filament impact dynamics study. This research was presented to ISASI in 1986 and is the international standard within ICAO on how to

PHOTOS: ESPERISON MARTINEZ

analyze light bulb filaments to determine if they were on or off during impact forces. He then shifted gears to flight recorders and was responsible for initiating and driving the development of the Recovery Analysis and Presentation System (RAPS) for flight data analysis in his early days at the TSB.

"Mike's innovative and unique approach to using software to decode the black box instead of relying on the recorder manufacturer's interface was the first system in the world that enabled investigators to accurately recover data dropouts. In 1986, he became the first person worldwide to use flight data to develop an interactive 3-D flight animation on a mini-computer. He was a leader in the use of animation systems and the ethics of how they should be used objectively so as not to be misleading since 'seeing is believing.'

"The software developed under his leadership was used to recover data on Tornados for the German Air Force in 1989 as prior to this data were lost every time the aircraft executed a high 'g' turn. This technology was also used for the first time on a major civil accident—1991 Bangalore, India A320—to recover data initially lost during the first impact. This radically changed the outcome of the investigation as the investigators initially suspected engines to be a factor, which was subsequently discounted when the missing data were recovered. He was also a pioneer in applying digital audio analysis techniques to cockpit voice recordings.

"Ever creative in business solutions, Mike created a 'specific purpose account' in Canada whereby Germany, the U.S., France, and Australia contributed to co-fund the development of the unique TSB software replay system culminating in international collaboration on the software development and its eventual commercialization to Flightscape in late 2001 to enable other countries to use the TSB technology. Mike was a co-founder of Flightscape and is a now a member of the executive management team at CAE Flightscape, after CAE acquired Flightscape in August 2007.

"The Flash Air accident in Egypt was the first accident in history in which the state of occurrence (investigating authority), state of manufacturer, state of passengers, and the aircraft manufacturer all used the same flight data analysis software supplied by Mike's company, significantly improving the investigation progress and trust. Mike assisted several countries with the development of their lab capabilities both from when he was at the TSB and in the private sector. He has represented Canada at ICAO on the FLIREC (Flight Recorder Panel) where he succeeded in establishing FOQA as an ICAO standard. He has also represented the TSB at EUROCAE for international flight recorder standards.

"Mike is a long-time member of ISASI and has presented papers at many seminars. He is a long-time friend of mine and of this organization. Mike, it is my great pleasure to present you the 2010 ISASI Jerry Lederer Award. Congratulations!"

"Mike's innovative and unique approach to using software to decode the black box instead of relying on the recorder manufacturer's interface was the first system in the world that enabled investigators to accurately recover data dropouts. In 1986, he became the first person worldwide to use flight data to develop an interactive 3-D flight animation on a mini-computer. He was a leader in the use of animation systems and the ethics of how they should be used objectively so as not to be misleading since 'seeing is believing.'"

When the thunderous applause had quieted, Poole, standing at the lectern, looked out at the audience and said, "This is indeed a surprise and an honor." He then looked down at his tropical stark white linen vested suit and said, I want to start off by explaining why I am dressed like this! He went on, "I wasn't planning on being here. I was on my way to Nigeria…." He, of course, was unaware that he had been selected to receive the Lederer Award. But Barbara Dunn, president of the Canadian Society, knew and when she discovered he was going elsewhere on a business trip she e-mailed him this message: "You have to come. You have to come. You HAVE to come." But she didn't tell him why.

Mike, always independent minded, ignored her plea and

Lederer Award Selection Process

Presentation of the Jerome F. Lederer Award is the culmination of a thorough consideration of a nominee's experiences by the 12 member ISASI Awards Committee, chaired by Gale Braden. The selection task is not taken lightly and involves multiple steps that begin with an early announcement of the open nomination period, which begins with the close of the annual seminar and goes through May 31 of any given year.

Chairman Braden shares the selection process steps in the hope that it will entice a greater number of nominations for the prestigious Award. He urges members to begin their nomination consideration now and to watch for the nomination submission procedure in the January-March issue of the ISASI Forum, which is also available on the ISASI website. From time to time, through the Forum, he reminds the membership of the opportunity to submit nominees.

"When I receive a nomination letter, I evaluate it against the criteria and accept or reject it. If I reject it, I respond to the nominator and explain the reason for the rejection. Most often the rejected letters fail to discuss any degree of accident investigation activity. After explaining that accident investigation is the focus of the Award, the nomina tor will often rewrite the letter and make it acceptable.

"Our Committee consists of 12 members, including the chair. Six are from the USA and six are international. When the nominating season closes, I copy each letter and add a notation to it indicating if it is a 1st, 2nd, or 3rd consideration. I then mail it along with a ballot listing each nominee, a copy of the selection criteria, and a cover letter to each member reminding them to vote for three nominees by placing a 1, 2, or 3 beside their name on the ballot.

"The votes are weighted in the following manner, a number 1 vote is worth 5 points, number 2 is worth 3 points, and number 3 is worth 1 point. Thus, each member's vote is worth 9 points spread over any three nominees. When there are three or more nominees, a tie is almost impossible; but with only two nominees, a tie can occur. In such cases, the ISASI president has the prerogative of casting a tie-breaking vote. In both instances in which a tie vote occurred, the president determined both parties were deserving and allowed the multiple presentations."

The scoring criteria for selection used by Committee members follows:

- Selection of award recipient: Emphasis should be placed on original and remarkable contribution and personal effort beyond normal duty requirements. Mechanics, engineers, and others not at the top administrative or research levels should be considered for any outstanding contributions to accident investigation. The nominee's manner of operating, the duration and persistence of his (her) efforts, and his (her) standing among peers shall be considered. A nominee shall not be eliminated because of lack of popularity. Nationality, creed, sex, or race shall not be considered.
- In general, the contribution should be important to aviation safety, or if from another field of safety endeavor, one that could be applied to the aviation field.

Advancement should be clearly attributable to the person or associated group nominated (in case of many developments, it is often difficult to determine an individual who is responsible.)

- The dedication of the nominee to safety and aircraft accident investigation is a guiding criteria, such as his (her) imagination in working beyond the requirements of his (her) job to direct his (her) efforts to safety and accident investigation on his (her) own initiative. These efforts may be multifaceted.
- The contributions should have relatively broad application to the investigative area and may stem from a particularly effective manner of pursuing accident investigation objectives. The contribution need not be of recent origin so long as it has improved accident investigation. ◆

headed for Nigeria via France for some informal meetings. In France, he discovered the person he was to meet in Nigeria (chairman of the AIB, Dr. Sam Oduselu) wanted to also go to ISASI in Sapporo. Mike contacted Dunn and said, "It looks like I am coming to Japan after all." But he still did not know what awaited him. Thus he had not packed a traditional business suit, instead packing for very hot weather in Nigeria. Once the white tropical suit was explained, Mike answered the proverbial question: How did I get into aviation? He said: "My father was a fighter pilot, and it's in the blood." Then he added the real story, which follows in extracts from his acceptance speech:

"When I was about 15 years old…, I was in a school yard and met a young man who was taxiing a radio-controlled airplane around the parking lot. I couldn't believe it—it was just amazing. I started talking to him and I asked, 'Are you going to fly it?' He said, 'I don't know how to fly.' I said to him 'the winds are light, visibility is 93 million miles (we could see the sun). How hard can it be?' He then proceeded to advance the throttle and then came that magic moment when an airplane takes off. I say a 'moment' because it literally was a 'moment' as 8 seconds later we had what is called in our industry a major hull loss! I got my first taste of accident investigation due to this accident. I was the investigator, I was the primary witness, and as it turns out, I was also a primary cause, having persuaded him to fly when he should not have!"

His interest never waned. His college years were dedicated to aerospace engineering study and an internship with the Canadian Aviation Safety Bureau. The internship didn't come easy, and it wasn't glamorous. "But I got exposed to many cool things. One of them was the ground work in light bulb filament study." Unbeknownst to him, that exposure was his career grail.

Mike received a standing ovation and enjoyed the personal thanks that followed from the many people who have had the pleasure of his friendship over the years.

Down that career road, the exposure led to winning a light bulb filament impact study contract that required heavy research looking at light bulb filaments with a scanning electron microscope. That work led to development of a paper presented at an ISASI seminar in the mid 80s. The subject created a lot of interest and he caught the attention of the then executive director of the Canadian Aviation Safety Bureau (now the TSB) who was at the ISASI meeting where Mike presented. "Before I left for the ISASI conference, I asked about a job at the Bureau, but I was told that it didn't look too good—hiring freezes. When I got back home, I had a letter that told me I won a competition, which I never remember applying for, and that was the start of my TSB career." And that opened the doors to all his achievements and outstanding service to aviation that was outlined by President Del Gandio.

Mike also spoke to his association with ISASI: "In 1985 in Phoenix, my first ISASI, I was 25 years old and what did I see: I saw an opportunity to learn from a lot of experts. I saw an opportunity to hear a lot of diverse views. And I saw a truly multicultural, international organization. Mostly, I saw a community that I wanted to be part of. Since '85 I think I have missed maybe four seminars. Many people in aviation are really dedicated, and that's what I really like about ISASI. ISASI exemplifies this quality."

Throughout his shared recollections, Mike kept his narrative light, causing eruptions of laughter at some of his more humorous descriptions, especially when he took a few moments to poke fun at some of the highlights of the seminar. But he also had his serious moments, such as when he spoke of his award. "It's a great honor, but it also means I'm getting older and I would like to think wiser. Maturity has given me a very valuable and broad perspective, and ISASI has significantly influenced the way I think professionally and in my personal life. For that, I'm very thankful…. I stand before you wiser and older. But it's about you, the members of ISASI whom I deeply respect. Having received this award from my peers and colleagues is quite rewarding. I do thank you very much."

Mike received a standing ovation and enjoyed the personal thanks that followed from the many people who have had the pleasure of his friendship over the years. ◆

Past Lederer Award Winners

1977: Samuel M. Phillips
1978: Allen R. McMahan
1979: Gerard M. Bruggink
1980: John Gilbert Boulding
1981: Dr. S. Harry Robertson
1982: C.H. Prater Houge
1983: C.O. Miller
1984: George B. Parker
1985: Dr. John Kenyon Mason
1986: Geoffrey C. Wilkinson
1987: Dr. Carol A. Roberts
1988: H. Vincent LaChapelle
1989: Aage A. Roed
1990: Olof Fritsch
1991: Eddie J. Trimble
1992: Paul R. Powers
1993: Capt. Victor Hewes
1994: U.K. Aircraft Accidents Investigation Branch
1995: Dr. John K. Lauber
1996: Burt Chesterfield
1997: Gus Economy
1998: A. Frank Taylor
1999: Capt. James A. McIntyre
2000: Nora C. Marshal
2001: John W. Purvis and The Transportation Safety Board of Canada
2002: Ronald L. Schleede
2003: Caj Frostell
2004: Ron Chippindale
2005: John D. Rawson
2006 : Richard H. Wood
2007: Thomas McCarthy
2008: C. Donald Bateman
2009: Capt. Richard B. Stone
2009: Australian Transport Safety Bureau

How Can We Have an Authentic Investigation?

By Guo Fu, Deputy Director, Aviation Safety Office, East China Regional Administration, Civil Aviation Administration, China

Guo Fu is the deputy director of the Aviation Safety Office of the East China Regional Administration of CAAC. He has been an accident investigator of CAAC for more than 13 years, and has participated in a number of major accident investigations and hundreds of incident investigations. He was graduated in 1982 from the Civil Aviation University of China with a major in avionics and in 2000 from Shanghai No. 2 Polytechnic University with a major in computer technology application. He also holds a masters degree in public administration from Shanghai Jiaotong University, earned in 2005.

Abstract

The ultimate purpose of the safety investigation is to prevent reoccurrence of the similar event, and the best way of prevention is cause-targeted or related remedies adopted after investigation. Therefore, the "authentic" is the soul of investigation. But how can we achieve that goal is still a tough issue for the safety investigator. We have successful investigations, which in turn make contributions to aviation safety. However, there are still some other undetermined cases. My investigation practices told me that we do have some limitations that hinder us from getting the authentic investigation, of which the constraints are mainly the knowledge, technology, and the attitude toward cooperation. We have examples demonstrating that the authentic investigation is very hard and sometimes is made just by chance or by luck. In my presentation I would like to share with colleagues in the community my perspective on the authentic investigation and ways of doing so.

Introduction

Each unsafe event is different and has its own unique features, but as the aviation safety investigators we all clearly understand that our mission is to promote aviation safety by way of providing preventive recommendations based on causes or contributing factors revealed from an event. Sometimes I ask myself what a successful investigation means and how we can achieve it. A successful investigation bears certain features that have been hinted by the theme of this year seminar "Investigating ASIA in Mind–Accurate, Speedy, Independent, and Authentic." My investigation practices tell me that the authentic is the soul of the investigation, and one of the most difficult challenges is how to find or access the root causes, otherwise the recommendations will be just like shooting at random. I would like to share with colleagues in the community my perspective on the authentic investigation based on my interpretation and our investigation activities.

Discussion

1. "Accurate" is the key to a successful investigation

"Accurate" means free from error, conforming to fact or truth, and its synonyms are exact, precise, and correct. Safety investigators will always put causes of an event as the first things first in our investigation. It is not merely the need for understanding the causes but preventing reoccurrence as well. Our follow-up remedies and recommendations will be more precise and target-oriented, and the prevention will be surely effective if we can accurately identify the root causes of an event. The accurate investigation depends on the following components: well trained and qualified investigators, technical expertise and appropriate equipment, attitude toward the investigation, and sometimes luck.

Well-trained and qualified investigators are the first and indispensible component of the accurate investigation. Their qualification will finally determine the quality of the investigation. Well-trained means he or she has mastered the necessary knowledge for the investigation, including investigative procedures, means of evidence collection, on-scene self-protection, knowledge of the aircraft, etc. Qualified means he or she has both the technical competence and the analytic abilities for in-depth investigation; he or she has personal traits and experience necessary to perform the investigation.

An accident occurred to a foreign cargo flight last November in Shanghai. The airport security cameras had recorded the movement of the accident aircraft on the runway. Immediately after the accident, the airport staff screened recorded video and found the segment of the accident flight, and they told some of our investigators that they saw fire on one engine before it crashed, or the engine might have exploded before it crashed. Their story quickly got popular within the investigation team. Some of the investigators suggested that we should focus on the engines after they watched the playback of the video themselves, but one didn't agree and said that we could never narrow our attention at the early stage of the investigation. We then arranged a senior investigator to check. He reviewed the video carefully with his assistant, and checked it with the scene. He told me later that the accident aircraft in the video is very small due to the distance from the runway to the monitor and the low pixel of the camera, but they still could find that the "fire on the engine" only appeared at a constant interval, and finally realized that the "fire" was the wingtip strobe light flashes after comparing with other aircraft moving on the runway in the video and verified it in the runway vicinity.

The spirit of "never let any trace go without questioning" and "never follow a 'hear-say' without checking" shows an important trait an investigator must have. His or her experience, analytical skills, and comprehensive abilities will make the investigation accurate.

Technical expertise and appropriate equipment are the supportive elements to an accurate investigation. Nowadays the state-of-art technologies are wide applied in our new aircraft and it becomes more advanced and complicated technologically. We could never conduct a successful investigation if not technically prepared. The preparation not only requires the investigators to have the expertise for investigation, but the suitable equipment for field and laboratory investigation as well. Technical expertise will bring the

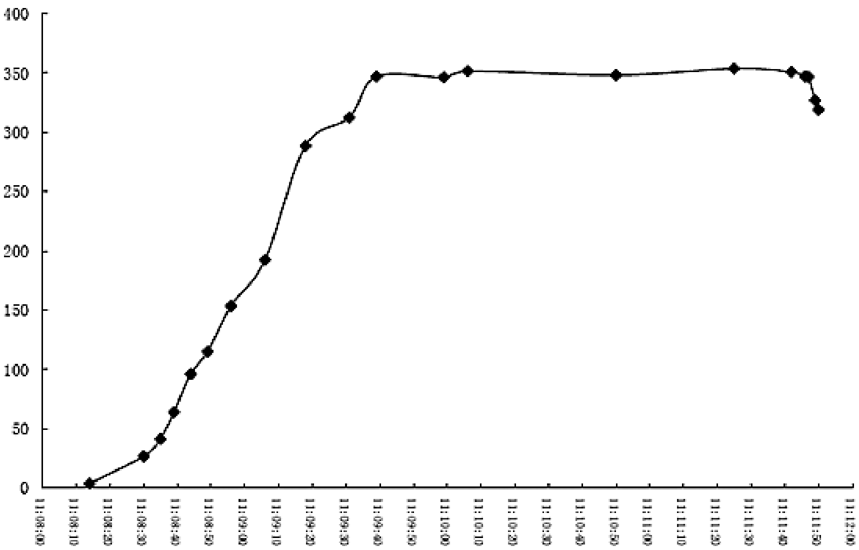


Diagram 1: Main rotor speed chart of the accident flight based on security video camera recording.

couldn't find any evidence from the CVR since it didn't have any recording track for the main rotor speed and furthermore it didn't work at the accident flight.

There are 25 security cameras on the ship, of which 3 cameras have recorded different phases of the accident flight from helicopter liftoff to falling into water in different positions. One video clip shows the whole process of the main rotor rotation from blade starting to turn to the helicopter leaving the deck. Our lab staff used his machine and software to count the number of blades within each frame at a fixed time frame, a special algorithm to calculate the blade rotational speed. His research precisely revealed the main rotor speeds at takeoff phase, and it reduced to below the underspeed aural warning threshold just 2 seconds after liftoff from the deck, which means what the captain heard is an underspeed warning rather than overspeed (see Diagram 1).

investigator's knowledge, experience, and insightful judgment into the investigation in a qualitative approach while the equipments will assist the investigators through a quantitative method that will provide with accurate measurement. The integration of the qualitative and quantitative methods will make the in-depth and accurate investigation a reality.

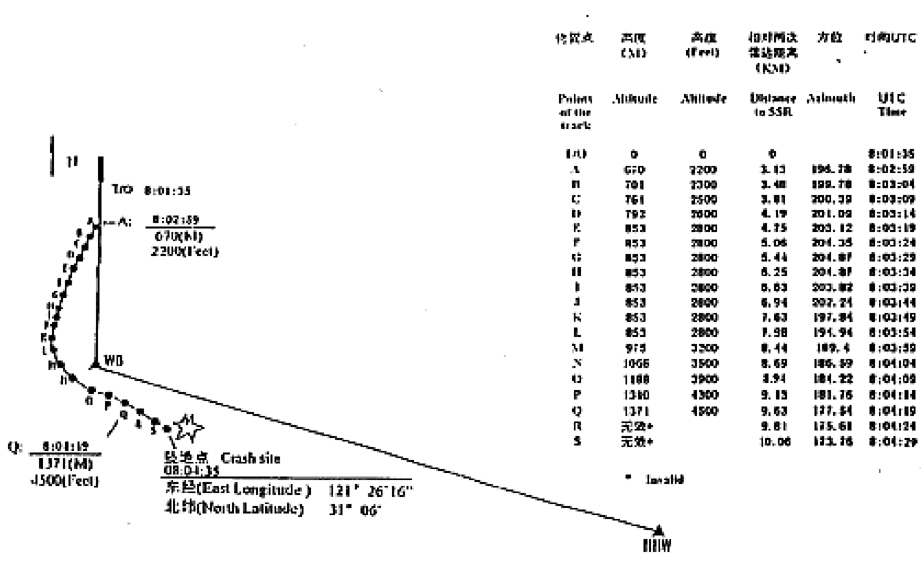
On April 12, 2009, a helicopter on a ferry flight crashed into water immediately after lifting off from a ship deck. The survival captain told us that he heard an aural warning of the engine overspeed during his maneuver approach to the portside of the ship, and then the helicopter descend into water no matter how hard he had lifted his collective level. Theoretically speaking, the scenario described by the captain was not correct, and we know that the theory can disprove his explanation. But it will be better if we can collect physical evidence to prove the theory in this accident. We should have gotten main rotor speed from the CVR because our regulation requires that helicopters shall at least record main rotor speed on one track of the CVR[1] if the FDR is not equipped. The investigation

We have reasons to believe that expertise equipped with technology and suitable equipment will be a great assistance to the investigation in revealing or accessing the causes in an accurate way.

Attitude toward the investigation means the attitude of individuals, organizations, or authorities involved toward the investigation, which is another important factor concerning the accurate investigation. The attitude varies sometimes in the investigation even though the standards[2] in Annex 13 have clearly stated the responsibilities of related the State to provide relevant information.

I once experienced an unwillingness to cooperate in our investigation. It was a cargo crash accident; it's my first participation (1999) in the major accident investigation. The only recorded information we had collected were CVR, air-ground communication, and radar plot. We soon got the transcriptions of CVR and air-ground communication, but had difficulty making a complete trajectory chart of the accident flight due to our technical incompetence to retrieve all the data recorded in radar. We know that the radar should have recorded some other points of the accident flight according to the flight time and radar rotation. We contacted with the representatives of radar manufacture in Shanghai for their assistance. They at first refused to provide the software to download the raw data from the radar by a number of excuses. With the help of the investigation authorities and several contacts, the manufacturer finally offered a means (special software) of extracting the data and told us that the radar had recorded two other targets of the accident flight but did not show on the plot for it took them as false data due to high descent rate at the time of recording though it still kept them in the memory. We could accurately make the complete chart at last (see Diagram 2).

Coordination difficulties in some of our investigations left cases unclosed—those are rare though compared to what we have finished, which reflected the consequence of



轨迹点 Points of the track	高度(M) Altitude	高度(Feet) Altitude	相对雷达站距离(KM) Distance to SSR	方位 Azimuth	时间UTC UTC Time
T/O	0	0	0		8:01:35
A	670	2200	3.13	196.78	8:02:59
B	701	2300	3.48	199.78	8:03:04
C	761	2500	3.81	200.39	8:03:09
D	792	2600	4.19	201.09	8:03:14
E	853	2800	4.75	203.12	8:03:19
F	853	2800	5.06	204.35	8:03:24
G	853	2800	5.44	204.87	8:03:29
H	853	2800	6.25	204.87	8:03:34
I	853	2800	6.63	203.82	8:03:39
J	853	2800	6.94	202.24	8:03:44
K	853	2800	7.63	197.84	8:03:49
L	853	2800	7.98	194.94	8:03:54
M	975	3200	8.44	189.4	8:03:59
N	1066	3500	8.69	186.59	8:04:04
O	1188	3900	8.94	184.22	8:04:09
P	1310	4300	9.13	181.76	8:04:14
Q	1371	4500	9.63	177.84	8:04:19
R	无效*		9.81	175.61	8:04:24
S	无效*		10.06	173.76	8:04:29

* Invalid

Diagram 2: Accident flight trajectory chart from second surveillance radar.

the negative attitude. We understand that each nation has its own requirements and standards to investigate an occurrence; but the problem is that when some thing occurred, mainly those concerning non-traditional failure like software-related control systems issues, and the post-event mechanical and functional examination and test are all satisfactory, you just don't understand the failure mechanism. Sometimes you have to take or accept what others give you. Consequently you will never know how to prevent from repeating, and don't know at what time it will appear again.

Here "luck" has nothing to do with the lucky numbers for lottery, and it doesn't mean that you are lucky enough to have 777 while playing the slot machine, but it does mean you never let slip any clue or evidence and make your "luck" to find or access the causes of an event. It's not a windfall, but the capability that is dependent upon one's analytic skills, comprehensive judgment ability, and experience in addition to his/ her knowledge and technical expertise, and if you are observant and conscientious you will have the luck to find evidence "by chance." Sometimes you are lucky just because the outcome of an occurrence makes your investigation easier.

The investigation with the security camera on the ship is an example of the lucky investigation. The luck is that not only the main rotor rotation was recorded in the previous helicopter falling into water case, but the whole process of the liftoff without hover and passenger compartment overloaded condition were revealed as well by the cameras. We couldn't have the luck to get all the video information containing the accident process if the ship wasn't equipped with the security cameras. We wouldn't find the luck in the cameras if we hadn't carefully searched the ship deck, and we wouldn't have the luck to find the causes of the accident if we hadn't thoroughly reviewed all the recordings.

The other two "lucky" investigations are consequence-related events. One is a general aviation accident in 2005, which caused the helicopter to crash into water during its mission to pick up the marine pilots from an outgoing container ship. Only the captain survived that accident, and he told me that his left foot went straight to the flight deck floor during his maneuver to lift above the containers. His helicopter turned quickly to right and fiercely spun immediately after his left foot went through the floor, he couldn't remember what happened afterwards. It was in the water he came to himself, and was saved by a rescue helicopter. Fortunately we found the left rudder pedal on one of the top containers on the ship. Further investigation disclosed that rupture of the left pedal was caused by design, processing, and quality control. You could never tell what had happened from the CVR though a weak sound of snap off could be heard if the captain hadn't survived and/or the pedal hadn't been found.

Another "lucky" investigation is about pilot incapacitation at landing. It concerned a modern jumbo jet passenger flight, and all phases of the flight were uneventful except landing. A "landing" instruction was given by the captain after an aural "minimum" was alerted, the copilot felt the aircraft had dipped toward his side with an abnormal high descent rate just after "100" was called by the synchronizer. He hardly pulled back the stick toward the left by instinct (the FDR revealed the copilot control input at 38 ft, 2 seconds before touchdown), then the aircraft touched down and veered off the runway from the side and then back to the runway. The captain regained his consciousness soon after the aircraft returned to the runway and asked copilot why he put his hand on the throttles and why the emergency vehicles were nearby. He never believed what the copilot told him and was 100% sure that he landed the aircraft himself not the copilot. Several careful and thorough medical examinations were conducted and found the captain's incapacitation at low altitude was caused by a transient loss of consciousness resulting from a petit mal epilepsy (absence seizure) due to a tiny insula cavernous hemangioma. His medical record revealed that he had a history of hypertension for 5 years. We might never know what had happened if the copilot didn't pull the stick and the aircraft crash. We wouldn't know the captain has a tiny insula cavernous hemangioma if his incapacitation was at high altitude and recovered within a short period of time. We have to admit sometimes that luck will help us in some way. Our investigation can never only wait for or rely on "luck," but we will never refuse "luck" when it comes to help us.

Accuracy is the key element that determines an investigation's success but can be easily affected by some factors including uncertainty.

2. "Speedy" reflects efficiency of the investigation

I interpret "speedy" with three different meanings from a safety investigator's point of view, which may vary from the conventional dictionary definitions. My first description of "speedy" is a timely action to collect any traceable evidence by all means. During the investigation, we will collect and secure any evidence in the scene search including eyewitness interview while the fresh memory is still there, or in the lab examination without any delay, especially those that will perish quickly or easily with time or in a certain environment. For instance, the marks left on the ground or grassland, fluids from the aircraft systems, recorded information, or people's memory, etc.

I learned lessons from an incident investigation. In 2007, a runway incursion occurred to a foreign airline in Shanghai Pudong airport, which caused an abort of another aircraft during its takeoff roll. We only seized the FDR, the CVR from the intruder (foreign) aircraft, air-ground communication record, and ground movement surveillance radar. We could hardly reconstruct a precise event sequence according to the statements from controllers and pilots on different airplanes. We used available recorded information but still couldn't exactly describe the sequence of abort action initiated by the crew and "stop takeoff" instruction by the controller, though in this case it is not as important as the causes of the incident. We could have reestablished the scenario easily if we had gotten the DFDR on another aircraft its elapsed time before it went through 26 hours.

The second explanation of "speedy" is to immediately issue safety recommendations if something is found obviously safety related at any stage of the investigation[3]. We once issued a safety alert to the industry when we found the accident helicopter's CVR without any track for recording the main rotor speed, and it didn't work at the accident flight before our investigation was finished. We keep in mind that we should recommend any preventive action considered necessary to be taken promptly to enhance aviation safety in the investigation, though it is seldom the case in our investigation.

The third interpretation of "speedy" is the efficiency, but this doesn't mean we will jump to the conclusion or haste to wrap up a case. Safety investigations are time-consuming activities; they are gradually understood. But that doesn't imply we will waste of our time. Actually, we still have pressures sometimes for an early final report not only from the superiors, public, but ourselves as well as even for the incidents due to workload. We investigate incidents in accordance with the provisions of our regulations and Annex 13, which count for the majority of our safety investigation. For us, some incident investigations, such as engine inflight shut down (IFSD), will take as long as almost an accident. It's not about the investigation itself, but several other factors will influence the progress. One is the priority getting lower as outcomes of new events that need our immediate response. The other influencing factor is the coordination between the manufacturers, the authorities of the State of manufacturer, even the visa application, factors like expertise and languages will also count.

In fact, our investigation revealed most of IFSDs have much to do with the design, manufacture and overhaul, certain remedies, improvement or redesigns have been adopted by the manufacturers after investigation. It could be quickly finished if we completed our report just by filling out a simple format titled with IFSD without further examination and analysis. The problems won't be solved if the investigation finished in a hurry.

Efficiency concerns about the time spent, but what is more the quality of output, which means less time with greater accuracy.

3. "Independent[4]" is the guarantee of an objective investigation

The main purpose of an "independent" investigation is to find or access the causes of an event by means of preventing any interested parties from interfering or pressure to the most extent during the investigation. Some elements, such as law, organization, and investigator's traits, are the basic requirements for ensuring an objective investigation. The independent investigation will be legally guaranteed if the relevant rules are set up in law or regulation. They will dominate and protect the investigative activities and people who conduct the investigation. It is better if we can have an "independent organization" since it is the carrier of the investigative activities, which is the second layer of protection from external interferences. It is the investigators who perform the investigation. They are the decisive factors, and their personal traits have a great influence over the investigation at last. Independence and integrity will act as the third layer of prevention and will further guarantee the independence of investigation.

We have many rules to follow if we conduct an air safety investigation in China, which include both international and domestic standards. In addition to Annex 13, provisions of our regulation list four basic principles that must be abided by if an investigation is conducted. They are Independent: Investigation shall be conducted independently; no any other organization or individual is allowed to interfere. Objective: Investigation shall be fact driven, objective, fair, and scientific and cannot have any intent of subjectivity. Detailed: Investigation shall analyze and determine the causes of the accident or incident and contributing factors, including any defect concerning aircraft design, manufacture, operation, maintenance, personnel training, company's management policies, and regulator's rules and regulations and their implementation. Thorough: Investigation shall not only analyze and determine the cause of the accident and contributing factors, but also analyze and determine factors that are not directly related the accident but have potential impact to flight safety and related issues.

According to our regulations (National Work Safety Accident Report and Investigation, or China Civil Aviation Regulation 395), the investigation function is conducted by different organizations depending on the consequences of an event. To be more specific, it is shared between the CAAC and the State Council or its authorized department, usually the State Administration of Work Safety (SAWS). SAWS is an affiliated organization of the State Council and it acts as the executive office of Work Safety Committee of the State Council. One of its major functions is to supervise the national work safety and conduct or coordinate investigation into significant major accidents, and major accidents that occurred within the territory of mainland China. As for civil aviation safety investigation, it will mainly investigate Significant major air transport accident, while CAAC investigates and major air transport accident, accidents, and Incidents. Actually, SAWS has the authority to investigate all the unsafe events, from incident to accident including general aviation accident and ground aviation accident if it has interest. I myself have experienced its supervision and involvement in the investigation. SAWS will conduct all types of investigation when it has its own aviation sector and enough professionals in the future. So right now we adopt a so-called two-leg investigation system in my point of view.

The majority of our investigation is incidents. This year up to now we have collected, processed and reported 585 unsafe events, of which 11 incidents we have investigated, some of them haven't finished yet. We also investigate so-called typical "other unsafe events," which means the unsafe event is not so serious as those of incident but still need our close attention. We have benefited a lot in improving aviation safety from the incident investigation. Our safety recommendations are issued not only to the operators, service providers, manufacturers, but also to regulator in terms of regulation revision or strengthening front line oversight. My investigation practices tell me that we rarely have outside pressure or interference, in fact our investigators enjoy a healthy environment for the investigation in addition to legal protection. We are always told to follow the four principles and stick to the standards by our superiors. The only pressure we have is the time.

I have two examples for your information. One case is about an incident that occurred to a flight which was far away from the localizer and below the published minimum safe altitude, and trigged the terrain warning during approach. The investigation revealed that the copilot was the PF and he wanted to perform a visual flight in good weather. A conflicting traffic made it difficult for him, and it was too late for the captain to take the flight. It was an incident according to our incident classification. One of my colleagues received a short message from the captain, asking to downgrade the nature of the event to avoid a bad record. We didn't change our judgment, and the conclusion of the event in the final report is classified as an incident.

Another case is about one of our inspectors; he is a captain and flies for a cargo airline in our region. He recently encountered a low-altitude windshear event during takeoff, and immediately reported to us after he returned. Before takeoff the crew found weather to the right alongside the runway centerline, and two airplanes, one jumbo and one regional jet, just departed without any weather report. They then decided to takeoff. A "windshear ahead" warning was displayed and a thunderstorm was detected soon after takeoff since the weather was moving toward the runway. To avoid the windshear and the thunderstorm they asked a detour, and then descend from 1,300 ft to 700 ft. We issued a notice to the airline that the crew member must be treated equally in addition to the safety recommendations.

"Independence" is the basic guarantee to find the root causes without outside manipulating. It is very difficult to have an absolute "Independence" due to different national institutions and traditions. The most important thing is that we shall have the law as the prerequisite, which provides a legal framework to protect the independent investigation. The investigators who have integrity are the critical force for an independent investigation if an event will be investigated internally. They may have all kinds of influences from different corners even though they have the legal protection.

4. "Authentic" is the soul of the investigation

When talking about the purposes of the safety investigation, the most popular saying is to prevent recurrence of the similar event by way of investigation and further to promote safety. In reality, the same or similar event does reoccur sometimes. Some of the reasons[5] are 1) Failure to recognize and identify the hazards correctly, 2) Failure to identify root causes in depth, 3) Failure to act appropriately to the causes, and 4) Failure to inform others in a more motivating way. The first two reasons are cause-related issues. It is obvious that we will effectively prevent the event from repeating if we can correctly identify hazards or root causes.

Authentic has the meaning of conforming to fact or origin, worthy of trust. Here I interpret it as data driven, no bias, detailed, and thorough; it means "factual" from the theme of this seminar. We understand that "accurate, speedy, and independent" are used to describe the requirements for the investigation from different aspects. "Accurate" means fact, truth, precise; "speedy" implies accuracy with less time; "independent" relates to finding root causes, and the result of their combination is "authentic," which shows the true value of the investigation. "Authentic" mainly relies on accuracy, efficiency, and independence, and comprehensively represent them as the soul of the investigation.

Conclusion

From the above discussion, we may comprehend that "authentic" is the soul of the investigation, which is on the basis of "accurate," "speedy," and "independent." The legal protection/the structural support will safeguard the investigation conducted in an independent environment and away from the external influence so that the conclusions will be objective; well-trained and qualified investigators equipped with advanced and necessary equipments and facilities will ensure that the evidence gathered is carefully reviewed or precisely examined and comprehensively analyzed; timely reaction will guarantee the prompt evidence collection and the remedy issuance accordingly in order to achieve greater accuracy in less time with effective prevention; and cooperative attitude will help to promote the ability of fact finding in addition to efficiency.

In so doing, our safety investigation, as part of safety management, will follow the path to a successful investigation through identifying hazards and revealing or accessing the root causes of an unsafe event in a proper way, and then we can make our recommendations or remedies cause targeted or related, make our industry a reliable system, and finally provide the public with a safe travelling environment and save people's lives and properties to the greatest extend possible. ◆

Endnotes

1 Similar to that requirement in Annex 6 (4.3.5.2 All helicopters of a maximum certificated takeoff mass of more than 3 180 kg up to and including 7 000 kg shall be equipped with a CVR, the objective of which is the recording of the aural environment on the flight deck during flight time. For helicopters not equipped with an FDR, at least main rotor speed shall be recorded on one track of the CVR; Annex 6).

2 5.14 Any State shall, on request from the State conducting the investigation of an accident or an incident, provide that State with all the relevant information available to it; 5.15 Any State, the facilities, or services of which have been, or would normally have been, used by an aircraft prior to an accident or an incident, and which has information pertinent to the investigation, shall provide such information to the State conducting the investigation; Annex 13.

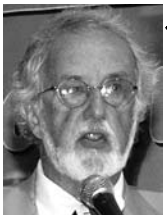
3 6.8 At any stage of the investigation of an accident or incident, the accident or incident investigation authority of the State conducting the investigation shall recommend to the appropriate authorities, including those in other States, any preventive action that it considers necessary to be taken promptly to enhance aviation safety; Annex 13.

4 5.4 The accident investigation authority shall have independence in the conduct of the investigation and have unrestricted authority over its conduct, consistent with the provisions of this Annex; Annex 13.

5 Ladislav Mika (MO4226), Czech Republic, and Thomas Fakoussa (FO3366), Awareness Training, Germany; "Go-Arounds: A Problem for Certain Pilots?" *ISASI Forum* (July–September 2003); 11-13.

A Quarter Century and Still Learning—Lessons From the JAL 123 Accident Investigation

By John Purvis (LW3002) and Ron Schleede (WO0736)



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***Ron Schleede** has spent more than 42 years involved in aviation safety, particularly international accident investigation and prevention. He spent more than 28 years with the U.S. NTSB and has worked worldwide as a consultant since he retired in July 2000. Before he retired, Ron was the director of investigations for air at the Canadian TSB. He has been a member of ISASI since 1975 and was named an ISASI Fellow in 2009. He was awarded the ISASI Jerome F. Lederer Award in 2002. During most of his career, Ron specialized in major aircraft accident investigation management and international aviation safety affairs. He also represented NTSB senior management during the JAL 123 investigation.*

Introduction

This paper is a joint effort between John Purvis and Ron Schleede. The authors were the lead investigators into the JAL 123 accident for their respective organizations, the U.S. NTSB for Ron and the Boeing Company for John.

Even though Ron will not be in Sapporo for this presentation, he contributed to it and reviewed its contents. The contents of this paper and the associated PowerPoint presentation are primarily John's viewpoints and his responsibility. This presentation will focus on the challenges posed by this accident and the personal lessons learned about the profession of accident investigation, ultimately stressing the need to build and maintain relationships. So readers will be treated to two perspectives of the investigation. Ron was doing more investigation management, interacting with the Japanese authorities for the NTSB, while John was often at the accident site or in the labs on behalf of Boeing. They saw things from different perspectives so their stories, and those of some others, may not always be in perfect harmony. The authors, obviously, approached events from different angles, especially during the early days of the on-scene investigation, and, even today, they do not always agree on how the inquiry progressed. This is especially understandable when trying to establish time lines and recreating scenarios 25 years after the fact with fading memories.

Throughout the paper we will highlight lessons learned from our experiences.

Part 1 of our paper describes the accident and the investigation, both the on-site portion and some of the early follow-on work. It will illustrate the different perspectives that individual professionals and their respective organizations bring to an accident investigation.

Part 2 describes issues that affected the investigation process positively or negatively. Some issues were technical in nature, some were at a personal level, and some involved important institutional challenges. For example, Japan's JAAIC (as it was known then) was pushed to its limit, yet the JAAIC did an extraordinary job. The JAAIC also chose to permit the U.S. delegation to participate fully in the investigation, though ICAO Annex 13 did not require it at the time. This was a brave decision on the part of the JAAIC, and it is to be commended for it. Part 3 concludes by emphasizing the importance of building and maintaining relationships and trust. The authors learned, and will illustrate in this presentation, how building and maintaining relationships can affect the successful outcome of a particular investigation, but also how it can and should influence professional investigators throughout their careers.

From this point onward the story will be related from John's perspective, and Ron's perspective will be noted as indicated.

Background

Twenty-five years ago, on Aug. 12, 1985, a Japan Airlines 747SR-100 (registration JA8119) took off from Haneda on a short internal Japan flight to Osaka. It eventually crashed at Osutaka Ridge, in mountainous territory approximately 100 km northwest of Tokyo, killing 520 of the 524 occupants.

After taking off and during climb out from Haneda, while approaching 24,000 feet about 12 minutes after takeoff, a loud bang was heard on board and the airplane lost cabin pressurization. About 4 minutes later, the crew reported the airplane to be uncontrollable. It continued flying for 32 minutes in phugoid and Dutch roll oscillations with heading and altitude being "controlled" essentially by engine thrust. All of the primary hydraulically powered controls had been disabled.

Ultimately, the primary cause of the accident was determined to be an improperly repaired aft pressure bulkhead in the airplane. The repair, accomplished by Boeing some 7 years earlier, had included replacing the lower half of the bulkhead. This necessitated splicing the upper and lower bulkhead halves. During the repair, it was found there was inadequate edge margin in which to install the usual double row of rivets in the connection between the upper and lower bulkhead sections. A splice plate insert was deemed necessary to accommodate the short edge margin. In order to "fit" the splice plate into the structure, it was cut by the repair team. This resulted in a section of the bulkhead splice joint being fastened with only one row of rivets where two should have existed. (Note: This does not indicate a "missing" row of rivets; it says that only one row went through the load-carrying part of the bulkhead.) After being installed, the incorrect repair could not be detected because all the joints had been hidden by sealant material. Eventually, the loads in this single row of rivets lead to multiple site fatigue cracking and eventual rupturing of the bulkhead.

Seven years later, this sudden release of the pressurized air from the passenger cabin into the tail of the airplane over-pressurized the aft potion of the airplane. The fuselage pressure relief doors were not sized for this volume of air and some escaped into the vertical fin, splitting it open. The top half of the fin and the entire rudder were lost. All four hydraulic systems were also lost and airplane directional control was essentially gone.

It turned out to be the world's worst single-airplane accident in terms of fatalities. It holds that tragic distinction even now. Some of the lessons learned in that accident are still applicable today. The "technical" lessons have been long since successfully applied, but some of the "softer" lessons can still benefit today's investigators.

Lesson 1: Avoid speculation.

At the time of the accident, I was the manager of Boeing's accident investigation group. We covered all events that occurred on Boeing commercial jet aircraft. In hindsight, as manager, I probably should not have been launching on an accident as our team leader, but the magnitude of the accident was not apparent at the time. I was only in my fourth year on the job; but because I firmly believed that in order to lead well, I needed to interact on a level playing field with peers, I planned to do at least one onsite accident annually. Just sitting in the office to "manage" or attend a periodic ISASI seminar won't cut it—you really need to be able to say you've "been there and done that." So I launched myself with the rest of the Boeing team to Japan that evening of August 12, Seattle time.

One of the reasons for choosing to lead this accident was early reports that indicated the accident was probably caused by a bomb in one of the aft lavatories. The common opinion from early indicators, including reports radioed from the airplane, pointed us in that direction, This was a common opinion among all of the people I was talking to, including the NTSB, in those chaotic hours leading up to our finally launching. How complicated could it be? How long could this investigation take? A week? Ha! A year later I was still traveling back and forth across the Pacific, sometimes being away for weeks at a time. In the early days, on one pair of back-to-back trips, I was in Japan for 6 weeks out of 7 weeks. This accident ultimately consumed the better part of 2 years of my time and it, along with two or three others, defined my career.

Herein is the first lesson learned: Avoid speculation. Keep an open mind. This lesson goes beyond blindly agreeing with current sources of speculation; it also means to not speculate inside your head, lest it lead you to some poor judgments up front.

However, there is a difference between speculating and making informed decisions based on your best technical knowledge. For example, you need to do that to send the correct experts. In the case of JAL 123, the line between the two was perhaps somewhat blurred.

Ron's recollections begin with his memories of the notification, launch, and his subsequent dispatch to Japan. Here is his perspective:

When the NTSB received notification of the accident involving JAL 123, we coordinated with the U.S. Embassy in Tokyo to send a small team of NTSB and FAA personnel to assist the Japanese Aircraft Accident Investigation Commission (JAAIC) with the investigation. At that time, the NTSB did not have direct relationships or contact information to deal directly with the JAAIC. We relied on our State Department personnel in Tokyo to coordinate on our behalf. At the same time the NTSB and FAA team was being dispatched, Boeing was sending a group of engineers to provide a two-prong effort—support the U.S. team led by the NTSB and to respond to its customer, Japan Airlines.

At the time of the notification and dispatch, there were several factors in play that influenced the U.S. team decision-making. One important factor involved an earlier JAL Airbus event in which a bomb had exploded in the aft lavatory area. That aircraft had landed safely and the cause was clearly determined by the Japanese criminal investigators to have been a terrorist event, not requiring NTSB or similar involvement. Based on that prior occurrence and the initial notification circumstances surrounding the JAL 123 occurrence, there was strong speculation by U.S. aviation senior managers that we had another terrorist event and the traditional safety investigation team would not be necessary. That speculation soon proved to be wrong; however, it slowed the response by the U.S. experts to some degree. It also influenced the manner in which the Japanese approached the investigation. Basically they were focused on a criminal act. More about this matter later.

A second factor that complicated the dispatch of a U.S. team to participate in the investigation and the acceptance of the U.S. assistance by the JAAIC was the manner in which Annex 13 to the Chicago Convention was written at the time. Annex 13, which specifies the rights and obligations of States involved in international aviation accident investigations, as well as procedures for cooperation between States during investigations, was "not applicable" to this particular accident. The reason for this was that Annex 13 only applied to accidents involving an aircraft registered in one State having an accident in another State, an "international accident." Because the JAL 123 flight was a domestic flight of a Japanese-registered aircraft, Annex 13 did not apply. Thus, the U.S. NTSB had no right to participate in the investigation and the JAAIC had no obligation to invite participation. This factor delayed the formation of the team by the JAAIC to include assistance from the NTSB, the FAA, and Boeing, etc. More about this matter later.

The third factor involved was the fact that in April 1985, only months before the crash of JAL 123, an Air India 747 broke up in flight and crashed into the Atlantic Ocean off the coast of Cork, Ireland. Sabotage was strongly suspected in that case; however, it had not been verified. In fact, at the time of the JAL 123 crash, there was a major underwater search and recovery effort being conducted by Canada to recover wreckage from the Air India aircraft to determine the cause of the crash. There was growing news media attention to the possibility of a generic structural or other airworthiness flaw in the Boeing 747 that may have led to both accidents. This placed tremendous pressure on the U.S. team to determine the cause of both accidents.

Lesson 2: Don't let "coincidentally timed" events lull you into thinking they have the same causes. Each accident is unique. You need to investigate.

Ron continues:

It would have been easy for air safety investigators and their managers to "assume" that the two accidents were the result of sabotage and therefore the investigations would be conducted by criminal investigators, who operate differently than safety investigators. We didn't let that happen with JAL 123; however, this factor did influence the manner in which the investigation of JAL 123 was initially conducted by most parties. Basically, the criminal investigators were "in charge," and this situation hampered the expeditious safety investigations.

Because of the above factors, the JAAIC was reluctant to grant access to the accident site by the NTSB team. The lack of "rights" in Annex 13 for the NTSB team to participate and the leadership of the investigation by criminal authorities in Japan hampered access to the accident information, including CVR and FDR data, and to the wreckage site by the NTSB's team of experts. Because of this situation, high-level diplomatic discussions took place, and I was dispatched to Japan to deliver a letter from the chairman of the NTSB to the chairman of the JAAIC requesting permission to join the Japanese team to assist with the investigation. The NTSB team's main theme was its concern about determining if airworthiness factors were involved in the accident, which is an obligation on the part of the U.S. according to Annex 8, Continuing Airworthiness. Basically, as the State of Manufacture of the Boeing 747, the U.S. was obligated under Annex 8 to determine if airworthiness matters were involved.

The U.S. Embassy in Tokyo arranged a meeting between me and the JAAIC chairman at which I delivered the letter from the NTSB chairman. We discussed the need for the NTSB team, including FAA and Boeing experts, to be part of the investigation to assist the JAAIC in determining the causes and factors involved in the accident for accident prevention purposes.

After lengthy discussions, it was initially agreed that NTSB and FAA government investigators could visit the site; however, they did not want Boeing experts to be at the site. After we explained the need for the expertise of the Boeing engineers, who designed and built the airplane, to be on site to identify parts, etc., the chairman agreed to let Boeing personnel accompany the team; however, they had to be accompanied at all times by NTSB personnel. The NTSB team members would also have to be accompanied by JAAIC investigators at all times, which was logical and acceptable. The meeting was adjourned, and the NTSB team members made several trips to the accident site, which eventually led to the determination of the causes of the accident, which was not sabotage.

Lesson 3: Plan ahead. Work to ensure all regulations, agreements, MOUs, etc., are in good order and reflect the real world.

Ron continues:

The NTSB, the FAA, and Boeing senior managers should have anticipated the flaw in Annex 13 provisions for domestic flights well before this accident. In fact, there were other similar domestic accidents in which the State of Manufacture of the airframe was precluded from participating in on-scene investigations that involved airworthiness matters. As a consequence of the JAL 123 experience and other cases involving aircraft manufacturing States, in 1992, at the ICAO AIG/92 meeting held in Montreal, Annex 13 was amended to be applicable to all accidents involving aircraft over a specified mass, wherever they occurred, whether on domestic or international flights. These revisions permitted States of Design/Manufacture to participate in all accidents, domestic or international flights, to evaluate any continuing airworthiness matters that may be involved, in accordance with Annex 8.

Besides Lesson 1 of "don't speculate," John learned another early lesson. Some of these lessons are (unfortunately) learned by making mistakes and such was the case in this Lesson 4.

Lesson 4: Be prepared to talk to the news media.

After hearing about the accident in the morning and during a very busy day, we assembled a team, got our technical material together, made travel arrangements, got money, went home and packed, and made it to SeaTac Airport in Seattle in time for an 11 p.m. departure on a Northwest Airlines 747 to Tokyo. My Boeing team consisted of five people including me. Our first news media confrontation occurred at the airport lounge. There was a big disturbance up front when a local television crew forced its way in looking for us. The crew was adamant about talking to us, using the line "the public has a right to know." As the melee ensued, the airline staff helped us escape via a back door and allowed us to board early to the sanctuary of the aircraft.

So here is Lesson 4: Expect to be pursued by the local members of the press and be prepared to talk to them. Unfortunately at the time, I had had no news media training and was woefully unprepared to deal with the passion and furor this tragic crash had caused. In preparation for launch, you must take time with your public relations experts to develop a key statement and have it memorized. If it turns out that you must launch without it, get a local expert to at least give you a quick briefing and help you prepare a statement, even over the phone if necessary. Don't get blindsided by the news media. Our answer to the news media was to flee—a very bad response in every way.

Also, avoid putting identifying stickers on your hand-carry luggage. It only serves to identify you as a target for the press and with your fellow passengers. It only serves to identify you as a target and acts as flags saying, "Talk to me, I'm your guy!"

Lesson 5: Appreciate cultural differences and learn to apply them.

Lesson 5 presented itself when our flight arrived in Japan. In those days, the press and news media in Japan seemed to have free reign of the airport, even airside—that is, where the airplanes land and the passengers disembark before customs procedures. When the airplane landed in Tokyo, it was parked at a hard stand, away from the gates. Since we were riding first class, we could have exited at any time; but for some reason, we decided to wait until all the other passengers deplaned. This left us coming down the air stairs alone as a group, an easy and visible target. In hindsight, I should have had the other team members disembark the aircraft one at a time amongst the other passengers where they could have gotten to the terminal safely.

Our local technical rep had made arrangements for a private transport bus to get us to the terminal.

We were besieged by the press and news media as soon as we hit the ground at the foot of the air stairs. This group was super aggressive. We got to our "private" bus where we expected to be safe, but the crews forced their way on board, and we made the trip to the terminal with TV camera lenses literally inches from our faces and questions coming from all directions. With my lack of news media training, my reaction was to clam up and say nothing. On TV, I looked scared and dumb as I sat there, in stoic silence. That was another mistake. Once again, I should have had a separate key message prepared and memorized for the Japan end of the trip.

It should be noted here that the statement for the press in the United States would have been quite different from the one required in Japan, should I have had both ready. But I didn't. My lack of news media training was a great hindrance, and I did a disservice to Boeing and the accident investigation community, as well as the Japanese people.

Once we got through immigration and customs, the press was waiting again, but we managed to escape to some waiting minivans. Once we got to our hotel, followed by the news media in their own cars, we checked in without further trouble. However, shortly after settling into our rooms, all of the people in my team were approached by the news media in their rooms. There would be a polite knock on the door, but outside was a newspaper reporter who had somehow learned which rooms we were in. Once again, I declined to talk to the first one, but a minute later another reporter was at the door. At that point I called hotel management and they somehow stopped the unwanted intrusions.

The news media was also present at the accident site in huge numbers but was well-controlled by the on-site authorities. They were there as we landed each day; but once we were at work on the wreckage itself, they were kept away. The news media seemed to have its own fleet of helicopters, nicer and newer than anyone else's, to get them up to and back from the site.

Lesson 6: Be confident in the safety and quality of your transportation. Cheap is not always better.

Ron relates:

Another factor that hampered the NTSB team was the fact that for legal or other reasons, the Japanese could not provide assistance to transport the NTSB team experts to and from the accident site. Thus, the NTSB team used U.S. Army helicopters to reach the site. The accident site was remote and in extremely rugged terrain. Military search-and-rescue personnel and perhaps some of the JAAIC investigations stayed at the accident site in makeshift tents; however, the conditions were difficult at best. The flights carrying the NTSB team had to come from the Tokyo area in the morning and because of an early sunset behind the mountain, the team had to leave early to avoid being stuck on the mountain overnight. This factor, plus the rugged nature of the terrain, made progress on documenting the wreckage difficult and required multiple visits to the site.

Regarding the Army helicopter support, there are other lessons learned. The helicopters were old Huey's based in downtown Tokyo and were used primarily for VIP transport of U.S. military and other officials in day, VFR conditions, locally around Tokyo. The mission to transport the NTSB team members to the mountain accident site was not an easy one. Visibility and navigational aids were poor, and the helicopters had to land on a make-shift pad on the side of the mountain. On one occasion a flight of three U.S. Army helicopters enroute to the accident site became disoriented about the location and had to return to base to refuel, wasting time. On another occasion, when the helicopters returned to pick up the team from the accident site, they had difficulty finding the landing site and the sun had nearly set before they found us. Lastly, on a return flight that both John Purvis and I were on, the crew began to experience some mechanical difficulties. At first, there was an amber light and then a red light dealing with the main rotor transmission gearbox. The pilot made an autorotation to an emergency landing in a dry creek bed in very rugged, mountainous terrain. A replacement helicopter was sent to retrieve us.

It turns out that the Army had permitted the helicopter to overfly one of its routine inspection items and a plugged filter had caused the emergency, when fluid bypassed the filter, causing it to overheat.

Lesson 7: Be prepared for the complications of a criminal or judicial investigation—it changes the rules dramatically.

Ron continues:

When the NTSB team first arrived at the accident site and was able to reach the location of the aft fuselage and empennage, which was the suspect area because of survivor statements and wreckage that had fallen off early in the flight, the criminal investigators were in full control. The safety investigators were able to take pictures and handle wreckage; however, not at the critical location of the aft pressure bulkhead during the first visit to the site because criminal investigators were documenting the wreckage. They were taking swabs to test for bomb residue and they employed artists to make three-dimensional color drawings of the entire aft pressure bulkhead area. This delayed the NTSB and JAAIC team from examining the wreckage.

Before the NTSB team experts had an opportunity to examine the aft pressure bulkhead and empennage in detail, it became known that the accident aircraft had incurred a serious incident years before that involved a tail strike. Subsequent to the tail strike, the lower aft fuselage, the APU area, and the aft pressure bulkhead had been repaired. Therefore, the NTSB team focus was on this area to determine if the repair had been completed incorrectly and had led to the accident. Once we were able to examine the aft pressure bulkhead, it was quickly determined that the repair had not been completed correctly by Boeing. This finding was significant because it was clear that there was no generic flaw in the 700 plus Boeing 747s flying around the world.

Lesson 8: Linguistic hurdles can be daunting but need to be addressed. Have the ability and funds to hire qualified technical interpreters.

Another factor that impacted the investigation of the JAL 123 accident involved language. At that time, JAAIC personnel had limited English language capability and NTSB Japanese language capability was nil. Although the U.S. Embassy provided interpreters to support the JAAIC interpreters during high-level meetings in Tokyo, the U.S. Embassy provided no support for the NTSB team members while on scene or during routine group meetings. The NTSB had no funds allocated for such support. The JAAIC did provide an interpreter, who assisted with interpretation between JAAIC and NTSB team members on scene; however, he did not understand technical terms. The NTSB should have had the ability and funds to hire qualified technical interpreters to assist its team to enable it to provide better support to the JAAIC.

Lesson 9: Be prepared to keep the news media, the public, and the families up-to-date on the investigation. Leaks are inevitable and can hurt your credibility.

Ron continues:

Once the actual cause of the accident was determined, that information was relayed clearly to the JAAIC team members. However, because of cultural matters and the criminal investigation ongoing, the factual findings that clearly showed the causes of the accident were not disseminated to the news media by the JAAIC. In accordance with international protocols (Annex 13), the State conducting the investigation was the only entity that could release the findings and progress of the investigation to the news media. The NTSB pressured for a release of information by the JAAIC, but it was not forthcoming.

Because of the worldwide concern about the safety of the Boeing 747 fleet and the lack of news releases about the facts by the JAAIC, the facts eventually were leaked in the U.S. and became known around the world. Annex 13 was eventually amended to allow States participating in investigations to release information to support safety recommendations to prevent future accidents, as long as it is coordinated with the State conducting the investigation. Annex 13 still prohibits anyone other than the State of Occurrence conducting the investigation from releasing routine factual findings and progress of the investigation. It was clear in this case that the NTSB team had information that needed to get out to the world and when the JAAIC did not release it in a timely manner, the information was leaked.

Lesson 10: Building and maintaining relationships and trust are key to a successful investigation, especially in countries foreign to your own.

Ron and I have worked together many times in the past, teaching accident investigation management and various other things. Whenever we teach or work together on these jobs, one major theme permeates our entire presentation. It is that of building and maintaining relationships and trust.

Relationships and trust are absolutely critical to doing a successful job. Establishing and maintaining them takes work and planning. Attending industry meetings, giving papers, leading panels, participating in industry working groups, and in general being a friendly, positive, and action-oriented person are some of the ways to do this. You should plan on making periodic visits to the major investigative authorities around the world, and especially in your own country. You can never cover all possible scenarios, but having contacts within the government authorities will pay major dividends in the long run.

Once the basic contacts are established, be sure to maintain them by keeping in touch via e-mail, phone, and more visits. If you receive requests, act on them promptly and positively—be a source, not a vacuum. In other words, get to know as many people as possible in the industry and strive to maintain your friendships.

Include in this process people who may be your commercial competitors. Remember that when it comes to safety, you need to cooperate. Safety should not have any business barriers. To build relationships and trust, especially with government agencies, you must always come across as a safety person or an investigator first, with company loyalty a distant second.

Building relationships does not have to be an expensive process, especially with today's communications systems. Face-to-face meetings are always best, especially during the first contact, but you can use your travels to meetings, seminars, or training as ways to visit these agencies and companies.

Your range of contacts should go from local to international. On the local level, get to know your NTSB (or equivalent) or FAA. Also consider joining your local or regional ISASI chapter.

In building these relationships, don't forget about internal relationships within your own organization or company. Good relationships foster respect and internal support, qualities you need to do your job. During this process you may speak at employee meetings, write articles for internal publications, and support off-hour gatherings.

The important part of all of this is to do it before you need to—by then it is too late. Over the years, Ron and I have collected some of the processes and qualities needed to develop and nurture relationships. This list includes the following:

- Be a communicator.
- Be motivated in your task.
- Be a source, not a vacuum; be ready with timely, reliable data whenever you are asked.
- Truly like people and enjoy pleasing them.
- Have common sense.
- Always be yourself (who better than you can do that?).
- Be trustworthy, credible, and have integrity (integrity is not trainable; it is inherent in the person.).
- Be willing to help people.
- Within various cultures you should consider the following: languages are important; have empathy with other cultures; understand multiple cultures and ethnic origins; understand their history, food, current events, politics, and what is in vogue now.

Conclusions

Many excellent "technical lessons" were learned during this JAL 123 investigation. Many of them led to significant aviation safety improvements, changes to Annex 13, and revisions to operating policies and procedures of many organizations, including the JAAIC, the NTSB, Boeing, and ICAO.

You may ask: Do technical lessons get learned or applied widely enough in the industry? Our answer is mot always—we may be able to prevent more accidents by doing a better job.

As Ron points out:

For example, the structural repair that led to the loss of control of JAL123 highlighted a design feature that placed all four hydraulic systems in a single location. None of the 747's four hydraulic systems were protected by fuses or standpipes. The rupture of the pressure bulkhead led to the loss of the aft portion of the vertical fin, which severed the lines for all hydraulic systems, rendering the airplane virtually uncontrollable. Those design items were fixed to prevent a similar accident in the future.

However, a few years later a DC-10 experienced a fan disk separation that ruptured all three hydraulic systems, and the airplane eventually crashed on landing at Sioux City.

Similarly, several years later, a China Air Boeing 747 broke up in flight near Taiwan because of structural damage in the aft fuselage. That investigation revealed that a tail strike occurrence 20 years before had severely damaged the lower aft fuselage area, which was eventually repaired. The repair was done improperly by the airline and fatigue occurred, under circumstances not unlike the bulkhead situation on JAL 123. A program had been put in place to inspect airplanes that had major structural repairs over the past several years to ensure the integrity of the repairs; however, it had not been implemented in time to identify the improper repair of the China Air airplane.

Another thought to ponder is whether "soft" lessons learned should be more closely scrutinized and perhaps find their way into reports or some other vehicle of record. Ron and I believe they are definitely worth documenting and having available for future generations to use, as well as for current investigators to improve their own operations. Better application of all lessons—both the technical ones and the soft ones—can lead to improved safety and better investigations. Technical lessons have been our bread and butter for years and clearly lead to improved safety. The "soft" lessons are more difficult to discover and document, but they can be useful. They can lead to smother and better investigations overall.

Summary

Ron and I have given you a brief look at our involvement in the JAL 123 accident in 1985. Both of us also confessed some of our own shortcomings during the investigation. Can we learn even more lessons from an accident, beyond the technical ones? Our answer is yes, and this paper is our attempt to document just a few of those "soft lessons."

Perhaps some of my own problems could be justifiably blamed on my lack of experience at the time and lack of formal training, especially on matters dealing with the news media.

My unintentional lack of providing public condolences to the Japanese people and to the bereaved families was surely one. I should have had some cultural sensitivity training, even if it had been a one-hour intensive course before departing for Japan. I should have had a key message statement in my head for the news media. Ron feels the same way about his experience.

Of course, the significance of talking about this accident at this time and at this seminar is that last month was the 25th anniversary of the event. Together, Ron and I would like, in this 25th anniversary year, to say to the families of those lost in the tragedy of JAL 123 25 years ago that we profoundly regret the incorrect repair that eventually led to this accident. We would like to convey once again our heartfelt sympathy to the survivors and to the families of the passengers and crew.

Our obligation to you is to continue to improve the safety of our products and the aviation system as we strive to prevent accidents in the future. ◆

Leading 'Just Culture' Toward Pragmatic Application in Japan

By Hiromitsu Mizutani, Member of the Flight Safety Committee,
Japan Aircraft Pilot Association, B-767 Captain

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Abstract

This paper examines the present condition of so-called "just culture" in an organization in Japan. According to Dr. Reason (1997), the components of a safety culture include just, reporting, learning, informed, and flexible cultures. Dr. Reason further describes a "just culture" as an atmosphere of trust in which people are encouraged (even rewarded) for providing essential safety-related information, but in which they are also clear about where the line must be drawn between acceptable and unacceptable behavior.

As we all know, the latest approach to mitigate aircraft accidents and incidents in sophisticated aviation system is the concept of safety management system (hereafter, SMS), which has been introduced in a state and in an organization all around globe. Here in Japan, SMS became law in 2006. SMS shall never be more than just pie in the sky but shall be practically functional for the purpose of proactively preventing aircraft accidents and incidents. In this sense, "just culture" plays a crucial role in terms of positively gathering bare safety-related information that is provided by the people who are willing to report for the sake of aviation safety. Therefore, an intention of this paper is to lead "just culture in Japan" toward the environment in which the practical application of a reporting system which in turn makes true integration of SMS possible.

I believe among many components that structures SMS, changing someone's culture, especially the culture like "just culture," is the most time consuming process because it requires people's trust, and most probably the challenging theme of which many countries are facing under diversity of cultural issue today.

1. Introduction

"Has SMS been integrated in our organization yet?" Many of you know that ISO9000 QMS has become the prototype for the concept of SMS. QMS is to ensure certain quality or manufacturing processes of the product versus SMS, which manages what is "organizational tolerance or resistance" from the human errors and environmental changes that may cause an accident or an incident.

The safety thinking has evolved its interest from the technical to human factors and to the organizational factors as ICAO designs the concept of SMS.

Back in 1984, it was the prototype of SMS, ICAO Accident Prevention Manual has been issued to systematically present the accident prevention, and many countries had introduced this idea to challenge the persistent problems at that time.

- The UK issued the guidelines for SMS in the early 1990s.
- In Canada in 2005, SMS was signed into law.
- In 2003, IATA started the IOSA (IATA Operational Safety Audit) program of which criteria is based on ICAO SMS.
- The U.S. was not using the term SMS; but in 1995, the FAA mandated appointing an accountable safety director for the airline and issued an advisory circular in 2006, which consisted of many elements of SMS.
- In Japan in 2006, SMS was signed into law.
- In Australia in 2008, SMS was signed into law.

The reason why I have come to the question of "Has SMS been integrated in our organization yet?" is as follows. I am neither the management pilot nor involved in the management of the company. The present duty at my position is to safely operate B-767 as a captain, as well as to perform internal safety audit as an auditor for the company I belong to. In other words, I'm one of the frontline workers who is in direct contact with daily hazard.

Through interviews with my colleagues and the overwhelming atmosphere which I felt during the internal safety audit, I shall not say all, but many of the frontline workers either do not know about SMS or they may know SMS but they do not feel direct relationship between their everyday work and SMS.

Effective building of SMS depends on the degree of cultivation of the "safety culture" in the organization. Assuming my working field is still far from understanding the idea of SMS, it can be said that the reality of SMS is still in the framework stage, and the priority is to gear "safety culture" into the organization. Therefore this paper is centered the view from a frontline workforce to present what is the current condition in terms of understanding SMS within the organization, which is based on some interesting surveys conducted by ANA.

2. ANA safety culture assessment

In order to assess the state of "safety culture," Japanese airline ANA Group has made an interesting effort with a collaboration of "Research Institute for Social Safety (RISS)."

2-1-1. Purpose of the assessment

ANA Group has adopted this term to express the "corporate culture that gives priority to safety," and the group companies are striving for safety improvement efforts using it as the key term. However, further advancement in these efforts cannot be expected without determining the degree to which the safety culture has been cultivated within the ANA Group. As a measure of knowing the state of achievement of these safety efforts in a tangible form, ANA corporate safety and audit carried out its first corporate-wide survey using a questionnaire on the safety culture (hereinafter, a "safety culture assessment") in October 2007 and July 2009.

2-1-2. Why is the safety culture assessment is important?
Of late, accidents and mishaps relating to rail transportation, nuclear power generation, food processing, health care, and other fields are making news. At first sight, it would appear that personnel problems and technical hitches were the causes of these accidents and mishaps. However, the real causes are most often in organizational systems—that is, these cases are less attributable to simple mistakes by individuals than problems lurking in today's more-complex, more-immense organization systems when tracked to their root causes.

The term "organizational accident" is often used to describe accidents occurring as a result of organization-dwelling problems. What is believed to be of major significance in preventing organizational accidents is a good atmosphere or a climate that reflects positive attitudes of the organization's entire workforce and each individual employee toward safety activities—in other words, adequate safety awareness that takes root in the ground of an organization. In the fields of nuclear power and chemical industries in particular, programs for regularly assessing the companies' safety cultures are being introduced in an effort to cultivate them.

2-1-3. ANA Group definition of "safety culture"
Before embarking on a safety culture assessment, it is important to define the safety culture. Without any official definition of the safety culture currently existing, ANA Group has decided to adopt the following definition based on the suggestion of an expertise organization.

"Definition of the safety culture in ANA Group"
The safety culture as applicable to the ANA Group members is the integration of attitude and action taken by everyone toward achievement of the values and the conviction of the ANA Group safety principles while spontaneously assuming responsibility.

As shown in Figure 1, the safety culture constitutes a framework on which the entire ANA Group is founded. Of course it is impossible to directly measure the degree to which the safety culture is cultivated, but we can indirectly determine the safety culture by checking the following two points.

1. How well the organizational elements (organization size and structure; business execution systems; ordering, instructing, and educating systems, etc.) are functioning.

2. Whether the members of an organization share values and conviction that place primary importance on safety while constantly taking a safety-conscious attitude and action.

In the safety culture assessment, we use a questionnaire-based survey of employee to check the above two points to evaluate the current state of the ANA Group's safety culture indirectly. Based on the results obtained, we identified any problems with the safety system and plan measures for an organization to have a more advanced safety culture.

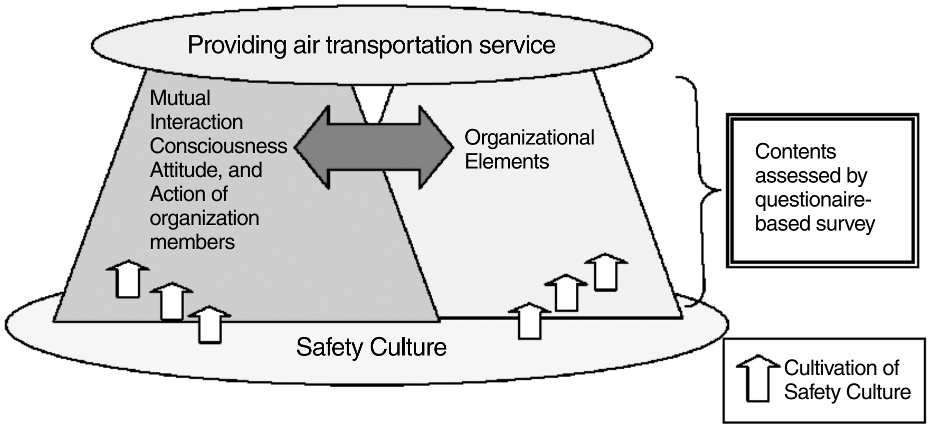


Figure 1. Concept of safety culture and questionnaire-based survey.

Evaluation axis (managerial element)	Interpretation
1. Governance	All members of the organization share a common recognition of the importance of safety, and a solid mechanism for improving safety has been established within the organization.
2. Commitment	All members of the organization are willing to accept responsibility for safety, and voluntarily and actively commit themselves to safety-related activities.
3. Communication	Information is shared and communication is maintained in a multidirectional manner with parties both inside and outside the organization.
4. Awareness	Employees are aware of latent risks present in the workplace and job environment and are prepared to deal with the worst consequences.
5. Learning	Employees are enhancing their knowledge and skills through education and training, in which lessons learned from past experience are actively used.
6. Work Management	Work management now implemented reasonably accommodates the needs and conditions of actual business activities.
7.Resource Management	The management of personnel and costs is implemented considering safety.
8. Motivation	Employees' safety activities are duly respected, and this gives the employees an incentive to improve safety activities.

Table 1. Eight axes of assesssing safety culture.

2-1-4. Measurement of safety culture
This section explains the way ANA corporate safety and audit measures the safety culture using the questionnaire-based survey. The safety culture is not so simple as to be measurable using a single yardstick with only the good and bad marks; ANA corporate safety and audit, therefore, sets up gauges representing the eight managerial elements that are all closely related with the safety culture. These gauges are called "evaluation axe," which are detailed in Table 1.

In order to measure the safety culture, ANA corporate safety and audit has defined a number of "scales" for each evaluation axis and set "questions" for these scales to be answered on the questionnaire sheets. The relationship among "evaluation axes," "scales," and "questions" is shown in Figure 2.

2-1-5. Definition of safety for the purpose of the survey
When asked about safety, you will probably first think about the safety of flight operations. However, the safety culture assessment for the ANA Group also covers those employees who are engaged in tasks not directly related to flight operations and, therefore, the questionnaire must cover safety issues other than flight operation's safety as listed below.

- Passengers' safety.
- Aeronautical security (protection against crime and terrorism).
- Freight safety (safety in transporting hazardous goods).
- Employees' safety (ensuring safety at work and preventing disaster while commuting).
- Food safety.
- Information security.
- CSR (corporate social responsibility) compliance.

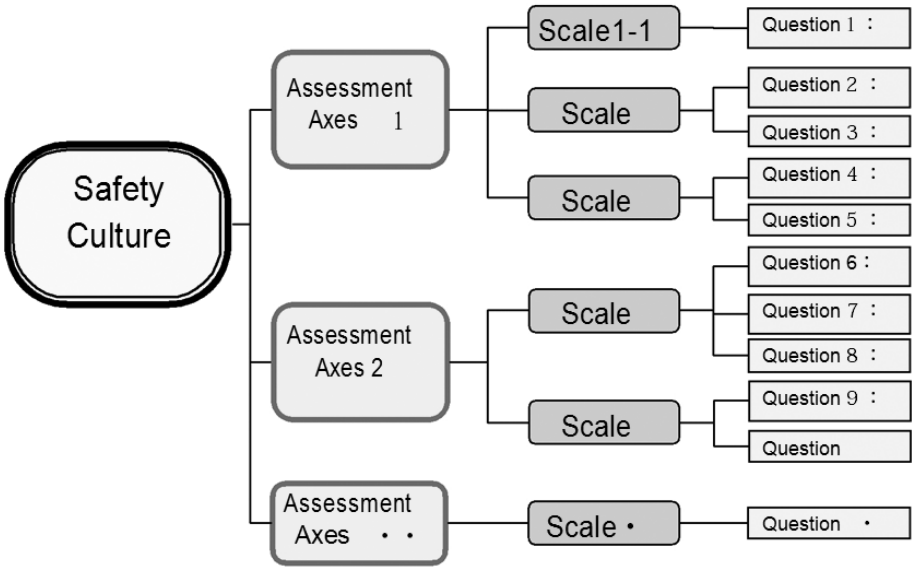


Figure 2. The relationship among evaluation axes, scales, and questions.

2-1-6. Employees classification

For the purpose of this questionnaire-based survey, all employees are classified into the following three categories according to their positions in an organization:

- Category A (positions relating to overall management of the organization).
- Category B (positions that carry what is decided by the Category A into effect).
- Category C (all positions other than Categories A and B).

There are three different types of questionnaires, each having a set of questions matched to a specific category.

2-1-7. Period of the survey

The questionnaire-based survey was conducted within a one-month period.

2-1-8. How the questions were answered

There are a total of 42 questions. For each, there is a bar marked with five options including "yes" and "no" and those in between. And they are rated in five levels from zero to 100; zero for "not true at all" to 100 for "particularly true." Besides these questions, the format of the questions also has a blank space for the employee to make free entry of comments and opinions related to safety issues. Including the time for writing these, it takes approximately 15 minutes to complete the questionnaire. And those questions are anonymously answered.

2-1-9. Scope for the assessment

Targeted organizations were ANA and ANA Group airlines. However, to make an effective evaluation, the organization needs to have a minimum number of employees, such as 25 to 30 for Category A, and 250 to 300 for whole group. At the time of the assessment, there were 41 ANA group companies, including seven airlines in ANA Group.

2-2. Result of analysis 2007 and 2009

2-2-1. Response rate

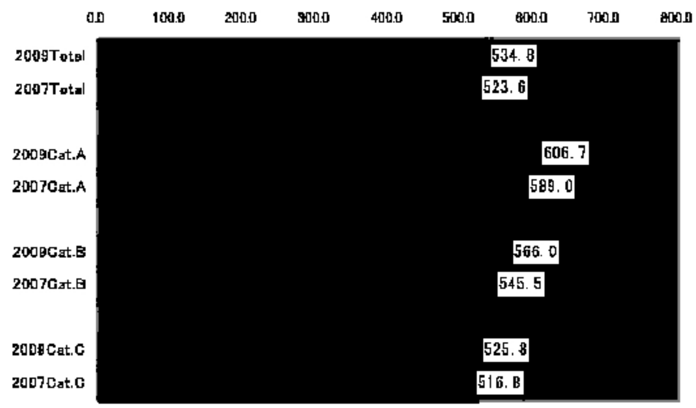
The answering rate in the 2007 survey was 78%, and 81.9% in 2009, which showed a 3.9% increase. The data were collected from 41 ANA group companies, which consists of approximately 27,600 employees.

2-2-2. Total score

As mentioned before, the answers were rated in five levels from 0 to 100; 0 for "not true at all" to 100 for "particularly true."

The graph below shows the total points for entire employee classification (100 points per axis, total maximum of 800 points for eight axes) has increased by 11.2 points to 534.8 points compared to 523.6 points in 2007.

The points of each category increased by the following: CAT A, 17.7 points; CAT B, 20.5 points; and CAT C, 9.0 points.



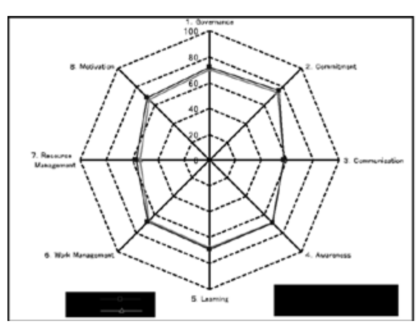
2-2-3. Trend of evaluation axis

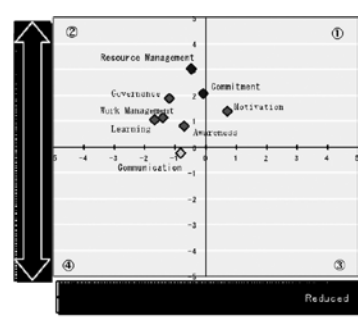
As shown in the left bottom cobweb chart, compared to 2007, an almost identical trend was apparent and there was no obvious change. However, when looking closer, there were statistically significant increases in all evaluation axes except for "Communication." The level of increase in "Resource Management" and "Commitment" axes are particularly significant.

The right bottom graph indicates the relationship between point differences (difference between highest and lowest classifications of the categories, indicated as "classification gap") in the 2007 comparison of every evaluation axis of all classifications and point differences among employee classifications.

The evaluation scale is indicated in four levels 1, 2, 3, and 4, with 1 being the best. In the entire ANA Group evaluation. Most evaluation axes were either in the 1 or 2 areas, which can be translated as a relatively good result.

Furthermore, by separately analyzing answers to questions other





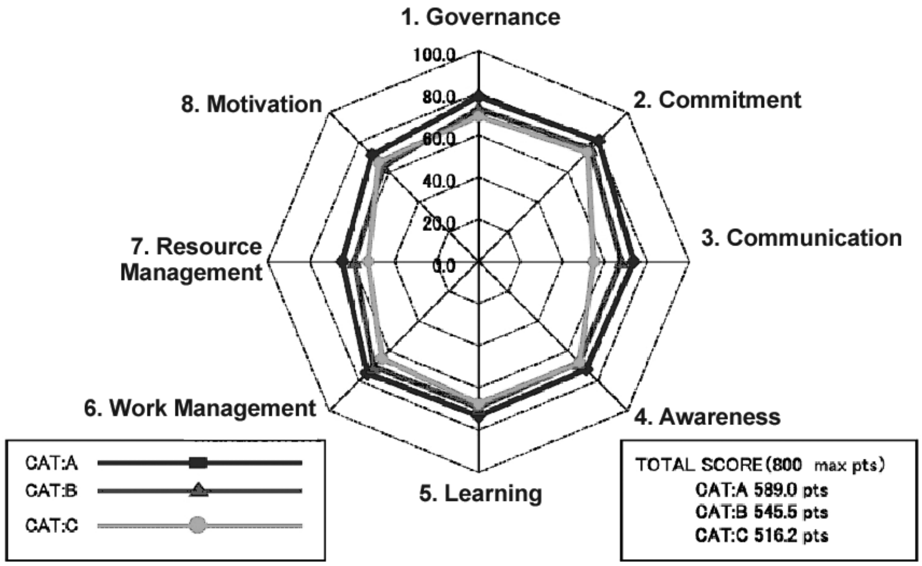
than “Resource Management” and “Commitment,” there were no obvious changes.

2-2-4. Evaluation

There were no obvious changes to the analyzed evaluation levels (right table) in total score or in each evaluation axis, and the conclusive second safety culture assessment had almost the same results as 2007. The Comparison against the 2007 result and the special features of results are as follows.

2-2-5. Analysis of features

1 “Commitment” measures the actual level of participation in activity planning, safety action, and observance of various manuals. Disseminating and exercising activity planning with “frontline department” employees as well as further developing manuals and documents are thought to be the causes of the point increase.



Cobweb chart for CAT A/B/C (2007 survey)

2 “Resource Management” measures the actual level of acknowledgement of safety investment and manpower positioning. Since the point increase occurred at almost all employee classifications, penetration of safety education conducted by the ASEC (ANA Safety Education Center), reviewing of turn-around time and safety investments made by management level using various communication channels gained understanding from the entire company structure, which resulted in the point increase.

3 “Communication” measures the actual level of intercommunion and interaction between top management and frontline people, within departments, among workplaces, and between divisions and companies. Each division is conducting various efforts; however, they are not yet resulting in the actual feeling of “adequate exchange of communication” at each workplace, which probably caused the points to remain the same.

2-2-6. Free opinions on questionnaire

ANA Group, a total of 4,421 free opinions were collected (20.5% overall) to be fed back into the organization for safety enhancement. There were varieties of comments classified as “Safety culture assessment related,” “Survey questions related,” “Communication related,” “Frontline work related,” “Environment related,” “Safety related,” “Opinions from non-Japanese crews,” etc.

2-2-7. Further developing safety culture

The outcome of the 2-year effort after the first safety culture assessment in 2007 is considered to be on 2-2-3 and 2-2-4 evaluations. In general, there was a slight improvement trend observed, but there was no obvious change between the two surveys. The corporate culture, not just safety culture, of a company group that has more than 30,000 workers will not change overnight. Rather, it will gradually step toward the desirable state. ANA Group will continue an effort to assess the level of safety culture in the organization every 2 years, which hope to answer the expectations.

2-3-1. Hypothesis

ANA group efforts so far have been presented in terms of the cultivation of the safety culture in the organization. And since “Informed culture” plays a crucial role when building an effective SMS in the organization, I have further analyzed the questionnaires and answers and found an interesting contradiction.

Firstly, Axis 5 “Learning,” on one hand the question “The environment in your workplace is not one where employees who have made mistakes are identified and criticized” scored high points, but on the other hand the question “In your workplace, you can report minor incidents and close calls of your own without hesitation” turned out to score low points.

The score of these two questions should ideally be synchronized. Furthermore, the points for the question “The environment in your workplace is not one where employees who have made mistakes are identified and criticized.” was lower toward frontline workers (as seen in 2007 result in the cobweb chart below.)

Hypothesis 1: “Safety culture” has not yet cultivated at frontline workers.

Secondly, Axis 3 “Communication” scored low points. According to Dr. James Reason, a safety culture based on information is interpreted as such—A just culture is an atmosphere of trust in which people are encouraged (even rewarded) for providing essential safety-related information.

Hypothesis 2: Since two-way communication (mutual understanding) requires trust between the workers within the organization, this may also indicate that “safety culture” is not cultivated in the organization.

2-3-2. Analysis of two hypotheses

The question is only the above two hypothesis represents that the safety culture is not cultivated in the organization? The answer is probably “no.” Let’s look at the implementation of SMS in Japan.

Until 2005, public transport in Japan, such as national railway and airlines involved in many accidents and incidents causing great damage to the confidence in public transportation in terms of safety. Because of this, the Japan Civil Aviation Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has established various expert committees to secure public safety of transportation. As a result, in October 2006, the purpose of the Civil Aeronautics Law (Article 1) was revised and the wording became explicit that ensuring the safety of transportation is the first priority over anything else. Therefore, MLIT and airlines in Japan together introduced SMS under the concept to disclose safety-related information to the public.

In addition ICAO emphasized that SMS shall be understood first by top management then to frontline workers. To do so, ANA issued many company newsletters about SMS, launched a homepage regarding safety, established so-called e-learning for employees to be able to receive training regarding SMS and risk management, also ANA carried out an annual event, "Talk Safe," to discuss any safety related issue. However the survey result speaks for itself—fewer workers understand SMS as it moves toward the frontline.

Only 4 years have passed since the first introduction of SMS in Japan, and given the conditions that airlines are still trying to promote understanding of SMS within the organization, my hypothesis stated above, "safety culture" is not cultivated in the organization," is not because of the degree of cultivation of safety culture in the organization but because of the promotion of SMS, especially to the frontline workforce.

Once the purpose of SMS is understood by the people working at frontline, they will be able to think the reason why the gearing the just culture is desirable, is not because he/she wants to escape from responsibility nor to limit the liability of individuals, but rather involved in improving safety by reporting slips/lapses, mistakes, violations, and omissions-type human errors and feel a part of the organization in contributing to the safety issue.

3. "The evolution of safety culture" (case study in Japan)

Readily find model on the evolution of safety culture was developed in collaboration with Leiden University (the Netherlands) Professor Patrick Hudson and Westrum (Philadelphia). According to the model, the evolution of the safety culture seems to be divided into five stages as follows;

From worst to best: Organizations can be distinguished along a line from pathological to generative.

- Pathological: The organization cares less about safety than about not being caught.
- Reactive: The organization looks for fixes to accidents and incidents after they happen.
- Calculative: The organization has systems in place to manage hazards, however, the system is applied mechanically. Staff and management follow the procedures but do not necessarily believe those procedures are critically important to their jobs or the operation.
- Proactive: The organization has systems in place to manage hazards, and staff and management have begun to acquire beliefs that safety is genuinely worthwhile.
- Generative: Safety behavior is fully integrated into everything the organization does. The value system associated with safety and safe working is system associated with safety and safe working is of invisibility.

On this basis, in order to categorize my working environment, I started out asking the following simple questions to my colleagues.

- What is safety to you?
- How safe are we?
- How do you think your organization maintains and promote safety?
- Do you know anything about the safety management system?
- What does the safety management system do?
- Does a safety management system have anything to do with your everyday work?

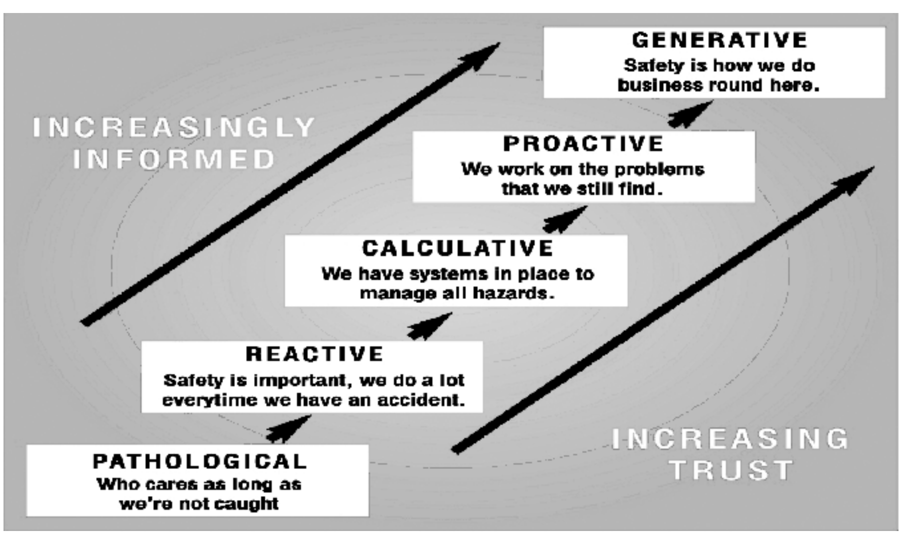
The typical answer was as follows. Answers from flight crews—

Safety means organizational tolerance, or resistance not to go beyond the limit at which cases an accident or incident. The law/company regulations/standards must be complied as we sharpen our competency to operate aircraft. However, the exception for those who engage in IFALPA activities, many of my colleagues either do not know about SMS or know very little about SMS, but even if they knew about SMS they did not know what it does.

A case happened during internal safety audit a few years ago—The auditee whose working section is the forefront of flight safety, it was a jaw-dropping case. The individual talked about IOSA as simply filling the check box to meet the requirements. Thus it will not drastically promote safety.

These were the unofficial interviews of those who are around me, thus this answer does not apply to everybody within the organization but at least true statement, which means even through SMS was introduced to our organization, not many people recognize that there is a direct relationship with their work.

The following are cases that occurred in Japan, extracted from news clipping for the past few years.



It's a long way to the top: The evloution of a safety culture.

Case 1:

In March 2010: The flight crew exceeded the specified value of BAC (blood alcohol content) during the test before the flight. After several attempts, he passed the BAC test but the flight was delayed for 22 minutes.

Case 2:

In December 2008: The captain was taking pictures (filming?) landscape during takeoff and landing. As a result, the JCAB suspended his license for 20 days.

Case 3:

This happened to me a few years ago at Kansai International Airport. It was a typical calm day and everything went absolutely without a problem. The weather was just fine, and it seemed we were the only traffic at that time and ATC was quiet. I received taxi clearance from ground control to taxi via parallel taxiway toward the active runway. Approximately halfway down on the parallel, I heard ATC saying "Wind...degrees at...knots Rwy...cleared for takeoff." It was rather unusual circumstances to clear us for takeoff while we were still a long way to the active. But I thought ATC cleared us because there was no other traffic.

Just prior to entering the active runway, I requested current wind information just to confirm. It was then that ATC told us, "Contact tower."

After the flight, I wondered whether I should make a report or not, but I didn't. I thought since I've done nothing wrong and even if I made a report I did not want to be involved in subsequent interviews, etc. Note that I did not know anything about SMS nor was I the internal safety auditor at that time.

In all the cases above, the organizations had already introduced SMS a few years ago, but the frontline workers did not feel the importance of SMS, thus these cases fall into the category of Calculative.

Case 4:

In February 2010; The captain ordered to replace the flight attendant because her lost voice (poor health) was judged as not being able to perform safety duty on the flight. For this decision, the president of the airline company came to an intervention. This time the captain was replaced and the flight attendant continued her flight. Furthermore, despite 2 years remaining on the contract period, the company canceled the captain's contract on the same day.

The ministry called top executives of the company chairman and the president for the acts that may threaten the safe operation and received a written warning. The president admitted that he was wrong to replace a captain who ordered a sick cabin attendant not to work on a flight.

Later that month, the Ministry of Land, Infrastructure, Transport, and Tourism launched a special audit to also include the Safety Management Department, which resulted in the Ministry ordering the operational improvement recommendations as follows.

- Maintenance is required if the aircraft runs into turbulence that exceeds a certain level.
- The pilot is required to wear an oxygen mask when the other pilot leaves his/her station for some reason.
- The flight must have a minimum number of flight attendants to demonstrate safety instruction before takeoff.
- Inadequate communication between non-Japanese pilots and Japanese cabin crew due to poor English proficiency.

In this case, the management has perfunctory introduced SMS to the organization; therefore this falls into the category somewhere between Pathological (The organization cares less about safety than about not being caught) and Reactive (The organization looks for fixes to accidents and incidents after they happen).

Case 5:

This is an example of the case happening in aerial survey flights. My friend, who works as aerial survey pilot, bravely confessed to me his working condition. But first, here is how the aerial survey company receives the order to survey. The executive authority or a major surveying company (sometimes consultancy) gives the aerial survey order to ABC general aviation company. The Sales Department of the ABC general aviation company receives the order, and the air surveyor draws the plan of where and what altitude should be flown. In many cases this requires coordination with ATC for the control zone, airport traffic area, and training area, etc. The Flight Operation Department does this coordination; but even if the coordination is unsuccessful, there is no way to stop the flights. Because if ABC general aviation company refuses the flight, the executive authority or a major surveying company will never give the order of aerial survey. And no flight means no work, no pay for ABC general aviation company. He added this is the typical mechanism and fate of general aviation.

In Japan, civil aeronautics law requires SMS for operators whose aircraft are more than 15,000 kg maximum takeoff weight or have more than 30 passenger seats. The management of ABC general company does not seem to understand how to adhere to aviation safety. It is obvious that the business is the priority over safety for the management.

Does this mean this ABC general aviation company falls into the category of Pathological (The organization cares less about safety than about not being caught)?

I do not think this is necessarily the case. Because whether the management personnel of ABC company prefers safety or not, they must fly in order to keep their business.

4. Safety culture on flight deck

4-1. Definition of safety culture

There is no explicit definition for "safety culture" in aviation. The following are the definitions for other industries.

"That assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance." INSAG-4 also states, "Safety culture is both attitudinal as well as structural and relates to both organizations and individuals." (INSAG-4)

The UK Health and Safety Commission developed one of the most commonly used definitions of safety culture, which describes safety culture as "The product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management."

ANA defined "safety culture" as "The safety culture as applicable to the ANA Group members is the integration of attitude and action taken by everyone toward achievement of the values and conviction of the ANA group safety principles while spontaneously assuming responsibility of contribution toward improved safety."

Common elements in these definitions are what is important and how things work that interact with an organization's structures and control systems to produce the way we do things around here. But what makes us achieve such an environment? For all practical purposes, a safe culture could be equated to an informed culture. That is, one in which the members of the organization understand and respect the hazards facing their operations and are alert to the many ways in which the system's defenses can be breached or bypassed. In short, an informed culture is one in which people, at all levels, do not forget having to fall over it.

4-2. How do we deal with the organization?

To enhance cultivating a safety culture in an organization, workers needs to feel certain level of fairness and justice to have a security in their mind. It is the balanced culture.

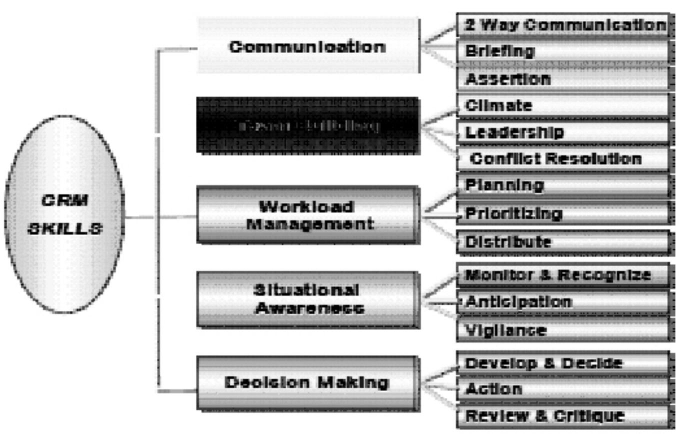
According to Dr. James Reason, just culture as an atmosphere of trust in which people are encouraged (even rewarded) for providing essential safety-related information, but in which they are also clear about where the line must be drawn between acceptable and unacceptable behavior. Effective reporting culture depends on how the organization handles blame and punishment. A "no blame" culture is neither feasible nor desirable. Most people desire some level of accountability when a mishap occurs.

Again I've asked my colleague pilots if they would report to the safety officer in charge in case slips/lapses, omissions, mistakes, violation types of errors were committed." The majority of the answers were "no" except for the events, which leaves evidence. This is how we deal with our organization, at least for now.

4-3. In a cockpit

What about the relationship between the cockpit crew? The relationship of the cockpit crew can be termed appropriate as long as proper TAG (trans-cockpit authority gradient) is maintained. The role of each crewmember is very clear—in this case utilizing the skill such as TEM (threat and error management) to be able to cut the chain of errors before lead to an accident or incident. The question is how the pilots have courage to speak up and admit an error.

This figure is a conceptual diagram of CRM SKILL. As is mentioned at the top, "Communication" plays a crucial role to demonstrate CRM SKILL. In other words, building trust and a mutual understanding between the pilots is essential.



The ANA operation policy manual sets the policy about "assertion" in the cockpit, "The flight crew shall assert to the other crew for any deviations from SOP, or any doubts about the actions." In addition, it is the PIC's duty to establish appropriate TAG in the cockpit so that the flight crew who is asserted will receive it sincerely with modesty.

The ICAO human factors training manual pointed out that an Asian crew has a tendency to weigh heavily on their authorities or superiors so that they are passive about speaking up and asking things. Japanese culture also respects the harmony in human relationships; therefore, it requires little courage to assert someone, especially the captain. But our asset in the cockpit is the "trust" to be able to assert an error without any doubt and without any fear.

5. How "just culture" and "voluntary reporting of safety issues and events" are linked

In Japan, the words "just culture" have an extremely low profile. As ANA's survey reveals, SMS is still not recognized at frontline workers. So what is the reason why "just culture" is necessary in order to build effective SMS. ICAO states SMS can be likened to a toolbox. It is a toolbox that contains the tools that an aviation organization needs in order to be able to control the safety risks of the consequences of the hazards it must face during the delivery of the services for which the organization is in business. In many cases, the organization itself generates the hazards during service delivery. It is important to acknowledge that an SMS itself is neither a tool nor a process. An SMS is the toolbox where the actual tools employed to conduct the two basic safety management processes (hazard identification and safety risk management) are contained and protected. What an SMS does for an organization is to provide a toolbox that is appropriate, in size and complexity, to the size and complexity of the organization.

ANA defines SMS as "A mechanism involving all activities to continuously maintain and improve the safety level and ensure safety as expected by customers through coordinated efforts of the company's departments; by defining the company's course of safety keeping flight operations through the establishment of the safety policy and objective; establishing and implementing safety systems, including standards and means; and evaluating the results of system implementation."

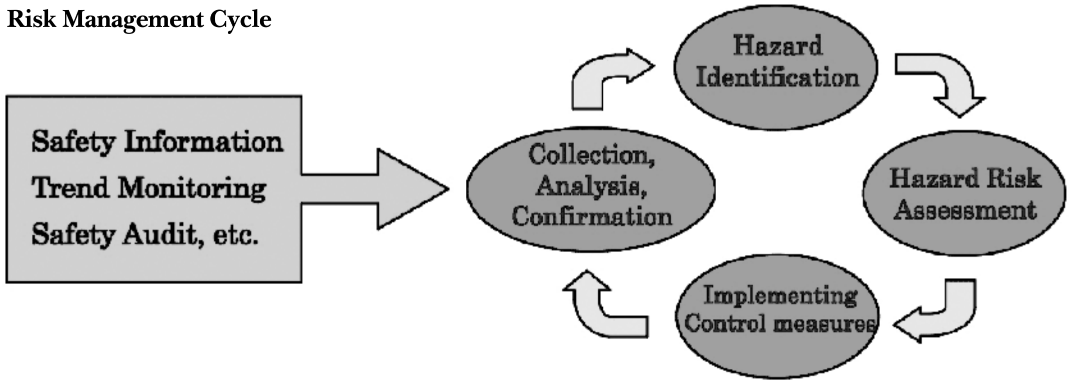
The basis of SMS is to identify hazards and conduct risk management based on the collected data to take corrective action as necessary, which creates the state that the hazards are maintained below acceptable level.

Aggregation of safety-related data (latent hazard) relies very much on the workers who are in direct contact with the hazard. In an aviation organization, there are air traffic controllers, pilots, flight crews, maintenance personals, and other who can provide key information about aviation safety problems and potential solutions. SMS will not function without safety-related information from those people.

The followings are the typical examples of safety-related information

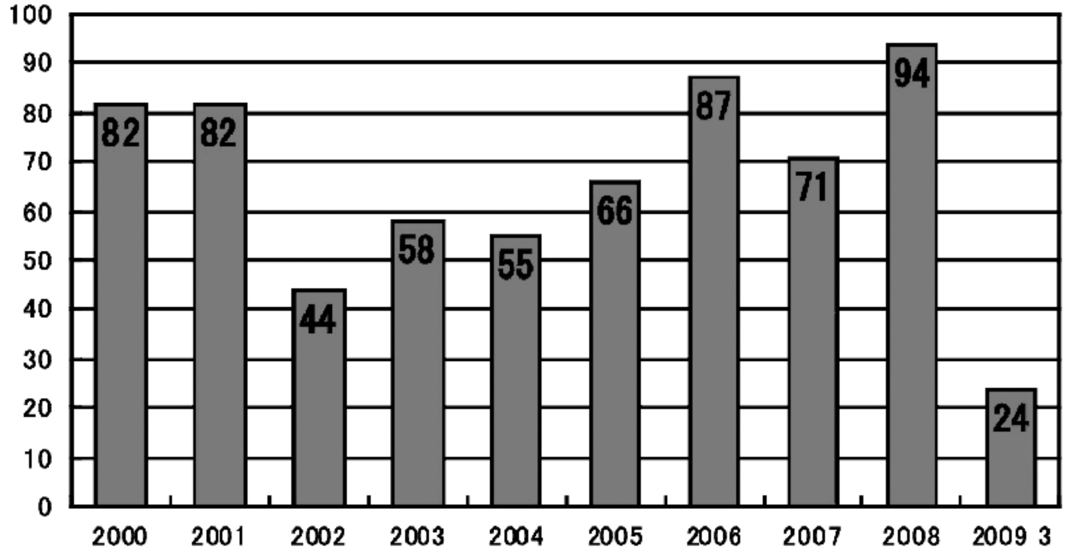
- Mandatory reporting items as per Japan civil aeronautics law.
- Voluntary reporting of near misses events (ANA has a reporting program called "experience can help others.").
- FOQA.
- LOSA.

Risk Management Cycle



• Findings and recommendation from an internal audit program.
• Findings and recommendation from an external audit program such as a safety management evaluation of transportation conducted by MILT and a safety inspection conducted by the JCAB, and IOSA if registered.

Among these listed above, safety-related information for a mandatory reporting items/FOQA/LOSA are automatically collected, but the other items truly require an atmosphere of trust in which people are encouraged for providing the information. That is why voluntary report/audit can become a benchmark to comprehend the level of the safety culture in the organization (see "Risk Management Figure on previous page).



Number of voluntary reports for large aircraft per year.

6. Voluntary reporting program in Japan

Chapter 5 explained how voluntary reporting can become a benchmark to comprehend the level of safety culture in the organization. ICAO Annex 13 will mandate voluntary reporting program and aggregation of accident/incident data to an authority later this year.

6-1. Examples of voluntary reporting program in other countries

The FAA has the Aviation Safety Action Program (ASAP), NASA has the Aviation Safety Reporting System (ASRS), CAA (UK) has a Mandatory Occurrence Reporting (MOR) under the law and those who submit a voluntary report are protected from being penalized. The way it works, using, for example, UAL (Flight Safety Awareness Program), is first the report must be submitted within 24 hours after the event takes place, and the report must be a sole source. Once the report is submitted, a so-called "event review committee" will be launched in order for the FAA/UAL/pilots' union to assess whether the event was acceptable or unacceptable with a prerequisite that intentional negligence, crime, drug abuse (including alcohol), and a cover up are clearly exempted.

6-2. Voluntary reporting program in Japan

In Japan, there is no voluntary reporting program that is established by Japanese authority except for ASI-NET (Aviation Safety Information Network), which is operated by judicial foundation ATEC (Association of Air Transport Engineering and Research).

According to ATEC, the anonymous report is treated as strictly confidential and will not be used to penalize by the authority. In addition, the authority has no direct access to the sources to protect the reporter and the information of the sources; however, the exemption of policy is only applied to the administrative sanction may be given by the JCAB. For the frontline workers, the legal basis of this statement is unclear and inadequate to convince us to make voluntary report.

7. Conclusion

The "safety culture assessment" conducted by ANA for the organization, which has approximately 27,600 employees, left the certain quantitative data.

As the survey showed, there were not many differences of the scores in communication (if equated as "atmosphere of trust") between the first survey (2007) and the second survey (2009), which revealed it is still too early to say that the organization cultivated a safety culture. As I stated earlier, voluntary reporting can be a good benchmark to comprehend the level of the safety culture in the organization, but it has already been 4 years since the first introduction of SMS to the ANA organization, while the top management endeavor to promote the importance of safety culture. Aside from SMS promotion to the employees from management to frontline workers, what obstructs workers to build a fair and justice culture for the organization to collect safety-related information.

Some countries have begun a non-punitive voluntary reporting program that is based on the national law. In April 2009, ANA took a big step toward making an in-house non-punitive environment. The policy on how to handle in-house safety reports is as follows.

Among reports on flight safety, voluntary reported occurrences including Hitari-hatto (thrilling/chilling) events will be handled as in the past, so "people concerned will never be treated unfavorably." And in case of unsafe occurrences required mandatory reporting, when the cause of the unsafe occurrence is determined as a result of unavoidable human error(s), the person concerned shall not be accused by the company's disciplinary sanctions, nor shall he/she be treated unfairly against his/her interest.

However, the above policy does not preclude such cases matters have that been caused by intentional unsafe action, by false or concealment actions, by intentional rash actions or by excessive idleness. Unsafe occurrences are not judged based on how gross the outcome is, but on what has caused them.

Outside of the house, the JCAB Engineering Department has established an expert working group to research toward making a voluntary reporting program at the national level. A desirable voluntary reporting scheme shall be subject to not just pilots, flight attendants, mechanics but also to include air traffic controllers, and people who are engaged in airport management.

It means thousand of people are involved in this activity and there are so many obstructions to overcome, such as the society that tends to pursue criminal liability, sometime the event will not be reported or treated fairly (e.g., the typical title of the newspaper says "the incident occurred by pilot's mistake or air traffic controller's error" even before the investigation begins.)

I would like to emphasize that in order to tackle those challenge, one administrative office should not undertake to solve the problems but with the collaboration of other administrative office(s) as well as the representative of people who are in direct contact with a safety hazard shall be included.

The first step to cultivate a safety culture in an organization (from management to frontline workers) is to establish the reporting program, which is free from fear.

Culture, in general in a society, is often described as the ideas, beliefs, and customs that are shared and accepted by people in a society (e.g., Superman and Batman have become a part of popular culture). So does the voluntary reporting program. The people who are engaged with everyday safety conduct must accept the policy and the mechanism of the program. Once it is accepted, then the new buds called "trust" will begin to appear.

Harmony is "trust"

Finally, I had an opportunity to speak to the former team leader captain of Japanese defense force acrobatic team "Blue Impulse." The team drew a perfect Olympic symbol in a cloudless blue sky on the day of the Opening Ceremony of the Tokyo Olympics in 1964.

According to the captain, the most important thing in an airplane operation is the "trust." To be trusted, the man needs to have a virtue. The Kanji (Chinese character in Japanese writing) of "trust" "信" is structured from two parts. One part of the structure has the meaning of "people," the other is "language." In other words, there should not be a lie or betrayal when people speak. "Trust" is realized based on the virtue, as it will be gained by his/her actions and attitude through many years of assiduous effort.

Making a policy on the voluntary reporting program shall also be based on the "trust" of everyone involved in the operation of the aviation industry. Again at this stage in Japan, it is no exaggeration to say that the integration of effective SMS in an organization depends on the rulemaking of a voluntary reporting program, which will be accepted by people who will make a report. ◆

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Accident Trends in Asia: Major Improvements and Remaining Challenges

By Robert Matthews, Ph.D., Senior Safety Analyst, Federal Aviation Administration, USA

__Bob Matthews__ has been with the FAA since 1989, where he has been the senior safety analyst in the Office of Accident Investigation for the past 15 years. His previous professional experience includes 9 years in national transportation legislation with the U.S. Department of Transportation, 2 years as a consultant with the European Union and the Organization of Economic Cooperation and Development in Paris, and several years as an aviation analyst for the Office of the Secretary at the U.S. DOT. His academic credentials include a Ph.D. in political economy from Virginia Tech's Center for Public Administration and Policy Analysis, and he has been an assistant professor, adjunct at the University of Maryland since 1987.

Several aviation systems in Asia have had low air carrier accident rates for decades, including our host country, Japan, but also Singapore, Hong Kong, and, depending on where the line is drawn, Malaysia. However, as recently as the early and mid-1990s, accident rates in the rest of Asia were fantastically high compared to the four countries noted above, or compared to rates in Western Europe and North America. That is no longer the case. A number of countries in Asia have achieved enormous gains in aviation safety and now have long-term accident rates that are among the lowest in the world, and several other Asian countries are approaching that level. The most impressive improvements include China, South Korea, and Vietnam.

On balance, aviation safety in Asia has become a good story to tell, but the good news is not shared by all countries. As we might expect with a geopolitical region as large as Asia, the pace of change has been uneven. In a number of countries, improvement has been less impressive, while recent trends, in fact, have gone in the wrong direction in a few countries.

The paper uses accident data, exposure data, and other standard aviation measures to document where and to what degree positive change has or has not occurred in Asia. The paper also examines common measures of broader economic performance and governance to help understand the different degrees of change among Asia's national aviation systems. The paper concludes with some comments on remaining challenges, both in countries that continue to struggle with high accident rates in those countries that have achieved dramatic improvement.

Defining "Asia"

Terms like "Asia" or "Europe" often are defined slightly differently by different speakers. A non-Asian country makes the point well. Aviation officials in Mexico often joke that their country belongs to more regions than any other country. Some speakers include Mexico in North America, while others put it in Central America, or the Caribbean, or "Latin America," or OECD countries (or not), or any of several other groupings. The same is true of certain countries that sometimes are included in "Asia" and sometimes not included.

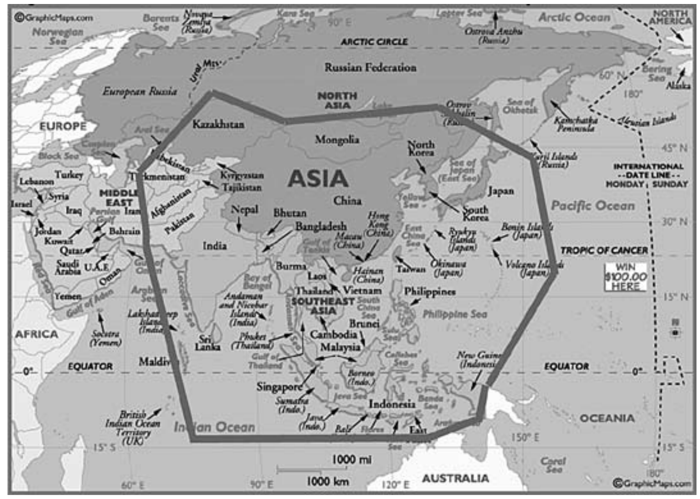


Figure 1. Definition of Asia for this paper: 29 systems—excludes southwest Asia ("Middle East").

Figure 1 illustrates the definition of "Asia" used in this paper. It includes 29 countries with a variety of political and economic systems, a broad range of wealth, and national populations that range from very small at one end of the scale to three of the world's four largest countries at the other end of the scale. It is bordered from northeast to northwest by Japan, Mongolia, and Kazakhstan, on the west by Uzbekistan, Turkmenistan and Afghanistan, the Maldives in the southwest, in the south by Indonesia, and in the east by the Philippines and several Japanese islands further east. Though this is a fairly standard definition, it excludes what some define as southwest Asia (or "the Middle East)." Finally, for the sake of clarity, it excludes the continent of Australia, as well as New Zealand and the Pacific states.

Changes in Asia's accident record

Table 1 compares 5-year hull-loss rates for the 29 countries of Asia to the rate of a "control group"[1] of countries long recognized as setting a safety standard for the world, and then the rest of the world, including Central and South America, Africa, the Middle East, much of central Europe, plus Australasia. From 1990 through 1994, Asia had a hull-loss rate that was nearly 8 times greater than that of the control group and 38% higher than the rest of the world. Note that Asia's data for 1990-94 includes Japan, which then was, by far, the largest system in Asia, plus Hong Kong and Singapore, all three of which had already established safe systems. Without those three systems, the rest of Asia exceeded the hull-loss rate of the control group by more than 10 times and nearly doubled the hull-loss rate in the rest of the world. By 2005-1009, just 15 years later, the ratio for Asia was just a bit more than four times the rate for the control group and, instead of exceeding the rate for the rest of the world by nearly 40%, it was just less than half the rate for the rest of the world.

	1990-94	1995-99	2000-04	2005-09
Asia	4.61	2.91	1.42	1.52
Control Group	0.61	0.51	0.33	0.35
Rest of World	3.35	3.90	3.70	3.07

Control Group consists of Canada, USA, and the EU-15.

Table 1. Hull Losses per Million Aircraft Departures 5-Year Rates, Asia Compared to Control Group and the Rest of the World

Though the improvement indicated above is dramatic, the aggregate data presented for all 29 countries obscures several great success stories. Figure 2 consolidates the data shown above into two 10-year period for selected groups of countries. The figure presents a telling story, supported by the data in Table 2. Figure 3 presents a similar decade-to-decade comparison for selected, individual countries.

Table 2 shows that in the 1990s, the four countries identified earlier as having long established good safety records (Hong Kong, Japan, Malaysia, and Singapore) already had combined hull-loss rates that were only about half those of the control group. Over the next decade, those four countries compiled a hull-loss rate that was just 30% of the rate for the control group. In short, these four countries already had set the world's standard for aviation safety in the 1990s, only to extend the margin that the standard already had enjoyed compared to the rest of the world.

	1990-99	2000-09
Hong Kong, Japan, Malaysia, and Singapore	0.29	0.10
China, RO, and Vietnam	3.68	0.287
India, Taiwan, and Thailand	4.00	1.53
Indonesia, Pakistan, and Philippines	4.78	3.66
Central Asia (six Countries)	10.59	5.20
Control Group	0.55	0.34

Table 2. 10-Year Rates for Selected Groups of Countries Per Million Aircraft Departures, 1990-99 and 2000-09

Japan, in fact, has not had a major fatal accident since 1985. With the world's sixth largest system measured by aircraft departures, Japan's only hull loss in 25 years occurred in 1993 when a DC-9-41, operated by the former Japan Air Systems, landed hard at Morioka-Hanamaki Airport. In that accident, all 76 occupants evacuated without injury, but a fuel leak led to a fire that eventually destroyed the aircraft. During the same two decades, Hong Kong had zero hull losses, and Singapore had one major accident at Taipei in October 2000, which was the lone fatal accident since 1972 from either Hong Kong or Singapore.[2] Each of those systems is considerably smaller than Japan's but they produced nearly 4 million flights over the 20 years.

The most dramatic changes

The story is perhaps most dramatic for the second group displayed in Figure 1 and Table 2 (China, South Korea, and Vietnam). Those three countries combined for a hull-loss rate in the first decade that was nearly seven times higher than the rate for the control group. Over the next decade, their combined rate was slightly lower than the rate for the control group. That is a very impressive change.

Vietnam had a very high hull-loss rate in the 1990s, followed by no hull losses the following decade. The high rate of the 1990s involved three hull losses produced by a very small system. Though the system remains relatively small, it has grown from fewer than 15,000 flights in 1990 to nearly 100,000 flights today. That rapid growth coincided with a sharp improvement in safety.

Much of that improvement came partly from upgrading the fleet, but some of it came as one benefit of opening up to foreign investment. Though Vietnam continues to struggle with the policy issues related to foreign investment and "foreign" brand names, the infusion others' experience has contributed.

The improvement achieved by South Korea may be even more dramatic than Vietnam's. From June 1991 through December 1999, South Korean operators had eight hull losses in a system that then averaged fewer than 200,000 flights per year. Most of the eight accidents could qualify as egregious accidents, including three fatal accidents that killed a total of 304 people.

South Korea's Civil Aviation Safety Authority (CASA), along with its major carriers, KAL and Asiana, undertook an active effort to ensure appropriate training and the establishment of and adherence to good standard operating procedures. The government and the industry also moved away from relying on punishment as a response to incidents or accidents, such as transferring authority in selected, lucrative markets from one airline to another after an incident. Instead, CASA upgraded its own staff and implemented more contemporary analytical procedures to improve safety throughout the system.

A closely related factor was pressure from the market. Both the U.S. FAA and the European Union, particularly the United Kingdom, restricted Korea's access to their markets until safety improved. Simply put, the loss of access to the world's biggest markets will get the attention of most companies. Simultaneously, international alliance and code-share partners pressed Korean carriers to upgrade safety and actively participated in the effort.

The results have been dramatic. After eight hull losses in just 9 years, South Korea has had no hull losses for the past 11 years, despite system growth of more than a third over that period. To everyone's credit, Korea's CASA and its carriers continue to invest resources and their administrative energies to ensure that the improvement is permanent.

Finally, China is perhaps the best recognized success story. Aviation and aviation safety have changed so dramatically in the past two decades or so that the change is hard to overstate. The early signs of change occurred in the 1970s when China first purchased a small number of Western-built aircraft, starting with Vickers and a small number of Tridents, followed by larger purchases of Boeing aircraft and more Tridents, and eventually Airbus aircraft. By the early 1990s, China had undertaken a conscious effort to retire most or all of its older, Soviet-era fleet and upgrade the fleet, again with Boeing and Airbus products and, later, Embraer and Canadair products. All these changes were accompanied or followed by significant investments in satellite-based air traffic control technology and a major effort to construct new airports throughout the country.

Different people may offer somewhat different time lines, but the profound change arguably began with a major structural change in the 1980s, when China's government reorganized the airline services operated by the Civil Aviation Administration of China into region-

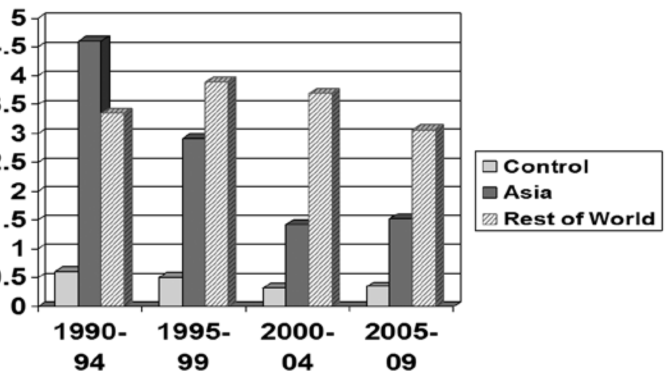


*Figure 2. Hull Losses Per Million Aircraft Departures, All of Asia Versus Control Group**

*Control group consists of EU-15 plus USA and Canada. Rest of world includes South and Central America, Caribbean, central-eastern Europe, "Middle East," Africa, Australia, New Zealand, and Russia.

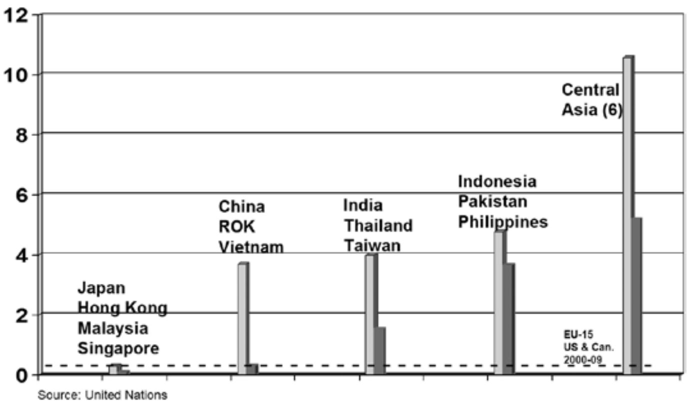


Figure 3. Change in hull loss rates, selected groups of systems, 1990-1999 (left) and 2000-2009 (right).

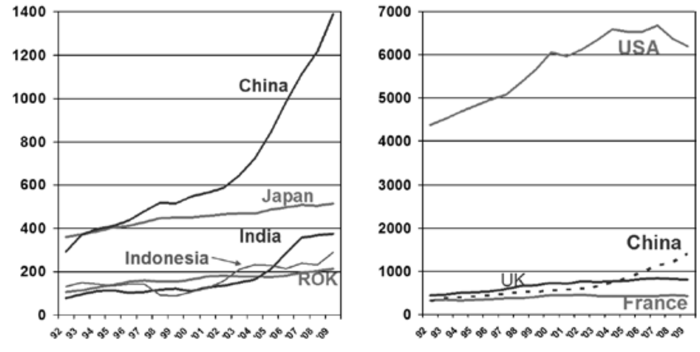


Figure 4. Fleet expansion and renewal, in-service airline jets. and turboprops of more than 50 seats in selected countries, 1992-

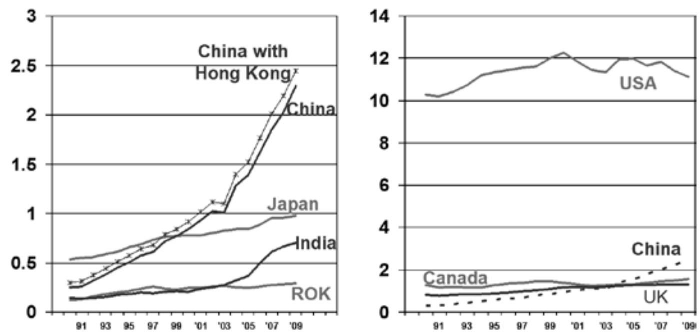


Figure 5. Airline revenue flights by selected countries 1990-2009 (in millions).

ally based carriers. By the late 1990s, China restructured its industry again by consolidating the industry around three successful carriers. China Southern, which is China's largest airline, eventually absorbed China Northern, China Xinjiang Airlines, and Urumqui Airlines, as well as several subsidiaries of those former carriers, and it has a controlling interest in Xiamen Airlines. In the same period, China Eastern absorbed China Northwest Airlines, China Yuan Airlines, and Great Wall Airlines. China Airlines, which already had been structured as China's long-haul overseas carrier, remained based in that market and absorbed China Southwest Airlines.

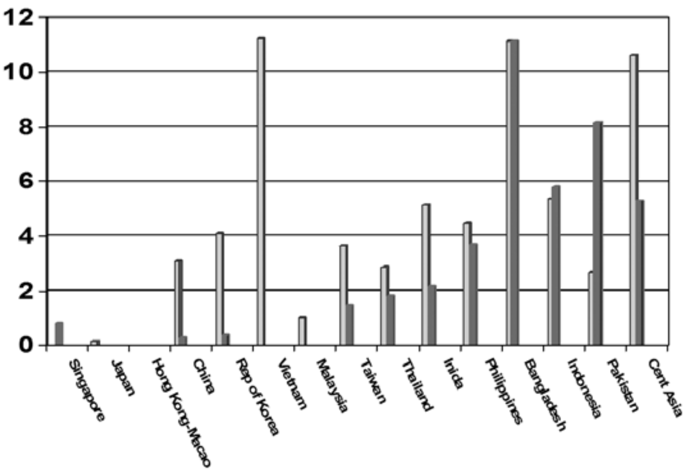
Safety was a significant part of the rationale for the latter restructuring. In addition to restructuring its airline industry, China, much like South Korea did, also took strong action to ensure proper training and the establishment of and adherence to good standard operating procedures. China simultaneously accelerated its fleet modernization, which introduced state-of-the-art automation, avionics, etc.

The net results have been dramatic. Throughout the 1980s and into the very early 1990s, China averaged two air carrier hull losses per year in an era when annual volume in China was the equivalent of about 1 week of exposure in the U.S. At that pace, we can only imagine the reaction if the U.S. were having a hull loss every week. However, in the 1990s, safety improved substantially in China, though its hull-loss rate still was six times greater than the hull-loss rate among the control group. However, in the past decade of 2000 through 2009, China's hull-loss rate was slightly lower than the rate among the control group. The magnitude of that turnaround is simply stunning. See Table 2 and Figures 2 and 3.

The truly impressive part of this improvement in safety is that it has been achieved during very rapid growth in the system. Figures 4 and 5 show changes in national fleets and total revenue flights for selected countries. Through the 1990s, Figure 4 shows that China's airline fleet increased by an average of 13.3% per year, a pace at which the fleet would double every 5.5 years. In the following decade, the rate of increase averaged a comparable 11.9% per year, with the fleet doubling every 6 years. As one might expect, the number of revenue flights has increased at a comparable pace over the past two decades, averaging 12.1% per year.

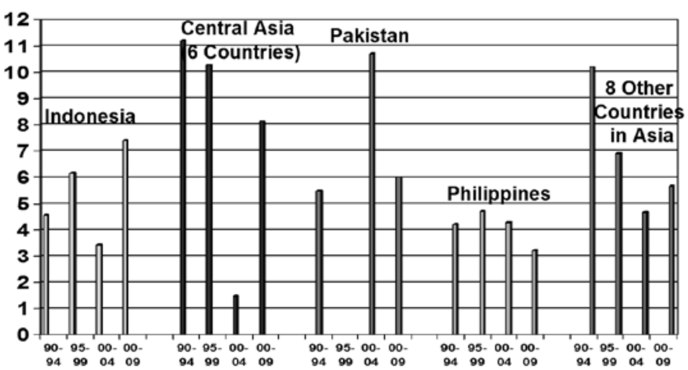
Figures 4 and 5 illustrate visually how sustained and how rapid the growth has been in China's aviation system. In 1990, the system had fewer than 300 aircraft and generated about 250,000 flights. These figures made China the 16th largest system in the world at that time. By 2005, China's system was the second largest in the world by either measure.

Rapid growth in any nation's aviation system can pose safety challenges. Yet China's aviation system has sustained a blistering rate of growth while simultaneously achieving nothing short of a revolution in safety. That combination is the truly impressive achievement. Yet, the rapid growth in fact is part of the explanation for the improved safety. Not only did China retire its older, mostly Soviet-built fleet, but it continued to accelerate the introduction of ever advancing state-of-the-art avionics and automation. That alone ensured a significant improvement in safety. Add the other efforts that China undertook, noted above, and the net result is a hull-loss rate that once was simply an embarrassment to one that, today, many countries must view with more than a little envy, and certainly a fair amount of respect.



Sources: Departures from JOS; Accidents from Airclaims-Ascend, Aviation Safety Network, and National Investigative Authorities.

Figure 6. Hull losses per million aircraft departures, by national system 1990-1999 (left) and 2000-2009 (right).



Sources: Departures from JOS; Accidents from Airclaims-Ascend, Aviation Safety Network, & National Investigative Authorities.

Figure 7. Hull losses per million flights, countries where accident rates remain high.

Countries with more modest improvement

India, Taiwan, and Thailand constitute a third group within Asian where hull-loss rates registered significant but more modest improvement than the successes noted above. Combined, India, Taiwan and Thailand achieved a 62-percent reduction in their hull-loss rate in 2000-2009 compared to the 1990s. However, even with such a substantial decrease, since they started with very high rates, their combined rate for 2000-2009 remains well above either the control group or the seven Asian states noted above. In addition, though Figure three shows all three countries achieved significant gains decade to decade, Figure 6 shows that hull-loss rates increased in two of the three countries in the past 5 years (2005-2009).

Taiwan achieved the most sustained improvement among these three countries, and for reasons similar to those that help to explain the positive changes in China and South Korea. Beginning around 1997, Taiwan's authorities accelerated its active oversight of the industry. Regional airlines, such as Formosa Airlines, were among the early targets, but China Airlines quickly followed. Aircraft and selected crewmembers were grounded or suspended for various periods, and the authorities initiated a sustained effort to improve crew training and the establishment of good standard operating procedures.

Taiwan also established its Aviation Safety Council (ASC). The ASC was responsible for regulation and accident investigation, but it also significantly upgraded the role of analysis and monitoring of trends.

However, Taiwan's improvement also was influenced by pressure from other aviation regulators. Much like South Korea, Taiwan's carriers found themselves either excluded from major markets or found that future growth was precluded due to their high accident rates of the 1980s and mid-1990s. Those restrictions in major markets helped to focus attention.

This did not prevent the takeoff accident at Singapore in October 2000, which killed 83 people. However, that is Taiwan's most recent fatal passenger accident. As Figure 6 illustrates, Taiwan's hull-loss rate has improved in each 5-year period on the chart. The rate for 2005-2009, at 0.8 hull losses per million revenue flights, was 83% lower than in 1990-1994. If Taiwan sustains its steady improvement, it soon will approach the very low rates enjoyed by the seven Asian countries noted above.

The hull-loss rate in India improved sharply through the early 2000s, leading to glowing commentaries similar to those about China's improvement. As with China, some of the improvement was explained by fleet modernization, with the government seeking to establish a 5-year cap on the age of passenger aircraft.

India's system has expanded rapidly since 2003. Prior to that, its system, measured by aircraft departures, doubled from 1990 to 2003. The pace of growth in that period, which averaged about 5.3% per year, was not dramatically higher than the increase experienced in much of the world in that era. However, since 2003, the system has expanded rapidly, averaging about 13.8% per year. Yet, despite this growth, India still generates just 4 million passengers per year in its domestic system, or about 2 days' of passenger traffic in the USA. Growth in supply has outstripped demand, creating excess capacity in many domestic markets, yet while leaving other markets underserved.

India's growth has created other challenges as well. New carriers have entered the market, some of which were short-lived, while others prospered and then encountered hard times, such as Kingfisher and Jet Airways, who now cooperate through a rather close alliance. In the meantime, India's former domestic trunk carrier, Indian Airlines, has been absorbed by Air India, with many of the normal difficulties of any large airline merger.

Though a cause-and-effect relationship may or may not exist, the improvement in India's accident rate has been reversed in recent years. A spike in non-fatal hull losses in just more than 4 years began in October 2005. That spike was followed shortly by the India Air Express accident in May 2010, in which 158 people died. Though that accident is not part of the rates computed for this paper, it dramatically makes the point that the sharp improvement in rates has reached at least a temporary interruption.

The good news is that India has responded by developing comprehensive aviation legislation and by reorganizing its regulatory structure to ensure a more independent and stronger regulator. Nevertheless, judgment on long-term improvement needs to wait.

In Thailand, the system expanded rapidly in the early 1990s, stagnated briefly, and then expanded rapidly again from 2000 through early 2007. Since then the system has contracted by about 15%. Like other countries, Thailand has had several new carriers enter and exit the system, and had to cope with the Asian financial crisis of the late 1990s and then the SARS scare. However, political uncertainty probably is the greatest current source of erratic growth patterns in the industry.

No improvement or marginal improvement

Figure 3 shows that the accident rate actually deteriorated in recent years in significant parts of Asia in recent years or improved only marginally. The hull-loss rate in the Philippines improved slightly from 4.5 per million departures to a still very high 3.8 per million. Elsewhere, Indonesia's hull-loss rate increased slightly from an already high level of 5.4 per million departures to 5.8 in 2000-2009, while Pakistan's rate jumped from 2.7 to 8.15 per million departures. In the six countries of central Asia, the rate improved by exactly half, from a very high level of 10.6 hull losses per million flights to 5.3 per million.

Figure 7 provides a bit more insight into these rates by showing rates for these countries in 5-year periods. Indonesia's rates increased in the second half of the 1990s, and then increased again over the past 5 years. In the Philippines, the rate also increased in the latter 1990s but increased again in 2000-2004, albeit marginally, then decreased in the past 5 years. But the rate remains very high compared to all the countries discussed above. Pakistan had no hull losses for 6 years (1995 through 2000), but its rate inflated again in 2000-2004 and remains very high.

Finally, the six countries of central Asia show an erratic pattern for rates over the two decades. Part of that is the problem of small numbers. A single accident or the avoidance of a single accident will significantly affect the computed rates for this region. Nevertheless, other factors help to explain the erratic pattern. For example, the rate for 2000-2004 is only a small fraction of the rate for the 3 other periods shown on the chart, with a sharp increase once again in the past 5 years. To a large degree that pattern reflects the virtual disappearance of aviation activity in Afghanistan from 2000 to 2004, followed by the reemergence of limited civil aviation activity in 2005-2009, accompanied by the reemergence of accidents.

Summary of trends

Several national systems in Asia have had good safety records for a long time, and their fatal accident rates continue to be among the lowest in the world. They include Japan, Hong Kong, Malaysia and Singapore. China, the Republic of Korea, and Vietnam have achieved dramatic improvement and have joined this club, while Taiwan/Chinese Taipei is rapidly approaching this level. However, the pace of improvement has been slower elsewhere or in some cases it has been negative. In short, the pace of change has been somewhat uneven, but the overall story is good.

Remaining challenges and broader factors that help explain these trends

As aviation professionals, we reasonably focus on issues that are within our domain when we try to explain differences in the level of safety from one country to another. However, broad factors that are well outside our domain may be more influential and may tell us which countries have the capacity to establish and sustain safety aviation systems. Simply put, aviation safety depends first on national wealth and governance.

Without some minimal level of economic mass, a country will lack the basic resources required to invest in aviation and safety. Gross domestic product (GDP) is the most basic measure of economic mass. Figure 8 shows GDP for 18 Asian countries in constant U.S. dollars for 1990 and for 2009. The correlation with the accident trends discussed

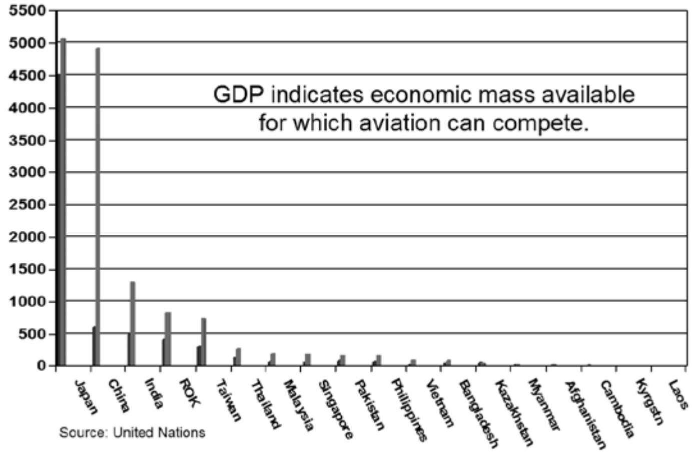


Figure 8. GDP, 1990 and 2009 (in billions of constant 2009 US $, or thousand millions).

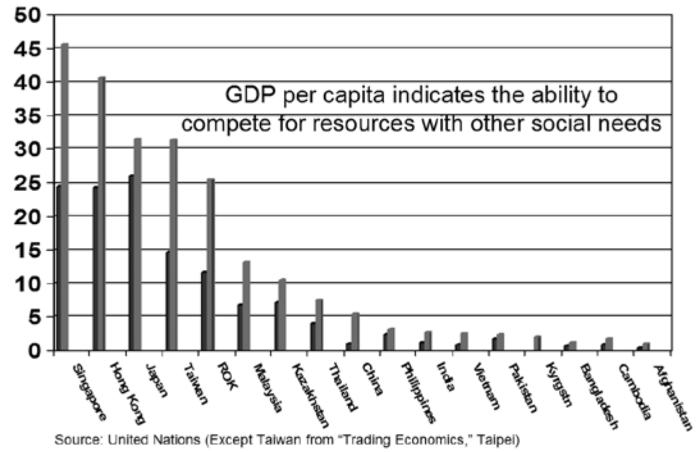


Figure 9. GDP per capita in purchasing power parity: 1990 (left) and 2009 (right) (thousands of constant 2009 "International Dollars").

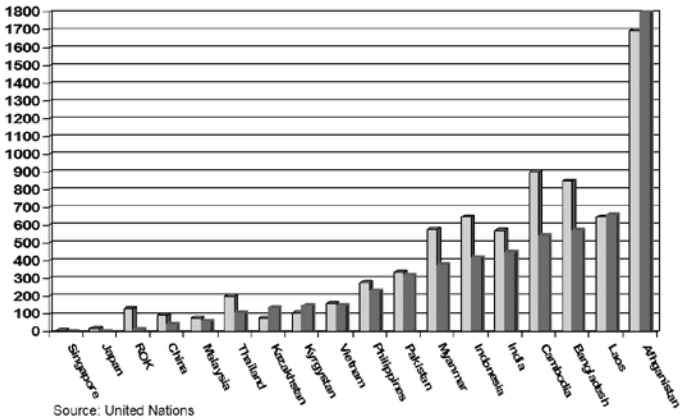
above is visually obvious. For example, Japan's was the largest economy in the region in 1990 and in 2009. Not coincidentally, Japan's system was already among the safest in the world in 1990, and before.

Figure 8 illustrates the stunning growth in China's GDP over the 20 years. Since China began implementing its economic reforms beginning in the late 1970s and early 1980s, economic growth has been nothing short of stunning. The same adjective applies to the change in China's aviation safety record: stunning. Again, the correlation with accident rates is not a coincidence, as China now has the economic resources to dedicate to aviation safety.

The same Figure 8 shows significant growth in GDP for India, South Korea, and Taiwan. We can easily forget today that, in the 1960s and 1970s, South Korea was the subject of worldwide discussions about the "economic miracle," as Japan had been a decade or so earlier. Taiwan's increase in total economic activity puts it in the same category, with GDP in 2009 nearly three times greater in real terms compared to 1990. Again, suddenly these economies had the resources to dedicate to aviation safety.

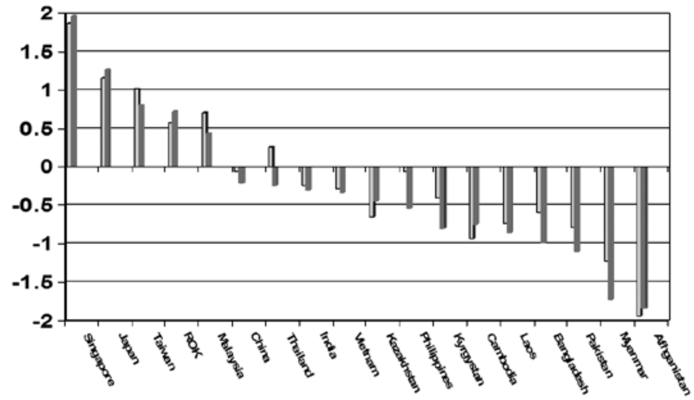
However, countries further to the right on the horizontal axis in Figure 8 illustrate what happens when a country lacks the resources. In those States, GDPs remain modest, and overall resources therefore remain modest.

Figure 9 adds a dimension to notions of national wealth by show-



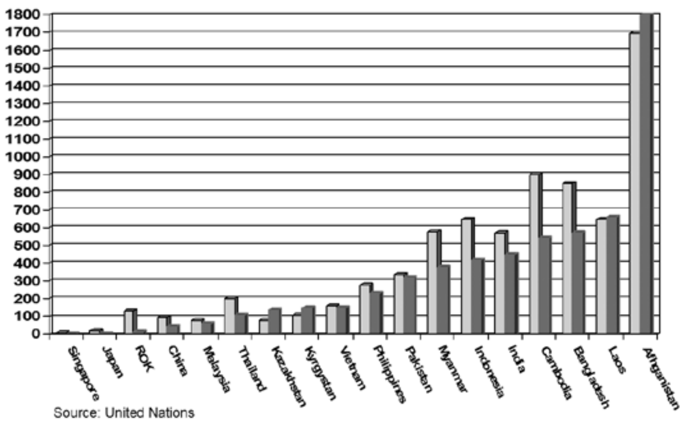
Source: United Nations

Figure 10. Maternal mortality per 100,000 live births, 1990 (left) and 2005 (right) (women who die in child birth).



Source: World Bank. Scores in this chart represent the mean of 5 indices (Political Stability, Government Effectiveness, Regulatory Quality, Rule of Law, & Control of Corruption).

Figure 12. World Bank Governance Index 1990 (left) and 2008 (right).



Source: United Nations

Figure 11. Infant mortality per 100,000 births 1988 (left) and 2008 (right) (infants fail to survive 1 year).

ing GDP per capita, adjusted for purchasing power parity, which accounts for differences in prices as well as exchange rates. This measure begins to indicate the level of competition from other socioeconomic demands for resources within a country. Even this measure, however, does not indicate the distribution of real wealth. Rather, it provides only the mean of GDP per person. Conceivably, a country could have a substantial GDP and a substantial GDP per capita, but a large majority of the wealth might be concentrated among a small elite. If so, competition for resources could still be severe. Combining GDP with the so-called Gini coefficient addresses that level of precision but GDP per capita is a convenient and more easily understood measure.

Figure 9 paints only a slightly different picture from Figure 8. The six highest measures of GDP per capita (Singapore, Hong Kong, Japan, Taiwan, Korea, and Malaysia) all have been shown to have very safe systems over the past decade or two. Conversely, most of the countries on the right side of the horizontal axis continue to have high hull-loss rates.

However, Figure 9 indicates that, despite its stunning growth of the past 20 to 30 years, China remains a relatively poor country. The same is even more apparent for India and Vietnam. This creates a possible long-term challenge for aviation's ability to compete for relatively limited resources.

Figures 10 and 11 are common measures of social well-being. Figure 10 shows maternal death rates (i.e., the rate at which women die during child birth), while Figure 11 shows infant mortality rates (i.e., the rate at children die before reaching one year of age). Initially, an observer might ask what maternal death rates and infant mortality have to do with aviation safety. The answer, at the most fundamental level, is "everything."

Of all the various social indicators available from international organizations such as the World Bank and the United Nations, maternal death rates, over the long term, always correlate more strongly with accident rates than any other measure, followed closely by infant mortality. The bottom line is that, if a country lacks the economic capacity or the social infrastructure to prevent the death of their women in childbirth or the death of large numbers of infants, the same countries will lack resources and infrastructure to ensure a safe or even a viable aviation industry. For example, in Afghanistan, maternal death rates, plus the fecundity rate, suggest that one in eight women of child-bearing age is likely to die giving birth. Similar rates apply to countries like Sierra Leone and Niger.

Figure 11 shows a similar measure, with the United Nations' Human development Index. The Index combines measures of per capita income, wealth distribution (Gini coefficient), infant mortality, life expectancy, and education. Again, the correlation to accident rates, in this case an inverse correlation, is visually apparent. Consistent with hull-loss rates, several countries established good rates on the measure a generation or more in the past, while other countries like China and South Korea made great progress. Conversely, more than a few countries with high accident rates made more modest progress or even lost ground on these measures.

Finally, Figure 12 shows the World Bank's Governance Index. However, this measure does not ask about a particular government or administration. Instead it asks broader questions about the state of the state. The chart combines scores from five other UN indices, including the following:

- Political stability. This measure asks about the basic stability of the regime, not the stability of a particular government or administration. Essentially the measure estimates the likelihood that the basic structure of the state tomorrow will be much the same as the basic structure of the state today. Without some reasonable minimum on this score, aviation or any other industrial activity lacks the most basic level of predictability that such activities require.
- Government effectiveness. Again, this measure does not necessarily reflect on any particular administration but asks about the degree to which a country has a bureaucracy that is professional, educated, well trained, and based on merit and the degree to which

the bureaucracy is free of political manipulation. At the high end of this measure is an ideal that probably no country quite achieves, but the opposite extreme almost certainly indicates a country that simply lacks the human resources to operate a functional and effective regulatory structure.

• Rule of law. This measure asks about the degree to which decisions are predictable versus the degree to which decisions are maid on the whim of a single ruler or a small elite. Again, predictability and the security of the operation is the issue for aviation.

• Control of corruption. This measure speaks directly to just how one gets something done. It also speaks to merit, effective bureaucracy, etc. Very low scores here usually correlate with low scores in all the above components of governance. At the extreme, low scores can identify a kleptocracy that simply strips the country of useful resources.

Low scores on governance generally correlate with poverty, high maternal death rates, etc. Simply put, countries that are very badly governed usually are also very poor. However, not all poor countries are badly governed. For any number of historical reasons, a country can be poor despite having a competent and honest state. Botswana may be the best example of a country that faces many challenges, but which has the benefit of a competent state.

The point for aviation safety is straightforward, though not very romantic. A country that is both very poor and very badly governed has no hope of establishing a safe aviation system. At the same time, a poor country that is well governed has many other priorities before it can entertain dedicating serious resources to aviation safety.

Some middle or lower income countries may choose to develop aviation as a tool of economic development, or to develop tourism, or what have you. Aviation can be an economic engine. However, the bottom lone is that aviation safety generally is a luxury item that depends on national wealth and governance.

Remaining challenges

Asian countries that have long enjoyed safety civil aviation systems and those countries that have achieved impressive gains in the past decade or so generally will continue to enjoy the benefits of a civil aviation system that becomes increasingly safer. However, this will not come without some challenges. Many of those challenges will occur within the domain of the aviation community, but some will come from the broader economy. The aviation community will be able to act upon some challenges, but others are external to aviation. The mix and severity of challenges will vary, but most systems face one or more of the following.

• **Adequate domestic workforces.** Countries with rapidly expanding systems will have to meet an equally rapid increase in the demand for pilots, controllers, mechanics, and managers, which in turn will place demands on or be affected by educational systems, demographics, and access to the economy enjoyed by the entire population.

• **Competing demands for national resources** where human development needs are great.

• **National challenges of basic governance and stability.** These issues are or have been resolved in some countries, but are chronic or newly emerging in others.

• **Rapid expansion of low-cost carriers (LCC).** Though LCC inherently suggests nothing more than an alternative business model, it implies nothing more than a business model that need not have any inherent implications for safety. Nevertheless, the LCC expansion also implies some level of overall volatility, the possibility of rapid entry and rapid exit from the industry, and the possibility of rapid growth for some successful LCC operators. All this, in turn, imposes challenges of resource allocation on the regulator, the ability to reallocate those resources quickly in response to entry, exit and expansion, and a general sense of scale for the regulator as the sheer number of operators expands.

• **Entry by several countries into the manufacturing of air transport aircraft** (China, Japan, and India), while some countries are significantly expanding their presence in the maintenance and overhaul industry (Singapore and Malaysia). All this is a great opportunity, but it also requires the development of a basically new regulatory capacity in design, production and continued airworthiness.

• **Getting ready in some countries for growth in general aviation,** such as a small but rapidly growing civil helicopter market in India and a promising market for corporate aviation in China. Again, this is an opportunity, but it also requires the development of basically new regulatory capacities, plus a shift in operating environments.

• **Aviation infrastructure.** As or if systems continue rapid expansion, which everyone expects will be the case, some countries may have difficulty keeping pace with the demands on aviation infrastructure. The recent accident in China is a case in point as is the recent Air India Express accident at Mangalore. At Mangalore, the aircraft landed 5,000 feet down an 8,000-foot runway, overran at high speed and traveled down a steep embankment at the end of the runway. The same accident in many richer countries likely would have occurred with am longer runway remaining after touchdown and with an overrun area or at least the absence of obstacles at the runway end. Though the result in a richer country may not have been benign after landing so long and so fast, it likely would not have produced 158 fatalities.

China, where some of the most dramatic improvement has taken place, may provide the best single example of how many of these challenges might interact. First, airline travel, though certain to continue expanding at impressive rates for another decade or so, eventually will flatten out as the industry faces increased competition from other modes of transport. Though airport investment has been nothing short of dramatic, it pales compared to China's recent and continuing investment in rapid rail and roads. Rapid intercity rail already is shifting travel from air to rail in some interurban markets, with corresponding reductions in airline capacity in those markets. Roads eventually also will become a major modal challenge within certain markets, depending on the time and distance between cities.

China, like several other countries, also is entering the field of civil aircraft manufacturing. New domestically produced turboprops and regional jets, and the spin-off technological benefits to the entire economy, are clearly an opportunity for China. However, entry into that market requires the development of a basically new regulatory capacity in design, production and continued airworthiness. That challenge will not be unique to China, as other Asian countries also are preparing to enter that market.

Even the recent boom in airport construction has introduced risk, with serious doubts about some airport locations. Those doubts likely will be part of the on-going investigation into the recent Henan Airlines accident at Yichun Lindu Airport in northeastern china, where an Embraer E190 flew into terrain in heavy night fog. Site selection for that airport had become controversial months before the accident, when China Southern abandoned night flights into the airport.

Conversely, with continued rapid growth ensured for at least the next decade if not more, China could be challenged to produce the broad range of professionals that any large, modern aviation system requires, from pilots and air traffic controllers, to managers, mechanics, etc. China soon will have to meet this challenge just as its working-age population begins to decrease. Most demographic projections cite 2014 or 2015 as the watershed year when that decrease is likely to begin. Total population could decrease by as much as one-third on the following several decades, as India, with the opposite demographic future approaching in the next couple of decades, likely surpasses China as the most populous country by about 2030 or sooner.

China's aviation system also could face challenging demands for resources in other sectors of the economy. As Figure 9 showed, despite the truly impressive gains in national wealth, China in fact remains a fairly poor country, with a GDP per capita that ranked 102nd. The challenge, of course, will be to expand the benefits of the recent growth further down into the population, especially the rural population.

Yet, if China succeeds in this challenge, and few concrete reasons exist to suggest China will not succeed at least somewhat, the aviation industry would benefit from an increase in the share of the overall population who could then afford to fly. In short, the aviation industry in many countries might envy China for having such "problems." In the end, despite real challenges, the next decade or two should continue to be an impressive period for aviation in China. The same may be true of Asia's aviation system in general over the next decade or two. ◆

Conclusions

Asia has achieved dramatic improvement in aviation safety over the past decade to 15 years. However, like any other region, improvements in Asia have been uneven. Yet, despite different challenges that face different countries, Asia has a good story to tell and the story should continue to get better for the foreseeable future.

Endnotes

1 The control group, or comparison group, includes Canada, the United States, and the "EU 15," which constituted the European Union prior to its recent expansion.
2 The count of fatal accidents excludes criminal actions and suicides.

AAIB's Use of Data Mining in the Investigation of the Fuel-Icing Accident: Innovative Outcomes and Challenges Faced

By Mark Ford, Senior Inspector of Air Accidents (Engineering), Air Accidents Investigation Branch, Department for Transport

Mark Ford joined British Airways in 1987, where following a 4-year avionics apprenticeship and university education, he was to become a development engineer specializing in data acquisition and recording systems, working within the Flight Data Monitoring/ Flight Operations Quality Assurance Department. Mark also worked as communications manager for the technical director of engineering, before leaving to join the Air Accidents Investigation Branch in 2003, where he is now a senior inspector of air accidents, working within the Flight Data Recording and Analysis Department. Mark has worked on more than 100 investigations to date and is the holder of a private pilot's license.

Introduction

On the Jan. 17, 2008, a Boeing 777-236ER powered by Rolls-Royce engines, registered G-YMMM, whilst on approach to London (Heathrow) experienced a loss of power to both engines, which resulted in the aircraft touching down approximately 330 metres short of the paved surface of the runway (see Figure 1). The investigation undertaken by the United Kingdom Air Accidents Investigation Branch determined that the probable cause was the formation and sudden release of ice in the aircraft fuel delivery pipes that caused a restriction at the engine fuel oil heat exchangers (FOHE) during a critical stage of the flight.

A second incident occurred on Nov. 26, 2008, when a Boeing 777-200ER registration N862DA also powered by Rolls-Royce engines, was being operated from Shanghai to Atlanta, when it suffered an uncommanded reduction in engine power during the cruise. Preliminary conclusions issued by the NTSB were that the FOHE on the right engine had become restricted with ice.

The intent of the data-mining activity was to identify if any parameters or a combination of parameters were unique to the accident flight and to understand further the reason why the engine rollbacks had occurred on the G-YMMM accident flight, the later N862DA incident flight, but not the other thousands of flights. Initial analysis of the accident flight data identified that certain fuel flow and fuel temperature features were unusual or unique when compared to a small number of flights having operated on the same route and under similar atmospheric conditions. However, it was difficult to place a statistical significance on these findings alone due to the small sample size. Analysis of a much larger data set was required, and this was best supported by tools specifically designed for the purpose of data mining. A team was formed of statisticians from QinetiQ, together with specialists from the aircraft and engine manufacturer, the operator and the AAIB. Data points from more than half a million flights were analysed during the course of the investigation. This paper discusses the data-mining process, results, and issues faced.

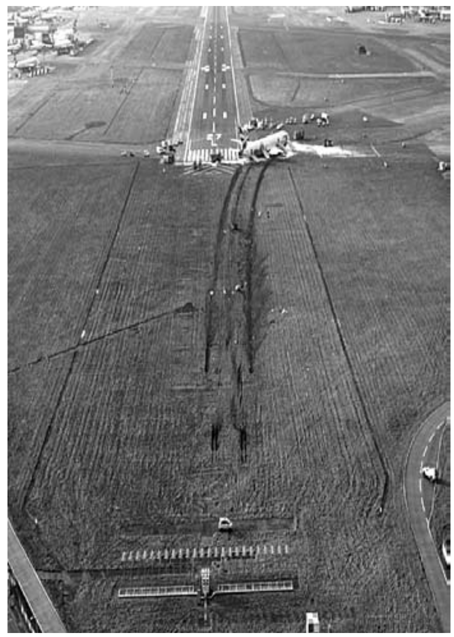


Figure 1. G-YMMM at Runway 27L undershoot shortly after the accident.

Data mining

Data mining in itself is not a new development, but its application to aircraft accident investigation is relatively new. Humans have been "manually" extracting patterns from data for centuries, but the increasing volume of data in modern times has called for more automated approaches. Early methods of identifying patterns in data include Bayes' theorem (1700s) and regression analysis (1800s). The proliferation and increasing power of computer technology has resulted in the increased collection and storage of data. As data sets have grown in size and complexity, direct hands-on data analysis has increasingly been augmented with indirect, automatic data processing. This has been aided by other discoveries in computer science, such as neural networks, clustering, genetic algorithms (1950s), decision trees (1960s), and support vector machines (1980s). Data mining is the process of applying these methods to data with the intention of uncovering hidden patterns. It has been used for many years by businesses, scientists and governments to sift through volumes of data such as airline passenger trip records, census data, and data for market research purposes.

An unavoidable fact of data mining is that when analysing subsets of data, the data may not be fully representative of the whole domain. In our case, data were not available for every flight made by Boeing 777's, so we were reliant on a smaller detailed subset equalling about

5% of the total flights (~4 million). Certain critical relationships and behaviours may only become apparent when analysing the whole domain. The investigation was confident of being able to identify unique or unusual features from the accident flight, although the difficulty was then demonstrating the features were contributory or causal to the accident.

Where only subsets of data have been available, data-mining results has been augmented with other approaches, such as experiments. In our case, the decision, independent of the data mining, was to conduct an exhaustive series of tests on the fuel itself and the associated fuel system to understand the principles of ice formation and its release. These tests are covered in more detail in papers presented to this conference by Brian McDermid from the AAIB and Mark Smith from Boeing.

The team

The investigation benefited from having an aircraft that remained relatively intact, all the persons on board survived, there were many witnesses to the accident and data was available from several sources. However, it was not possible to determine the most likely cause without an extensive test and research programme. Early in the investigation it became apparent that the reason for the rollbacks of both engines had been due to a restriction of the fuel flow, but the lack of physical evidence, apart from cavitation marks on the outlet ports of the engine high pressure fuel pumps, made the determination of the cause particularly challenging.

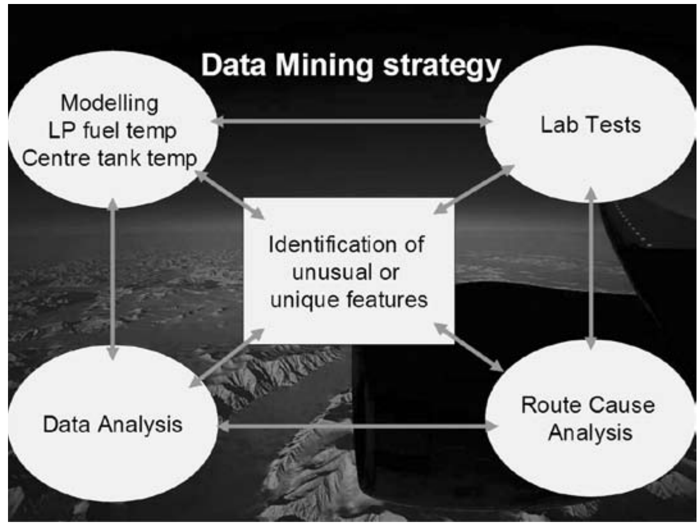
In the weeks immediately following the accident, data from the engine health monitoring program identified that both the takeoff fuel temperature (-2°C) and cruise fuel temperature (-34°C) were at the lower end of the distribution when compared to other flights made by Rolls-Royce powered Boeing 777 aircraft. A second-by-second evaluation of QAR (quick access recorder) data from the operator of G-YMMM for about 50 flights also indicated that the fuel flows and temperatures were unusual in having low temperatures and flow rates during the cruise, accompanied with a series of high fuel flow rates peaking at 12,288 pph immediately before the restriction of fuel flow had occurred to both engines.

Although useful, the engine health database consisted of a series of data snapshots taken at various phases of flight, such as takeoff and whilst in the cruise. The trigger for the snapshots was not predicated on fuel temperature being at its minimum and although the snapshots providing a good indication of cold routes flown by the Boeing 777, it could not be guaranteed that the minimum fuel temperature had been captured. The practicable solution was to evaluate QAR data[1], which leant themselves to being manipulated by data-mining tools.

A data group was formed within the existing group system. The group consisted of a team of statisticians from QinetiQ (contracted to the AAIB), together with specialists from the aircraft and engine manufacturer, the operator and the AAIB. The core team of ten was chaired by the AAIB. In the weeks immediately following the accident, staff from the AAIB and aircraft and engine manufacturer collocated to the operator's engineering facility at London Heathrow.

Strategy

The concept of the group was to be able to sit within the existing investigation group structure, with the aim of being able to not only identify unique or unusual features of the accident flight, but to explore the data based on requirements from other groups. It was especially important that the data group remained appraised of the fuels system testing so that analysis models could be progressively modified.



Tools for the job

There have been some efforts to define standards for data mining, for example the 1999 European Cross Industry Standard Process for Data Mining (CRISP-DM 1.0) and the 2004 Java Data Mining standard (JDM 1.0). These are evolving standards; later versions of these standards are under development. Independent of these standardisation efforts, freely available open-source software systems like the R Project, Weka, KNIME, RapidMiner, and others have become an informal standard for defining data-mining processes. Notably, all these systems are able to import and export models in PMML (Predictive Model Markup Language), which provides a standard way to represent data-mining models so that these can be shared between different statistical applications.

Boeing and Rolls-Royce utilised the MATLAB application produced by MathWorks (http://www.mathworks.com) with the operator using SAS (http://www.sas.com). QinetiQ predominantly used SPSS (http://www.spss.com/uk), although supplemented by in-house developed applications.

The data

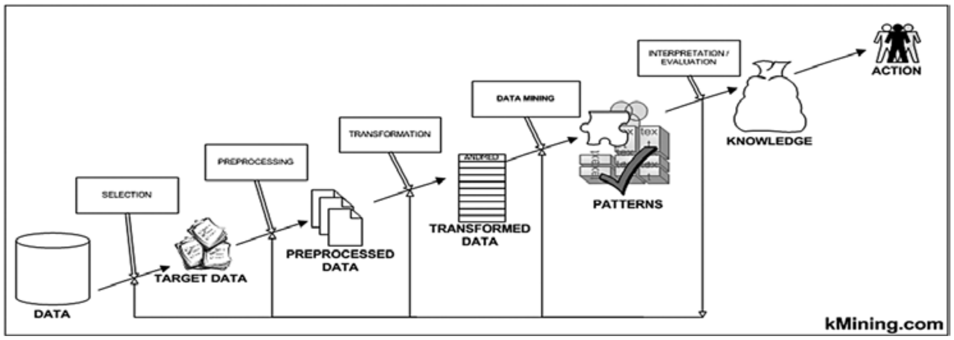
The data sets analysed consisted of

- takeoff fuel temperature snapshots—**610,000 flights** (11 operators globally based).
- QAR data from **13,500** flights provided by the operator of G-YMMM ~1,100 parameters.
- min fuel temperature snapshots from **191,000** flights (mix of northern, tropics, and southern-hemisphere-based operators).
- fuel flow and fuel temp snapshots at various phases of flight from **178,000** flights (mix of northern, tropics, and southern-hemisphere-based operators).

The takeoff fuel temp was one of the initial data sets analysed. The team then analysed the QAR data before moving to obtain data from other operators.

The analysis process

The process of data mining is well documented, from the initial stages of cleaning the data, selection of analysis techniques to final processing. When applied to flight data, the process is similar to



that for other data types.

An initial 600 QAR flights were selected from the 13,500; this was termed the "training set" and consisted of the accident flight and a selection of aircraft that had operated the same route, as well as some different routes. The investigation had identified that a fuel restriction had occurred and this enabled the team to select a subset of about 350 parameters from the 1,100 available. In addition to powerplant and fuel system parameters, a selection from other systems was also added, having to return to the main data set to add parameters at a later date is best avoided if possible due to the overhead in processing time.

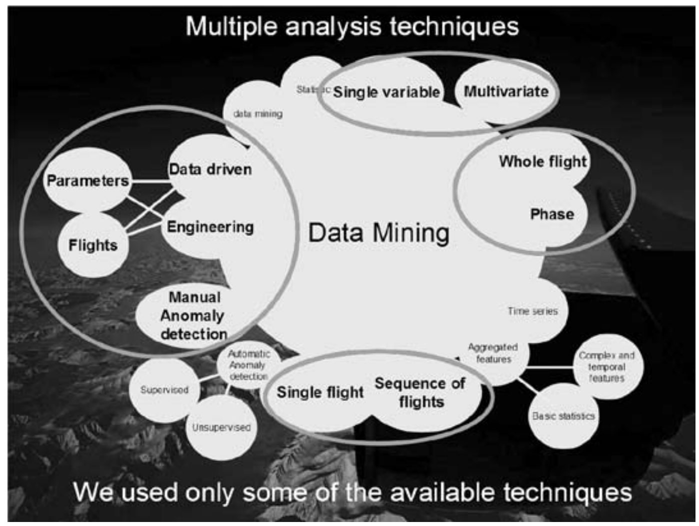
The training set was then used to develop algorithms and identify potential problems with the data, before analysis of the larger 13,500 data set. Several issues were identified with the quality of the QAR data. The most significant was that a small number of flights demonstrated sections of data where parameters changed instantaneously to a value that exceeded the practicable limits of the parameter. It was unclear if the erroneous data was a result of a defect in the QAR itself or the ACMF (Aircraft Condition Monitoring Function) system that provided data to the QAR. To ensure that these random parameter excursions did not impair the analysis, parameter filtering was rigorously tested and applied. Failure to include cleaning techniques before mining of the data may lead to erroneous results.

Whilst analysis of the initial 600 flights was ongoing, the operator was preparing the remaining 12,900 flights. The operator had a department dedicated to the analysis of flight data in its support of its FDM (Flight Data Monitoring program). The department had the ability to prepare the QAR data for the data mining systems, extracting the selected 350 parameters and provide it in a format agreed with the data-mining team. Due to the quantity of data (equivalent to an excel file containing more than 400 million rows and 350 columns of data), the extraction process took more than a week running continuously. The data were distributed on portable hard drives. Having an operator capable of pre-processing the data was beneficial. Had the facility not been available, data would need to be taken in its entirety (all 1,100 parameters) with the associated overhead of storage requirements and processing, or the data may need to be taken in its raw undecoded format and then converted to engineering units by the data-mining team.

Analysis techniques and results

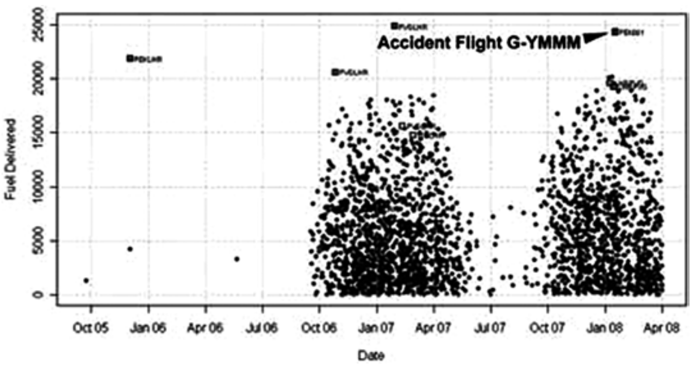
Data mining provided a number of analysis options, varying in degrees of complexity. Data-mining experts advised that the team should start with a simplistic approach before moving to some of the more complex techniques. This would enable us to learn about the data progressively, and circumvent the need to use some of the more time and resource hungry techniques, which could be employed later if necessary.

During the investigation, the team touched on only some of the available data-mining techniques. It was difficult to automate the detection of unique or unusual features when analysing a flight in its entirety. For example, when comparing average fuel flows of two flights, both may have been similar, but one may have uniquely experienced both a very high and low fuel flow which would not be evident in such a calculation. A number of analysis methods would need to be combined to determine if one or other flight contained higher or lower maximum fuel flows. The highest fuel flow rates normally occur at takeoff, which again would make determination of peak fuel flows later in the flight difficult to detect. To this end, the solution was to cut each flight into sections or flight phases so each phase could be analysed separately. The Boeing 777, as do many other modern aircraft, calculates and

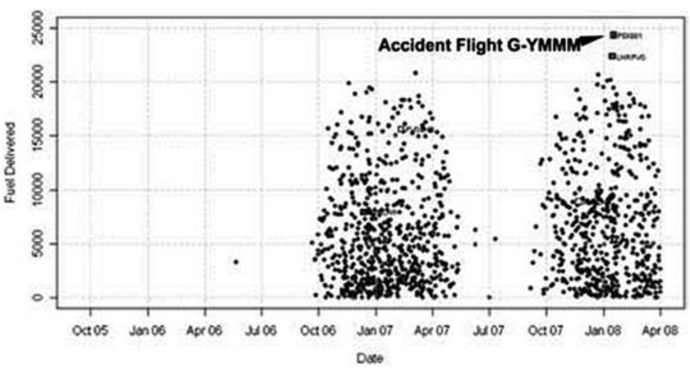


records its phase of flight on the QAR. Typically between 10 to 14 phases may be defined for modern aircraft, such as pre-start, engine start, taxi, initial takeoff roll, takeoff, initial climb, climb, top of climb, cruise etc. The team took a more simplistic approach and cut each flight into takeoff, climb, cruise, descent, and approach phases. It was found that the aircraft-generated phase was not sufficiently accurate though, with early analysis containing inaccuracies due to the data having been incorrectly cut. A more robust algorithm was later developed by the team and then run by the data-mining tools.

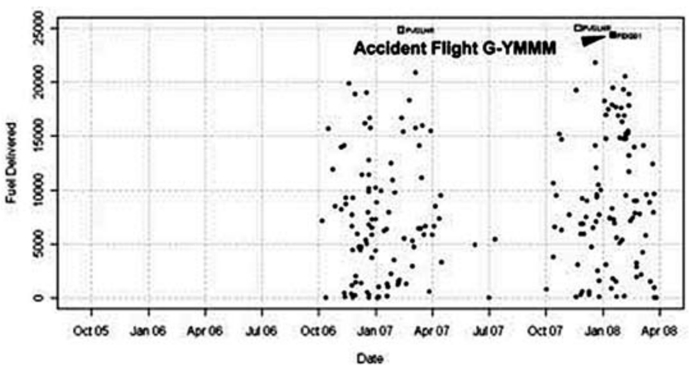
Once the data had been cut, it was easier to identify features of the accident flight that were unusual or perhaps unique during each flight phase. The data-mining tools could be used to extract relevant data sets, which could be readily manipulated using more simplistic spreadsheet programs. The term outlier was also used during the investigation, where a parameter or statistical measure was in itself not unique but sat within a small minority of flights having similar features. Some of the work based on whole flight analysis also provided some interesting results, with the accident flight being one of only a few other flights having operated for prolonged periods with fuel flows below 10,000, 11,000 and 12,000 pph with fuel temperatures of below -20°C.



Fuel delivered at less than -20°C and max fuel flow of 10,000 pph.



Fuel delivered at less than -20°C and max fuel flow of 11,000 pph.



Fuel delivered at less than -20°C and max fuel flow of 12,000 pph.

Although analysis tended to focus on fuel flow and fuel temperature features, each of the 350 parameters was also analysed for unusual or unique features. Some parameters were identified as outliers, but sound engineering knowledge was able to confirm that they were not contributory or causal to the accident.

Test observations indicated that ice could form at flow rates and temperatures similar to those experienced during the accident flight. Ice could then be released at a higher flow rate, similar to that which occurred during the approach, shortly before the fuel flow had been restricted. Testing also established that water, when introduced into the fuel flow at the boost pump inlet at extremely high concentrations, could form sufficient ice to restrict fuel flow through the FOHE. During these tests it was concluded that it was not possible to restrict the fuel flow through the FOHE when the temperature of the fuel in the main tank was above -10°C and the fuel flow was less than 12,000 pph. Fuel temperature at the time of the restriction had been -22°C.

Following analysis of the initial 13,500 flights, the investigation sought to obtain additional data from other Boeing 777 operators, with the aim of establishing the uniqueness of features believed to have been contributory to the formation of ice and its subsequent release. A total of approximately 178,000 flights were obtained, being a mixture of Rolls-Royce (35,000), General Electric (1,000), and Pratt and Whitney (142,000) powered aircraft. The process of how the investigation obtained this additional data is discussed later.

Initial analysis of a combination of takeoff, cruise, and approach fuel temperatures and flows identified that the accident flight was unique among the Rolls-Royce powered aircraft flights, with 32 Pratt and Whitney powered flights having the same features:

- Fuel temperature in the main tanks below 0°C at takeoff.
- Fuel flow from the main fuel tanks less than 10,000 pph, and fuel temperature in the main tanks remaining below 0°C during the cruise.
- Fuel flow from the main tanks greater than 10,000 pph, and fuel temperature in the main tanks at or below -10°C during the approach.

Further laboratory testing confirmed that adding warm fuel to cold fuel, as would have occurred during the accident flight refuelling at Beijing, or taking off with fuel below 0°C, would have had little or no bearing on whether ice was later formed on the inside of fuel feed pipes. The criterion of takeoff fuel was subsequently removed. Removal of this feature left the accident flight among a group of 66 Rolls-Royce powered aircraft flights.

Modification of the features based on the accident flight fuel flows and fuel temperature at the time of the restriction having occurred, which for N862DA had also been the same at -22°C, identified that the accident flight was unique among the 35,000 Rolls-Royce powered aircraft flights and only two flights from 142,000 Pratt and Whitney powered aircraft flights had the same features.

- Fuel flow from the main fuel tanks less than 8,897 pph, and fuel temperature in the main tanks remaining below 0°C during the cruise.
- Fuel flow from the main tanks greater than 12,287 pph, and fuel temperature in the main tanks at or below -22°C during the approach.

Flights having both features

- Accident flight
- Two Pratt and Whitney powered flights

Flights having similar features as the N862DA incident flight

During the incident flight of N862DA, fuel temperatures did not reduce below 0°C until about 3 hours into the flight, when the aircraft was in the cruise. Fuel temperatures then progressively reduced to a minimum of -23°C. Unlike the accident flight, N862DA had made four step climbs at fuel flows in excess of 11,000 pph prior to the restriction occurring. The third and fourth step climbs both occurred at fuel temperatures below 0°C. The third occurred shortly after the fuel temperature had reduced below 0°C and the fourth, just more than 3 hours later when the fuel temperature was approaching -15°C. The fuel then continued to reduce to its minimum temperature. About 3 hours later the aircraft carried out a further step climb, with a maximum fuel flow of just more than 11,000 pph. It was during this engine acceleration that engine oil temperature was observed to rise due to a loss of FOHE efficiency. The restriction gradually increased over a number of minutes. Fuel temperature at the time was -22°C. Approximately 20,000 Rolls–Royce powered flights were analysed for a combination of a maximum fuel flow of 11,000 pph and greater when in the cruise and fuel temperatures of -22°C or below. Sixty flights were identified.

Fuel temperature in flight

The accident flight's minimum fuel temperature of -34°C was identified as being unusual, although testing showed that most ice accumulates on the inside of fuel feed pipes at temperatures between -5°C and -20°C. The rate that ice accumulates will reduce as the temperature drops further toward the minimum experienced in flight. Therefore, the minimum fuel temperature experienced on the accident flight was not considered a causal factor; however, it did contribute to the low fuel temperature of -22°C on approach.

Engine fuel flow

The accident flight had operated for more than 8 hours in the cruise, at an average fuel flow of about 7,000 pph. During the same period, fuel temperatures had remained below -20°C and, due to the use of the vertical speed mode of the auto pilot (which was normal) for the step climbs, fuel flows had not exceeded 8,897 pph. Testing showed that at similar temperatures and flow rates, ice can be formed within the fuel feed pipes. Testing also demonstrated that ice may be released from the fuel feed pipes at higher levels of fuel flow, similar to those attained during the final stages of the approach when the maximum fuel flow reached 12,288 pph.

Unique features

Analysis of 178,000 flights identified that the accident flight was unique among 35,000 Rolls-Royce powered flights in having a combination of the lowest cruise fuel flow, combined with the highest fuel flow during approach while at the lowest temperature on approach. Just two flights from 142,000 Pratt and Whitney powered aircraft flights had these same features. However, analysis of the N862DA incident and subsequent data mining identified that this flight was not unique with respect to its combination of fuel temperature and fuel flows, although only a relatively small percentage (0.3%) of flights shared the same features.

The search for previous occurrences of fuel flow restriction

Following the reduction in fuel flow during the accident flight, the EEC (Electronic Engine Control) system commanded maximum fuel flow to its respective engine. This command (referred to as Control Loop 17) was recorded on both the DFDR (digital flight data recorder) and QAR. The position of the FMV (fuel metering valve) which directly controls the fuel flow delivered to the engine was also recorded albeit only on the QAR.

Prior to the N862DA incident on Nov. 26, 2008, it had been determined that a search for previous occurrences of fuel flow restrictions be carried out. If other events could be identified, information such as similarities in fuel flow and temperatures to that of the accident flight could be established.

A retrospective analysis of the 13,500 flights provided by the operator of G-YMMM was conducted for cases of the EEC system having commanded maximum fuel flow. An algorithm was also developed to identify a mismatch between the FMV position and expected fuel flow. Other than the accident flight, no occurrences were detected. It should be noted though that parameter recording limitations meant that the FMV position and expected fuel flow algorithm was incapable of detecting mismatches that had resulted in less than a 2,000 pph discrepancy (the accident flight had a mismatch of over 20,000 pph). Both detection methods were also implemented by the operator of G-YMMM as part of its ongoing fleet monitoring program. No further occurrences were detected.

For the previous 10 years, the aircraft manufacturer had records of six occurrences of the EEC system having commanded maximum fuel flow, triggering the Control Loop 17 message. Explanations were available for all of the occurrences and they were all for reasons not relevant to the accident to G-YMMM.

Following the incident to N862DA, retrospective analysis for previous occurrences of anomalous oil pressure behaviour was evaluated. Due to complexities of the engine oil pressure and FOHE relationship, an automated search of the 13,500 flights could not be readily implemented. A small subset of flights was manually analysed but no anomalies were found. The incident flight was also processed through the FMV position and expected fuel flow algorithm. The characteristics of the restriction to the FOHE on N862DA were different to that of G-YMMM, with a progressive rather than almost instantaneous restriction having occurred. The restriction was not detected by the algorithm until several minutes after the FOHE had started to restrict. This was due to the initial restriction resulting in less than a 2,000 pph mismatch.

Although other flights having similar levels of fuel restriction to G-YMMM and N862DA were not discovered, it could not be ruled out that other aircraft experienced a lower level of fuel flow restriction that could not be detected.

Provision of QAR data and sourcing data from other operators

The release of QAR type data is an especially sensitive one for most operators. During the course of the investigation the team had not only asked for historical data relating to the accident aircraft from the operator, but data from across its fleet of Boeing 777. The operator was keen to assist, but initial questions posed by the operator were "Why do you require this much data" and "How can it be protected." To this end the AAIB was able to demonstrate the need to mine the additional data and operator was also included within the data-mining team. The protocols for protection of the data took some time to put in place, but were ensured through a combination of agreements and UK laws. The measures put in place by the AAIB ensured that the data remained protected. At the end of the investigation, the QAR data was returned.

Following analysis of the initial 13,500 flights, the investigation sought to obtain additional data from other Boeing 777 operators, to determine the uniqueness of some of the features identified. A total of approximately 178,000 flights were obtained, being a mixture of Rolls-Royce (35,000), General Electric (1,000), and Pratt and Whitney (142,000) powered aircraft. To negate the need for operators to provide second by second QAR data, a specification was produced that enabled operators to extract data points using their FDM systems. The data points provided sufficient information so that the initial 13,500 flights could be compared directly with the new data. A downside of this method was that some of the FDM systems could not be readily modified. The AAIB approached all of the Rolls-Royce powered operators and some using different manufacturers. As the team were looking at how frequent certain features could occur, the significance of different engine types was not critical during this type of analysis.

Discussion

Where an engineering-based investigation is established, operators, in general, support the provision of QAR type data to accident investigators (at least in the UK). Where operational issues are being explored, the release of data is perhaps more tightly controlled. As the G-YMMM investigation was engineering based, the issue of analysing the data for operational issues was less of a concern. It may be suggested that if the need to explore operational issues is required, the need for a data-mining program as utilised during the G-YMMM investigation may be negated by using the operators own FDM/FOQA system with oversight from the investigator. Where an operator does not have an FDM system, it would be more likely that an archive of QAR data would not be available in the first place, as one of the main drivers for retaining QAR data is that of a FDM/FOQA program.

Summary

The investigation considered the possibility that the rollback on each engine occurred for a different reason. The fuel feed systems on each side of the aircraft are almost identical and were exposed to the same fuel, environmental factors, and motion of the aircraft. Moreover, there was a high level of repeatability during the tests to restrict the fuel flow through the FOHE and some consistency in the ice accumulation and release tests. Therefore the scenario that ice accumulated within the fuel feed system and subsequently released and restricted the fuel flow through the FOHE is consistent with the rollback on both engines occurring almost simultaneously.

The investigation, including the data mining activity of 178,000 flights, only demonstrated two engine rollbacks (G-YMMM right engine and N862DA) which were positively identified as consistent with ice releasing from the fuel system and forming a restriction at the FOHE. No other mechanism was identified throughout the testing that would have caused a restricted fuel flow elsewhere in the fuel system and the subsequent engine response on the accident flight. These occurrences are thus very rare and, therefore, although the data for the left engine ceased before it was possible to determine with certainty that its FOHE had become restricted, the likelihood of a separate restriction mechanism occurring within 7 seconds of that for the right engine is very low.

The data mining was successful in its remit of identifying unusual and unique features. Through laboratory testing it was demonstrated that fuel temperatures at the beginning of the flight were not causal to the accident, but that other features were conducive to the formation and subsequent release of ice. It was not fully understood why other Rolls-Royce powered Boeing 777 flights having similar features to the G-YMMM accident flight, and perhaps more so the N862DA incident flight, did not experience similar fuel restrictions. Laboratory testing did offer some explanation, with the observation of "randomness" in the formation of ice, indicative that there may also be a variance in the quantity of ice generated during similar flights. Similarly, differences between the G-YMMM accident flight and N862DA incident flight, with one experiencing a more rapid onset and the other a more progressive restriction, indicate that factors other than flow rate and temperature may affect the release of ice from within fuel feed pipes. The properties of ice generated within an aircraft, rather than a laboratory environment, may also have different characteristics.

Lessons learned

• Collocation of the team. In the weeks immediately following the accident, AAIB, Boeing, and Rolls-Royce data group staff collocated at the operator's engineering facility. This proved to be extremely beneficial for the following reasons:
–close proximity to the data ensured prompt and easy access.
–removed the difficulties of remote working, UK/U.S. time zone.
–enabled the exploration of ideas.
–number of areas expediently explored, with work being shared.
–daily debrief of progress.
–negated IT issues of inter company data transfer.
–time to build working relationships.
–used operator software to quickly view and analyse data.

• Team selection. The team consisted of a mix of data-mining experts, subject-matter experts (fuel systems and powerplant), and flight recording specialists.
–mix of expertise proved successful, with subject matter experts being able to steer the work of the data mining experts.

• Duplication of work
–AAIB, Boeing, and Rolls-Royce had access to the QAR data, and each had the ability to process the data independently.
–The team had a limited resource and so had to work smartly with regards to unnecessary duplication of work.
–Did not want to constrain the exploration of the data. It was important to remain flexible and allow the exploration of data, not constrain it.
–Regular progress meetings meant that as wide an area of the data could be explored in the shortest time frame.

• IT issues
–E-mail was restrictive in transportation of flight data due to file size limitations.
–IT policies regarding usage of non-company-approved software applications.
--WebEx used for dissemination of information.
–Data transfer, portable hard drives and encrypted data.

• Program set up—the initial planning phase proved to be time consuming.
–Agreement for release of data by operator.
–Selection of data, parameters, flights, etc.
–Elapsed time to prepare the data.
–Data distribution.
–Contract of support by third parties.
–Cleaning of the data.
–Initial processing.
–Results analysis.
–Subsequent algorithms development and evolution. ◆

Endnote

1 Parameters recorded on the QAR were available at data rates of up to eight samples per second. The sample rate used during the majority of the data mining analysis was set at one sample per second, which was the maximum recorded rate of the engine and fuel system parameters.

The Contribution of Safety Reporting And Investigations to Safety Management Systems

By Paul E. Mayes, Investigation and Analysis, Safety Risk and Environment, Cobham Aviation Services, Australia

Paul Mayes *is currently manager of safety investigations and analysis for the Cobham Group Operations in Australia and Papua, New Guinea. He is also a Fellow of the Royal Aeronautical Society and a Chartered Engineer, a flight instructor, and holds an ATPL. He served for 21 years as an air safety investigator with the Bureau of Air Safety Investigation, Australia, including head of air safety investigations, head of safety systems and analysis, and was with Air New Zealand in Auckland, New Zealand, where he held senior safety management positions, including aviation safety advisor for 8 years.*

The 28th of November 1979 was a very auspicious date for aviation safety. It was the date of the worst aviation accident in the Australasian region—257 people lost their lives when the DC-10 impacted the slopes of Mount Erebus in the Antarctic. It was also a major impetus to changes in the way we investigate and analyse accidents.

Many investigations are complicated by engineering or operational issues requiring technical expertise. This is an aspect that has become even more of a problem for the investigation of accidents involving later-generation aircraft with advanced systems and technology. However in 1979, although the DC-10 was still considered a very modern aircraft, the investigation was not confronted with such problems.

The investigation on site was, of course, difficult due to the accident site on the slopes of Mount Erebus. But the investigation was relatively straightforward because the digital flight data recorder and cockpit voice recorder were recovered almost undamaged. Dennis Grossi from the National Transportation Safety Board in Washington, together with Milton Wylie from the New Zealand Air Accidents Investigation Office, arrived on site on December 1 (2 days after the accident) and after a few hours returned to New Zealand with the DFDR and CVR.

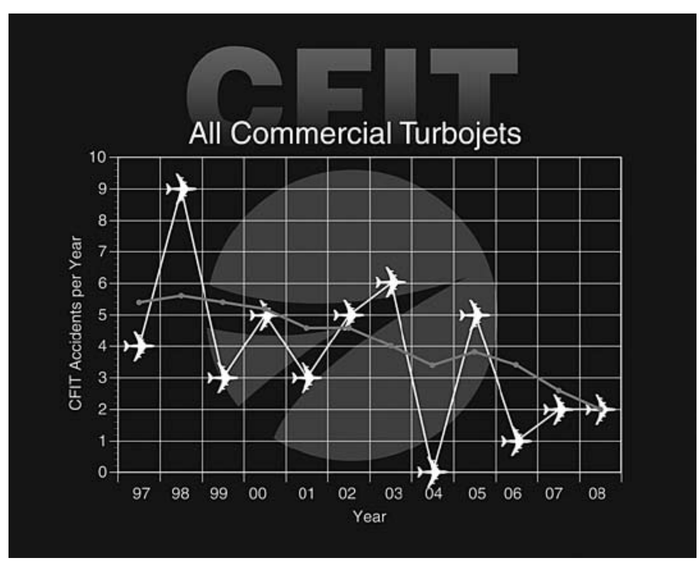
As New Zealand did not have the facilities to play back and analyse the recorders, they were taken to the NTSB laboratories in Washington. There the initial playback and analysis proceeded without difficulty. The obvious conclusion was that the aircraft had been fully serviceable and that this was a classic "controlled flight into terrain" accident. The term CFIT has been used now for many years as a "class" of accident. I personally find this term inadequate as it tends to dehumanise what are usually complex human performance accidents. CFIT accidents involving commercial turbojet aircraft still occur. The figure, right, shows a declining 5-year average, but only in 2004 were there no recorded CFIT accidents.

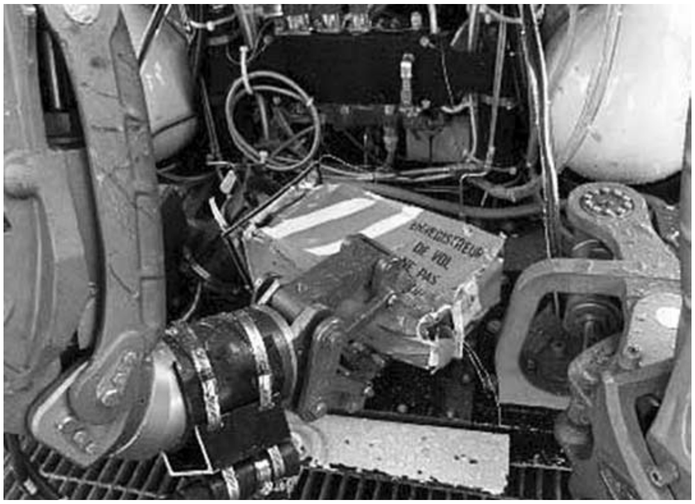
One of the advances since 1979 is the development of improved ground proximity warning systems, enhanced GPWS. So the GPWS of 1979 that only gave an inadequate 6-second warning to impact in the Erebus case has been replaced by the EGPWS of today with its advanced terrain awareness features. All the CFIT accidents over the last 5 years have involved aircraft without an EGPWS fitted.

So the investigation of *what* happened was relatively straightforward based on the evidence from the DFDR. A serviceable aircraft had flown into rising terrain. The question or questions were why, why, why? These are often the most difficult questions to answer because they involve human beings and human performance. The cockpit voice recorder, or more aptly called the cockpit audio recorder, is often the key to answering these questions, even if the crew survives the accident.

In the case of the DC-10, the CVR was configured to record the cockpit audio signals in accordance with the FAA specifications. One channel records the audio picked up by the remote cockpit-area microphone located centrally on the flight deck. The other three channels record the ratio transmissions from each of the three pilot stations. In the case of Erebus and many other investigations up to that time, this arrangement of recording had proved to be less than optimum. As radio transmissions are not a factor in many accidents, the investigations would rely on the recordings from the one channel recording all the sounds from the cockpit-area microphone, The determination of what was being said was often difficult and open to misinterpretation.

In the Erebus case, although the background noise was low, there were five people on the flight deck, four flight crew and one flight commentator who relayed information to the passengers on the progress of the flight and the sights to be seen. Hence the determination of what was said by which individual was not entirely without doubt.





Alaska Airlines Flight 261 CVR recovery.

Although this occurred long before the concept of an integrated safety management system, there were elements of SMS already in place. One of these was an internal reporting system. The captain of the previous sightseeing flight to the Antarctic on November 14, 14 days before the accident flight, compared the coordinates of the navigation beacon at McMurdo and the waypoints that the flight crew had been given by the Navigation Department. He discovered that there was a significant distance between the two tracks, almost 30 nautical miles. He advised the navigation section, which during the night prior to the accident flight, "corrected" the waypoints. Unfortunately the captain of the accident flight was not advised of this change and was expecting the track to take them into the area of the McMurdo sound rather than directly toward Mount Erebus.

As was demonstrated at Erebus in 1979 and many subsequent accident investigations, the prompt recovery and analysis of the recorders are essential for the successful outcomes of complex investigations. But many accidents occur over water, and the recovery of the recorders from the seabed becomes a major exercise. The location of the recorders, and in many cases also the location of aircraft wreckage, depends upon the underwater locator device, which emits a sonar signal for 30 days when activated by water. Since the mid-1970s missing or damaged recorders have only prevented a full analysis of the accident in a small number of major accidents. Out of more than 3,000 accidents involving Western-built commercial aircraft, fewer than a dozen CVRs and FDRs have not been found according to the International Air Transport Association. And in most cases enough wreckage was retrieved to piece together a probable scenario, although this could have taken many months and probably did not result in a definitive conclusion of why the accident happened.

Underwater searches were required for 26 aviation accidents over the last 30 years. The searches lasted anywhere from 3 days in the case of Alaska Airlines Flight 261, which crashed in the Pacific in January 2000, to 77 days to find the recorders in the Pacific in April 2008.

Air France 447 is the only commercial aircraft accident in which neither recorder has been found despite an estimated $40 million spent on the initial two searches.

The research emphasis resulting from the Air France accident is on satellite technology to transmit critical safety information from the aircraft. The idea of sending real-time safety data to a ground station has been around for a while. Certain maintenance data are transmitted now, and was in the Air France case. However, technology does not currently allow large quantities of data to be transmitted due to bandwidth and cost. When considering that flight recorders have hundreds of parameters recording each second, to transmit that data to a ground station becomes very problematic. One suggestion is to send basic flight information such as the heading, altitude, speed, and geographical location to a ground station on a regular basis. This is an interesting suggestion as it mirrors the original flight data recording requirements introduced in the 1960s, which were for a basic five or six parameters. These proved to be too limited for useful accident analysis. The easiest development would be to lengthen the duration of the locator signals. It has been suggested that the specification should be increased to 3 months. Other options for satellite tracking such as EPIRBs should be considered.

Despite ongoing studies for the potential for streaming data to a ground station during flight, the traditional onboard flight data recorder will still be the essential tool for air safety investigation. The reasons are the high costs of data streaming and the massive amounts of data currently recorded and often needed to understand the complexity of aircraft systems. A recent study found that even with a 50% reduction in current satellite transmission costs, the price tag for streaming data could be millions of dollars. Obviously in today's financial environment this is not the most economic solution to the problem. However the technology is available, and there are some military and commercial applications already in operation. So like many of the advances in aviation safety this may well become an accepted practice in the future.

Let's return now to November 1979 and the implications for air safety investigation. The investigation was conducted in the established manner, collecting all available factual information, utilising the resources of the U.S. NTSB, the British AAIB, the equipment and aircraft manufacturers, the CAA, and the various organisations representing the company and the staff. This resulted in a standard ICAO Annex 13 report and included a probable cause of the accident. For that time there was nothing unusual in this approach. However a royal commission was appointed to enquire into the Erebus accident. This commission had the advantage of not only the evidence from the investigation report but also the mandate to call witnesses from all areas associated with the aircraft, the aircraft operation, and the public. With the assistance of counsel: "By the time the hearings of the commission had concluded every aspect of the disaster and its surrounding circumstances had been explored by counsel in considerable detail." However the circumstances of the final stages of the approach without the advantage of the CVR and DFDR would never have been known at all.

The airline witnesses who appeared were intent on establishing pilot error as the effective cause of the accident. This was not unusual even in 1979 and late in the 1980s. A review of reports from that time, for example, will show that "pilot error" was still a common conclusion. However, the Erebus Commission went much further looking into the company decisions, policies, and procedures as well as the actions of the board and the middle-manager levels. This was perhaps one of the first applications of the "Reason model," which did not come into practice for another 10 years or more. But it certainly began the advances in air safety investigation where we looked back into the sequence of decisions, the training, and the basic human factors and human performance. Later this became the standard for safety investigation through the work of James Reason and Patrick Hudson, amongst others.

Reason's work on causation and the development of his model is well known and has become a basic tool for investigations. It is interesting that in talking to flight crews from various backgrounds, most are familiar with the Reason model and the so-called Swiss cheese analogy.

If James Reason was the innovation of the 1980s and 1990s, "safety management systems" could be considered the next stage in the development of improved safety of operations. For many of us safety management systems have been a way of life. It was not until ICAO defined safety management systems in 2005 that we realised what had become relatively common place for many of us. The regulations, eventually introduced by the Australian Civil Aviation Safety Authority as CAO 82.5 in 2009, defined the various elements and the need for a documented SMS.

It seems we are bombarded with information about "safety management systems" these days in everything we read in the safety press and publications. The classic SMS includes elements of safety occurrence and hazard reporting and safety investigations. It could be argued that without a good reporting culture, the management of "safety" is almost impossible. If we do not know what is happening on the flightline or in the hangar, then we cannot make the necessary improvements to reduce risk and improve safety levels. Managers and supervisors will be in blissful ignorance of the real situation until a serious event occurs that cannot be ignored. The ideal situation is that any safety hazard or safety concern is reported and action is taken to address these before they become an incident or accident. This is the utopia of preventive or proactive safety. In practice, this is very hard to achieve as operational staff members usually have very little time for non-operational tasks and do not perceive the benefit from reporting something "that did not happen." Changing the mindset is essential if SMS is to be successful. It is also greatly assisted if the reporting process is simple and readily accessible such as being able to submit a safety report during the cruise phase, for example. Electronic reporting is ideal, but the use of paper forms is still widespread and effective. They can be completed after the finish of a flight at home or in the hotel.

Safety assurance is accomplished through flight data monitoring, line operations safety audits, and safety actions from system improvement recommendations. An operator's SMS is an easy target for the investigators after an accident. Determining why the SMS failed is not so easy. However, it has been reported that many smaller operators have met the letter of the legislation by constructing a SMS manual, in some cases supplied by external consultants. But the elements of SMS have not been rolled out to day-to-day operations. Some of the reasons include cost, and a reluctance to be open with the staff about safety issues. This must change if the promise of SMS in reducing accidents is to occur.

If we return to the Air France accident, it has been reported that pitot failures were well known on the Airbus long-range fleet. Air France had reported problems to Airbus and Thales, the manufacturer of the pitot probes. What are the implications for the Air France and Airbus SMS? The interim BEA investigation report documents the history of the probe issues, yet the high risk of these failures does not appear to have been recognised and certainly did not generate prompt corrective action. There may have been several reasons for this. These reports were only a small part of the total reports received regarding Airbus aircraft operations. The critical step is to determine the severity and risk level associated with one or more reports and potential for a catastrophic outcome. This is a fundamental step in a safety management system.

There is no shortage of occurrence reports and safety hazards identified by staff. Although we encourage open reporting of any safety concern, it is not always successful. From my experience, for example, an operator of 40 jet aircraft could expect 1,000 operational safety reports per year. Of these less than 5% would be considered other than minor, low risk. The most difficult task is how to ensure that the reports that could be indicative of a critical failure, in the right circumstances, are treated with the appropriate level of response. Risk ratings are used as the main tool, but these are open to interpretation. Experience and corporate knowledge can be essential in this process. Some types of occurrences have obvious risks and are rated reasonably consistently. However, other proactive (pre-emptive) safety concerns can be much harder to risk rate. The concern of a line pilot may be an isolated instance and then it becomes a difficult judgement issue. Very often these safety concerns are related to changes in procedures, processes, or documentation. The investigation often finds that change management procedures were not followed or were incomplete. Communications are the key, as they were lacking in November 1979.

In Australia, the Australian Transport Safety Bureau is the government safety investigation agency that has a mandatory reporting requirement. Any accidents or serious incidents, as defined by ICAO Annex 13, are immediately reportable including a death or serious injury, serious damage , or missing aircraft. However, the ATSB also has a list of further immediately reportable events that include such things as airprox, violation of controlled airspace, takeoff or landing on closed or occupied runways, uncontained engine failures, fuel exhaustion, undershooting, over running or running of the side of a runway amongst several other event types. The ATSB also has a class of reportable events called routine reportable, which have to be reported. These include injuries, other than serious, other than serious damage, a ground proximity warning system alert, runway incursion, and several other broad definitions related to aircraft performance, weather, loading, and air traffic system events. The result is the ATSB receives around 15,000 notifications per year on average, 8,000 of which are accidents, serious incidents or incidents. many of which do not get recorded., However the ATSB only carries out approximately 30 investigations per year. So less than 0.2% of reports are investigated. Another 0.2% is published as Level 5 factual reports where the operators investigation reports are edited and published.

With so many reports, there will be issues that warrant investigation but are not always obvious from one or two reports. A robust effective analysis system is essential to filter out the reports that can be indicative of a significant risk. The Civil Aviation Authority is taking a greater role in the process of safety investigation as it can no longer rely on the ATSB to investigate many serious or significant events. It is also concentrating on auditing the operator's safety management systems to ensure that the operator carries out a full and unbiased investigation so that safety lessons can be learned.

Analysis of serious accidents indicates that many established aircraft operators have exhausted the advances offered by the earlier safety management strategies developed in the late 1990/2000s and that new ideas are needed. A step change for the better in airline safety performance took place around the year 2000, but those advances have become entrenched. And while safety today is at an al-time high, improvements in the safety rate stopped in the mid 2000s. The plateau marked a departure from a century of aviation safety that had shown a steady improvement since the Wright Brothers.

A review of serious accidents in 2009 shows that most were preventable. If accidents are analysed by broad category, then runway excursions and incursions, and loss of control, are the main types of accidents in recent years. If we look at runway excursions, the majority can be linked to poor decision-making, breakdown in SOPs, and poor CRM. Most occur off an unstabilised approach, which results in landing long and fast. If we look back 10, 20, or 30 years, we see the same symptoms and the same results. Why didn't the crew execute a missed approach rather than persevering with a bad approach? The investigations have not had the optimal outcome of safety actions to prevent these reoccurrences.

Dr. Tony Kern believes there is a need for check and training organisations to reinforce basic flying skills so that pilots fly accurately and do not accept deviations from target speeds, localiser and glide slopes, and the required stabilised approach criteria—basic flying skills we were all taught during our training. There is a train of thought that we are not as diligent in our aircraft operations in an automated flight deck as we were in the previous technology flight decks.

What is beginning to evolve is the complexity of flying highly automated aircraft when the automation starts to fail. What is apparent from some situations is that the failure modes and degraded status of some automated flight decks can be very confusing. It would appear that the designs do not provide as much help or guidance to the flight crew as they should. With multiple failures or erroneous data inputs generating various confusing, opposing signals, the automated systems should ideally review and advise the flight crew on the most optimum response. Also although modern flight decks make a positive contribution to safety performance, pilots are not as practised at manual flying as they used to be so that flying aircraft that have reverted to raw flight and navigational conditions becomes too demanding in difficult situations. Since the year 2000 serious accidents have frequently involved pilot failure to manage situations that they should really have been able to handle successfully. The year 2009 was no exception. Examples last year include the Turkish Airline Boeing 737-800 at Amsterdam, the Colgan Air Bombardier Q400 at Buffalo, New York, the FedEx Boeing MD-11F landing accident at Narita, Tokyo. Notice that we are not using the term "pilot error" but rather looking at the human performance issues, the system designs, the training, and lack of understanding of the degraded states of the automation. Hence the lessons from Erebus in 1979 are still very much part of safety investigation today.

In aviation we are very proud of our safety record and the advances in safety over the years through technology and improving human performance. We are often compared with other modes of travel, and depending how you analyse the statistics, aviation comes out as the model for safety. However, as many analysts have commented we may have reached a plateau, and further improvements may be very hard.

In conclusion, in the 30 years since the worst accident in the Australasian region, there have been many important advances in technology, in systems, in understanding, and influencing human behaviours and in safety assurance. However, it appears that we have reached a plateau in the quest for improved safety. We still have accidents that have the same elements of many previous ones and should therefore have been preventable. There is no shortage of reports, but the challenge for safety investigators is to have effective investigation findings and actions so that we can eliminate accidents such as runway excursions, loss of control, and CFIT once and for all. ◆

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Limitations of 'Swiss Cheese' Models And the Need for a Systems Approach

By John Stoop, Delft University of Technology, Lund University, and Sidney Dekker, Lund University

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Photo not available

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Abstract

A series of surveys on existing accident investigation models show a wide variety of models dedicated to specific industrial applications, domains, and investigation aspects. In particular, the investigation of human factors is exposed to a wide diversity of models. In reviewing such models, the majority proves to be a derivate from the Reason's Swiss Cheese causation model or the Rasmussen model on system hierarchy. Most of the models origin from the process industry and the energy sector. Application in the aviation industry has revealed their conceptual limitations. Due to their simplifications and lay interpretations, their intervention potential in practice is limited to linear solutions. In order to cope with socio-technological interactions in a multi-actor perspective, a full systems engineering design approach should be applied in a mission-specific operating envelope.

Such an approach is submitted to three paradigmatic shifts in investigation methodology. First, disengagement is required between event modeling and systems modeling. Second, a distinction in two design classes is required. A distinction is made between linear interventions within the existing design envelope and second order interventions focusing on expansion of the design solution space. Third, designing safer solutions in a multi-actor systems environment requires prototyping, virtual system model simulation, and testing of limit state scenarios.

Based on these constraints, a framework for safety enhancement is described, derived from experiences in the aviation industry itself. This framework is based on a new view on human error, a dynamic systems engineering design approach, analytical forensic abilities and institutional conditions for independent and qualified accident investigations.

Accidents and causation

Although accident models have been applied on a large scale in practice, a reflection on their methodological assumptions, scope, and deficiencies reveals several schools of modeling. Several surveys indicate consecutive generations of models, their poor methodological basis, absence of a systems approach, and a focus on the application of models by lay people (Benner, 1975, 1985, 1996, 2009; Sklet, 2004; ESReDA, 2005). The first accident causation models as derived by Heinrich, referred to accident analysis by metaphors, such as the Iceberg Principle and Domino Theory. In a second generation, Bird and Loftus applied a linear causality, while Kjellen introduced the deviation concept. Multi-causality was introduced by Reason, defining accident as an interaction between latent and active failures; and in order to avoid such interaction, a proactive involvement of top management is needed. Based on attribution theory, Hale and Glendon were concerned about how people process information in determining the causality of events. They focused on the non-observable elements of the system: perceptions and decisions. While Reason developed his model on organizational accident causation, a next step was taken by Hollnagel who identified the system as the full context in which errors and accidents occur. A gradual development of accident modeling shows three generations of human error modeling, from a sequential accident model, via human information processing accident models toward systemic accident models (Katsakiori et al, 2008). The evolution expands the scope of the investigation from sequencing events toward a representation of the whole system (Roelen et al, 2009). In practice, however, such accident modeling based on the Reason model proved difficult to apply, resulting in an increasing amount of varieties and simplifications (Sklet, 2004). Most of the models restrict themselves to the work and technical systems levels and exclude the technological nature and development of the inherent hazards. Sklet concludes that this means that investigators, focusing on government and regulators in their accident investigation, to a great deal need to base their analysis on experience and practical judgment, more than on the results from formal analytical methods. Much of the accident data are conceptually flawed because of the inadequacies of underlying accident models in existing programs (Benner, 1985). Due to these pragmatic objections, during the conduct of an investigation, the limitations and mutual dependence between causation model and investigation methods should be explicitly taken into account. (Kletz, 1991; Sklet, 2004; Katsakiori et al, 2008).

Over a period of about 20 years, the Swiss Cheese model of Reason

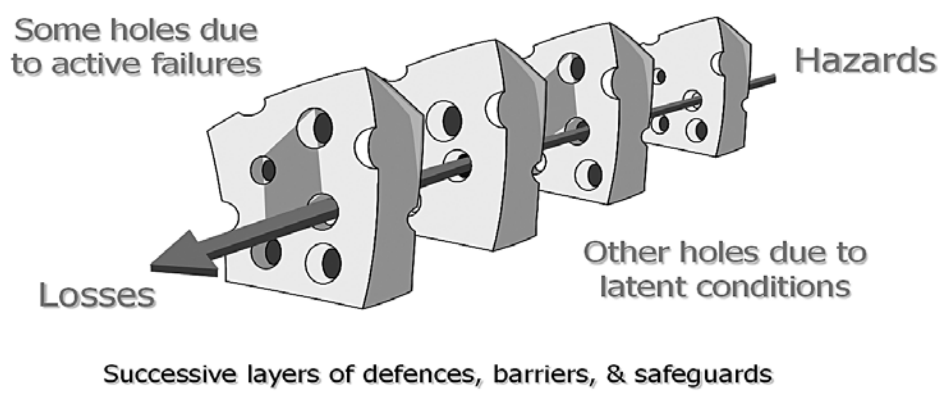

Figure 1. Reason's "Swiss Cheese" model of organizational accidents.

has gained popularity among many accident investigators and has become a benchmark of investigation practices. In particular, the transformation of the concept of hazards, mitigation strategies, and managerial intervention capabilities into a communication metaphor has supported the dissemination, providing transparency into risk management for lay people and practitioners (see Figure 1).

The Reason model

The widespread application of the metaphor however, also has raised concern from a scientific perspective and has raised questions on the application as an analytic tool dur ing accident investigations (Dekker and Hollnagel, 2004; Leveson, 2004; Young, Braithwaite, Shorrock. and Faulkner, 2005; Dekker 2006). Also Reason and Wreathall, who created the metaphor, have some concerns about the practical application as an analytic tool.

Concerns of the Swiss Cheese metaphor applied as an investigation model can be categorized as

- Remote factors have little causal specificity, are mostly intractable, and have no predictive potential. Their impact is shared by many systems and shift error up the ladder and do not discriminate between normal and deviant system states or take system dynamics into account.
- There are no stop rules in the expansion of the scope. The more exhaustive the inquiry, the more likely it is to identify remote factors. As such, it is a representative of the epidemiological school of thinking, dealing with a linear agent-host-environment model.
- It assumes technology as a constant, and focuses on barriers, rather than hazards, reducing risk management to a control issue, not a systems adaptation and redesign issue. It lacks resilience and adaptation on the level of systems architecture and configuration.
- It does not deal with uncertainty and knowledge deficiencies, nor does it take into account the variety of operational conditions and systems states expressed in an encompassing operating envelope. As such, the model is linear and single-actor based in its control potential, not taking into account a systems perspective and a multi-actor environment.
- The model is normative and deals with implicit standards of performance by compliance with rules and regulations and a normative concept of failure instead of recovery and reliance on human performance capabilities.

Similar to a technical toolkit for repairing technical systems, an accident investigator has to be able to choose proper methods, analyzing different problem areas (Sklet, 2004). This raises the issue of ethics involved in selecting an investigative method. It is of particular significance that hypotheses can be validated and falsified during the investigation process. If not, it requires additional losses to validate hypotheses and to permit a pattern recognition or statistical analysis (Benner, 1975, 1985). Finally, such modeling and accident phenomenon perceptions do not comply with the needs of investigators: a translation of human error models to practical investigation tools is still in its early phase of development (Benner, 1996; Strauch, 2002; Dekker, 2006). Investigation methods should support the visualization of the accident sequence, providing a structured collection, organization, and integration of collected evidence, identification of information gaps in order to facilitate communication among investigators (Sklet, 2004).

Developing such methods in the domain of human behavior will require a shift of focus from inferred and uncertain states of mind toward characteristics of human factors (Dekker and Hollnagel, 2004). Rather than allocating the cause of an accident to human error by complacency, loss of situation awareness or loss of control, the analysis could focus on falsifiable and traceable assertions, linked to features of the situation and measurable and demonstrable aspects of human performance (Dekker and Hollnagel, 2004). Rather than focusing on hypothetical intervening variables, more manifest aspects of behavior should be recorded during an investigation. While accuracy and comprehensiveness are rarely criteria for explanations, plausibility and credibility are. In addition, it becomes a necessity to shift the focus from the performance of an individual toward the performance of a joint system, according to the principles of systems engineering. The analysis should look at the orderliness of performance rather than the mental states of operators. If such an orderliness of performance breaks down, this can be the start of further hypothesizing and investigations. This raises questions about the rationale of why the performance seemed reasonable to the operator at the time of the event (Dekker, 2006). Such a shift toward the systems level in identifying new knowledge during air crash investigations has been proposed by Benner, applying an event-based analysis, defined in terms of relations among events, set in a process and operating context. Such an approach permits a distinction between knowledge of systems processes and their operation and knowledge of the accident process. Such an event-based analysis should be favored because of the amount of new knowledge discovered, the relative efficiency of the search, and the timely availability of corrective action guidance. Such knowledge can provide more valid indications of comparative performances and events (Benner, 1985).

The Rasmussen model

Rasmussen takes this modeling issue one step further (Rasmussen, 1997). He distinguishes the stable conditions of the past versus the present dynamic society, characterized by a very fast change of technology, the steadily increasing scale of industrial installations, the rapid development of information and communication technology, and the aggressive and competitive environment that influence the incentives of decision-makers on short-term financial and survival criteria. In answering the basic question: Do we actually have ad-

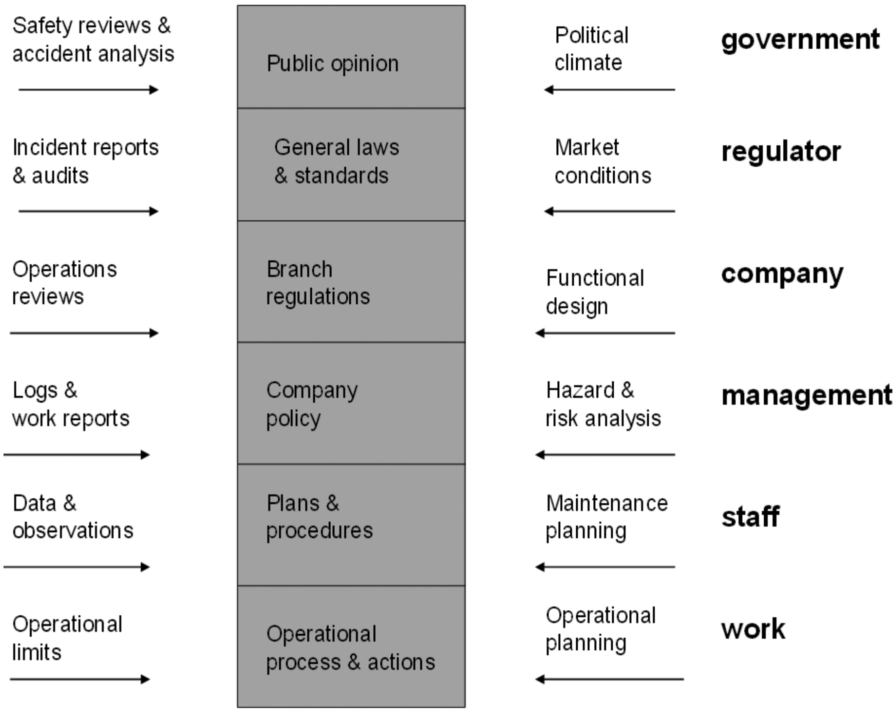

Figure 2. Rasmussen's systems hierarchy modeling.

equate models of accident causation in the present dynamic society, he states that modeling is done by generalizing across systems and their particular hazard sources. Risk management should be modeled by cross-disciplinary studies, considering risk management to be a control problem and serving to represent the control structure involving all levels of society for each particular hazard category. This, he argues, requires a system-oriented approach based on functional abstraction rather than structural decomposition. Therefore, task analysis focused on action sequences and occasional deviation in terms of human errors should be *replaced* by a model of behavior-shaping mechanisms in terms of work system constraints, boundaries of acceptable performance, and subjective criteria guiding adaptation to change. System models should be built not by a bottom-up aggregation of models derived from research in the individual disciplines, but top-down, by a systems-oriented approach based on control theoretic concepts. His risk management concept is a control structure, embedded in an adaptive socio-technical system. Since decisions made in a complex and dynamic environment are not only rational and cannot be separated from the social context and value system, a convergence occurs of the economist concept of decision-making, the social concept management and the psychological concept of cognitive control. Modeling task sequences and errors is considered not effective for understanding behavior. One has to dig deeper to understand the basic behavior-shaping mechanisms. Rather than striving to control behavior by fighting deviations, the focus should be on making the boundaries explicit and known and by giving opportunities to develop coping skills at boundaries. For a particular hazard source, the control structure must be identified, including controllers, their objectives, performance criteria control capability, and information available about the actual state of the system. The fast pace of technology has lead to the introduction of the "general due clause" and has enhanced the regulator ability to protect workers. Each employer "shall furnish to each of his employees a place of employment that is free from recognized hazards that may cause death or serious harm." By stating safety performance objectives, safety becomes just another criterion of a multi-criteria decision making and becomes an integrated part of normal operational decision-making. In this way, the safety organization is merged with the line organization and loses its independent position during the assessment. This requires an explicit formulation of value criteria and effective means of communication of values down through society and organizations. The impact of decisions on the objectives and values of all relevant stakeholders are to be adequately and formally considered by "ethical accounting." (See Figure 2.)

Depending on the nature of the hazard sources, three different categories are defined, characterized by their frequency of accidents and the magnitude of loss connected to the individual accident:

- occupational safety, focusing on frequent but small accidents. The average level of safety is typically controlled empirically from epidemiological studies of past accidents.
- protection against medium-sized, infrequent accidents. Safety systems evolve from design improvements in response to analysis of the individual, latest major accident. Safety control is focused on particular, reasonably well-defined hazard sources and accident processes.
- protection against very rare and unacceptable accidents. In such cases, the design cannot be guided by empirical evidence from past accidents due to the very large mean-time between accidents. Design and operation must be based on reliable predictive models of accident processes and probability of occurrences. A full-scale accident then involves simultaneous violations of all the designed defenses. The assumption is that the probability of failure of the defenses individually can and will be verified empirically during operations even if the probability of a stochastic coincidence has to be extremely low. Monitoring the performance of the staff during work is *derived from the system design assumptions, not from empirical evidence from past evidence.*

It therefore should be useful to develop more focused analytical risk management strategies and a classification of hazard sources in order to select a proper management policy and information system. The dimensions of a taxonomy for classification depend on the nature of the hazard source and the anatomy of accidents. Rasmussen identifies only a limited series of hazards: loss of control of large accumulations of energy, from ignition of accumulations of inflammable material, loss of containment of hazardous material. When the anatomy is well bounded by the functional structure of a stable system, then the protection against major accidents can be based on *termination of the flow of events after release of the hazard.* When particular circumstances are at stake, the basis for protection should be on *elimination of the causes of release* of the hazard.

Defenses can be based on predictive analysis. The design of barriers is only accepted on the basis of a predictive risk analysis demonstrating an acceptable overall risk to society. When the predicted risk has been accepted, the process model, the preconditions, and assumptions of the prediction then become specifications of the parameters of risk management. Preconditions and assumptions must be explicitly stated in a Probabilistic Risk Assessment. In this view, fortunately, it is not necessary for this purpose to predict performance of operators and management. When a plant is put in operation, data on human performance in operation, maintenance, and management can be collected during operations and used for a "live" risk analysis. Thus, predictive risk analysis for operational management should be much simpler than the analysis for a priory acceptance of the design. Such performance data can be collected through other sources than accident investigations; incident analysis and expert opinion extraction may compensate for the lack of abundant accident data. According to Rasmussen, the models required to plan effective risk management strategies *cannot be developed by integrating the results of horizontally oriented research* into different features of hazard sources and systems configurations. Instead, *vertical studies of the control structure are required* for well bounded categories of hazard sources, characterized by uniform control strategies (Rasmussen and Svedung, 2000).

Expansion toward "real" models

In accordance with the desire to create more encompassing models in a dynamic environment, the Reason and Rasmussen model are superseded by a new series of risk management models. In shifting from accident investigation to other system performance indicators and their data on a daily basis, there is a need for modeling all possible causal event sequence scenarios in order to understand what is happening. Such an analysis should include technical, human, and organizational factors, deeming the Reason model to be insufficient, due to its theoretical and partial modeling and the amount of occurrences that have to be processed every day (Roelen et al, 2009). There is a need for "real" models, covering every aspect and systems level, requiring a substantial mathematical background and user friendly software tools. Such models should incorporate fault trees, event trees and influence diagrams, which were adopted in the nuclear power industry in 1975. Sophisticated PRA methods should provide establishing a relation between cause and effect, while influence diagrams should represent the influence of the context. Since airline safety analysts, safety managers, and chief pilots have detailed knowledge but fail to identify systemic shortcomings, a framework is needed to help them to see the whole picture. Most of the effort is in classification of the data entry, with relatively little effort spent on analysis (Roelen et al, 2009). Such a "real" model should be integrated in order to represent the complexity and interdependencies, should be quantitative and transparent, and should provide reproducible results, covering the whole aviation system.

This approach does not favor the introduction of new concepts or models. The concepts of Dekker to see socio-technical complexity as a web of dynamic, evolving relationships and transactions or the Leveson concept of systems as interrelated components that are in a state of equilibrium by feedback and control are not considered useful (Roelen et al, 2009). The aviation industry should be too conservative and too slow responding in accepting new ideas, while Reason's Swiss Cheese model is still relatively new. An event model that fits current practice should make more sense than develop new models with a completely different concept, however correct these concepts might be (Roelen et al, 2009).

Modeling accidents

Across the various domains, accident investigation and event modeling have seen different points of departure. On one hand there is a bottom-up approach in occupational risk and road safety: prevention of accidents, separating process safety from personal safety. Focus on isolated causational factors and single-actor strategies (corporate management or the three E's of engineering, education, and enforcement. On the other hand, a top-down approach is applied in aviation, railways, and shipping aiming at systems change and learning without separation between personal safety, process safety, external safety, or rescue and emergency handling (ETSC, 2001). Modeling accidents by decomposing accidents into a limited category of hazards and a predefined set of generic failure types deprives the analysis of three major components.

First, learning lessons for prevention of similar events. Prescriptive modeling of accidents forces the decomposition and description of the event into the format of the model. It also forces the event into an assessment of the correctness of the event in terms of compliance with the models normative assumptions and notions. In particular with human error modeling, such normative assessment remains implicit and obscures an explanation of the behavior, based on motives, conditions, constraints, and context. Prescriptive modeling denies local rationality at the operator level. In particular where pilots, mariners, and drivers have their discretionary competence, such modeling rather obscures than clarifies human behavior in high-tech operating tasks. Their adaptive potential to new situations and ability to respond and recover in a flexible manner is the basis of their learning. It is a part of their internalization process of processing experience into knowledge. In a normative assessment, the operator is assumed to have a timely and full transparent oversight over all the available information, systems properties, and of all his actions and their consequences. Such an investigator hindsight bias obscures the decision-making in uncertainty, which the operator is submitted to in practice (Kletz, 1991; Dekker, 2006). Such an analysis in which operator performance is assessed against normative behavior is in contradiction with learning theory. In particular, in complex high-tech systems, such a assumptions of full and transparent information supply is not realistic and hence in conflict with bounded and local rationality theory.

Second, cross-corporate dissemination of lessons learned. In the Durkheimian and Weberian tradition, social sciences copied the notions of the most prominent scientific domain of the 19th century, the natural sciences, to mirror themselves to their merits and to surpass them by adapting their methodology (Matthews, 1978). This mechanism in establishing scientific esteem seems to be repeated in the 20th century, by mirroring management control modeling against engineering design principles. In 1972, the psychologist Edwards claims a more prominent role for the behavioral sciences in the integral design of aircraft and postulates the HELS model (Edwards, 1972). A "traditional" focus on technical components should be unjustified, the "linear" design method an anachronism. This claim is even more interesting because it is stated at the very moment of the development and roll-out of the major aviation innovation at the time: the first of the widebody generation of commercial jet aircraft, the Boeing 747. In his plea for involving psychology into aircraft engineering design, Edwards also criticizes accident investigation in aviation: the value should be limited, the frequency too low to draw useful conclusions, while the complexity should prevent an adequate analysis. Edwards follows the criticisms of Frank Lees in 1960, who did not se an added value for accident investigation in the process industry (Lees, 1960). Frank Lees shift a preference toward incidents, loss control, and risk management. According to Edwards, accident investigations should only be based on negative experiences, instead of positive experiences as well. Accident investigations should only be descriptive and lack explanatory potential. However, international aviation is a global, open transport network that can function exclusively on the basis of mutual harmonization and standardization, high-level performance demands, and open access to the global network. Learning from an accident in aviation, therefore, takes place at the international and sectorial level, not on national or corporate level, such as in the process industry or nuclear power supply. This learning is focused on technological improvements and open exchange of information at the level of international institutes such as the International Civil Aviation Organization (ICAO) instead of national governmental inspection and limiting learning to the level of the private, multinational company. Safety as a societal value is a prerequisite for the international transport community due to its existence as a public transport system.

Third, its specific analytic potential. Modeling of accidents has been derived from the paradigm as defined by Lees and initially elaborated by Reason and Rasmussen for the process industry. It is a legitimate question, however, to see whether the inherent characteristics of the process industry are generically applicable in other high-technology and knowledge-intensive industrial sectors, such as the transportation sector.

There are fundamental differences between the process industry and the various transport modes. The most prominent differences in system architecture and characteristics between the sectors are

- closed versus open systems. In public transport safety is a public governance value, managed in a dynamic network of mutually dependent actors and stakeholders. In the process industry, risk control is allocated to the corporate level from a top-down managerial perspective, dealing with fixed sites on a stand-alone basis. A company structure in the process industry is of a multinational nature, while entities in the transport modes are international by nature.
- continuous versus intermittent operations. The transport industries are operating on a 24/7 demand basis, providing direct and individual services at the level of global networks, while the process industry operates on a supply basis, facilitating intermittent production organization, creating room for temporary shutdown, reconfiguration, and adaptation of specific products without the requirements of a permanent availability of production capacity.
- the role of the human operator is fundamentally different. In transport modes, the concept of human-centered operations will be irreplaceable for decades, if full automation is ever desirable and feasible, such as in the process industry. Consequently, various cognitive levels of operations are required and various delegated responsibilities have to be allocated to the various control levels of the system.
- there are differences in the dynamics and pace of technological adaptation. In the transport modes, rapid adaptation by technological harmonization and standardization creates the basis for accessibility of the network, interoperability, and reliability for all actors. In the process industry, there is a more restricted pace of technological development, while the conversion of material properties produce only a limited set of hazards and critical events, such as fire, explosion, loss of containment, and health problems. In the transport modes, a wide variety of events in a rapidly evolving operating environment will occur, creating exposure to kinetic energy releases inherent to speed and mass. Consequently, managing the consequences of catastrophic failure is different.

It therefore is a legitimate question whether formal models on a managerial level of safety decision-making processes are appropriate for accident investigation and should replace metaphors or modeling as such is inappropriate for accident investigation of transport modes and should be replaced by another concept.

In overcoming present limitations and the necessity to achieve a shift from managerial control strategies toward a socio-technical systems perspective, the latter might be the case.

Toward new concepts

If we shift from managerial control strategies toward applying an engineering design approach to safety at the socio-technical level, what does this mean for the accident investigation process? How do we substantiate such an engineering design approach in the accident investigation methodology? How do we substantiate the concept of resilience engineering in practice (Hollnagel et al, 2008)? Two steps are to be taken into account: identification of the design solution space and the use of empirical evidence as an input for safety design specifications based on forensic engineering principles.

Safety-enhancing interventions can be categorized in two main classes:

- Linear interventions and first order solutions. Simple problems allow restricting the design space. This is valid only if the number of solutions is small, the number of design variables is small, their values have limited ranges, and optimizing within these values deals with sacrificing of aspects among the limited set of variables. Such interventions reinforce the design space *in the detailed design phase* by reallocation of factors, more stringent compliance with rules and regulations, elimination of deviations, applicable to simple, stand-alone systems
- Complex interventions and second order solutions. Complex dynamic problems demands expansion of the design space. Such solutions focus on concepts and morphology, reallocation of functions to components, reconfiguration and synthesizing of sub-solutions, involvement of actors, aspects, teamwork, communication, testing, and simulation. Such an expansion of the design space occurs *in the functional design phase* by developing conceptual alternatives and prototypes, applicable to complex and embedded systems.

When first order solutions have failed and did not prevent an event, a redesign of the system becomes necessary.

In order to achieve such redesign, the event must be redefined in the first place by applying an engineering design methodology (Stoop, 1990; Dym and Little, 2004):

- *decompose the event* to identify contributing variables and their causal relations.
- *recompose the event* by synthesizing safety critical variables into credible scenarios.
- provide *analytical rigor* to the scenarios by identifying their explanatory variables, based on undisputed empirical and statistical evidence and scientific research.
- make the transition *from explanatory variables toward control and change variables.*
- develop *prototypes* of new solutions.
- test the prototypes by *exposure to the accident scenarios* in a virtual simulation environment.

Designing safer solutions

In designing safer solutions, two fundamental questions are raised about

- how to design safer solutions?
- how to generate the requirements for such a design?

In contrast with linear interventions and first order solutions, in complex systems there is no direct relation between a single contributing factor and its remedy. In redesigning safer solutions, there are three different focus groups for communication of the safety solutions: operators and actors within the system able to achieve a safe performance, knowledge providers for a better understanding of the system behavior, and change agents, able to govern and control the system. Each of these parties has a specific set of communication means, applying respectively metaphors, models, or prototypes. Each of these parties applies its own vocabulary and reference frameworks but should share a common notion in the end by a common means of communication. Applying a "barrier" notion is a powerful communication metaphor but does not help in the case of a scientific modeling of the issue or applying a prototype in testing a solution.

Synthesizing solutions is necessary in order to establish a shared solution, based on the credibility, feasibility, compatibility, and selection of preferred alternatives in order to create consensus among all parties involved in accepting the solution. Synthesizing is about recreating interdependencies into a new concept, network, or configuration based on shared values. Complexity then can be defined as the interdependences of variables, choices, and design assumptions. To deal with this complexity, it is not sufficient to decompose a system or event into its contributing variables and explanatory variables within its existing solution space, but also the design variables must be identified in order to serve as input for the systems engineering design process.

In addition, dealing with complexity and context is not adding more detail and levels to an event by increasing the decomposition, but *providing transparency at higher systems levels* with respect to its functioning and primary processes, and clarification of the conceptual properties, its configuration and composition. Increasingly complex accident modeling such as Accimap or STAMP do not make the transition from the event toward systems characteristics (Rasmussen and Svedung, 2000; Leveson, 2004). If the inherent properties of a system are not identified during design, they will manifest themselves as emergent properties during operations. Such properties are to be specified by stakeholders, actors, and other parties that are to be exposed to the systems operational consequences and formulated in an overall Program of Requirements, leading to design specifications.

To assess the integral performance of the system, a synthesis should take place of all aspects in an encompassing Program of Requirements. Such a Program of Requirements becomes a consensus document, in which all actors involved have had the opportunity to express and incorporate their requirements, constraints, and conditions during the assignment phase of the redesign.

A language issue, creating scenarios

In reconstructing an event sequence, we easily refer to the mechanical reconstruction from an engineering perspective. In unraveling the event sequence from a psychological or sociological perspective, we might prefer the phrasing of reenactment of the event or reconfiguration of the system state and operating environment.

Recomposition of an event enables event analysis. In order to communicate, a common reference framework is required, clarifying the various perspectives in recomposing the event:

- a technical perspective dealing with a *reconstruction* of the physical system performance.
- a behavioral perspective dealing with the *reenactment* of decisions and discernable actions.
- a systems perspective dealing with the *reconfiguration* of the systems state and operating environment.

In order to create a common understanding among actors a common language and common notions are necessary. In risk discussions, the perception and acceptance of risk varies across actors, dependent on their position and interest. They may apply either a frequentistic or a scenario approach, dealing with either the frequency or the consequences of an event, a technological or a sociological approach, or may apply a rationalist or an empathic approach (Hendrickx, 1991). These different approaches each have developed their own notions and language. In order to be able to communicate, there is a need for either a common language or a translation between these languages. This implies an understanding of each of the languages in the first place with respect to its linguistics, syntaxes, grammar, and vocabulary. Decomposing such a language identifies the elements and building blocks of the language and facilitates analysis of their meaning and usefulness. For communication purposes, however, a language cannot be spoken at such a decomposed level. A recomposition of these elements and building block takes place into a more complex communication structure to facilitate meaningful conversation. In an analogy with music, poetry, and literature, such a communication language is also applicable for accident analysis. The scenario concept provides such a common language, creating event narratives that form the basis for common understanding and agreement on the description of accident phenomena in their context (Stoop, 1990). Achieving consensus on such accident scenarios provides a basis for a common risk assessment and shared solution space.

Shared solutions, redesign and prototyping

In complex interventions, the focus is on events in a systems context rather than on isolated factors and generic aspects, such as is the case with linear interventions. The reconstruction of events takes place by identifying and synthesizing explanatory variables into scenarios in their specific operating environment and constraints. Such synthesizing is primarily evidence based. The redesign of the systems is conducted along the lines of engineering principles by generating design alternatives in the enlarged design space into the form of a limited set of prototypes. These prototypes contain a relocation and addition of functions, changing the morphology and configuration and incorporate additional actors and aspects. The testing of these prototypes is conducted by running scenario tests, definition of limit state loads and simulation of complex, dynamic systems in virtual reality. Analyzing system responses, before they are put into practice, are based on First Time Right and Zero Defect strategies. The responses of a system can be determined by a gradual enlargement of the disruptions which are inflicted upon the system, until oscillation and instability occur. Responses of systems may become visible by a gradual or sudden transition to another system state by passing a bifurcation point. After such a transition, the safety of the systems can be assessed according to the acceptability of the new safety integrity level.

Technology in itself contains many forms, incorporating invisible knowledge, notions, principles, and decisions from previous

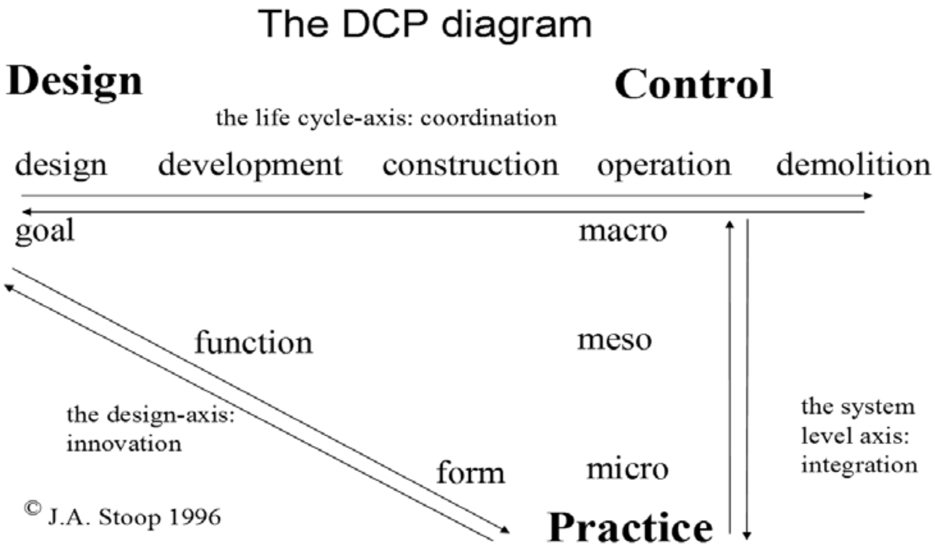

Figure 3. Stoop's systems architecture DCP diagram.

lifecycle phases. The physical appearance of a product and process does not disclose inherent properties, principles, or interactions to end-users in their operational environment. Design decisions are frequently made under conditions of high uncertainty. Safety margins and design standards, identification of failure mechanisms, probability assessment, consequence analysis, and identification of a design envelope should reduce the uncertainty again to an accepted level. Designers deal with optimizing performance and are not in a position to gain oversight into all uncertainties and unforeseen behavior of their designs (Petroski, 1991; Carper, 2001). Such behavior, however, can be designed into their processes such as with the Japanese design philosophy of Limit State Design or Critical Sate Design methodologies. Designers need an intellectual counterpart in assessing the safety of their design; accident investigators as forensic engineers play such a role.

Forensic engineering

Historically, designers needed a technical investigator, capable of recomposing the actual and factual sequence of events, the operating conditions and context, the factual technical functioning of the designs in practice. Such recomposition facilitated the drafting of redesign requirements. However, a recomposition ability should not only reproduce the physical, reality, but also should encompass the knowledge, assumptions, decisions and safety-critical issues that have been taken into account and assessed with respect to their acceptability. Such ability should also incorporate the ability to recompose the socio-technical context and operating environment (Stoop, 2004; ESReDA, 2009).

From an investigator perspective, three kinds of systems designers should be supplied with a counterpart, each qualified with diagnostic and analytical skills from a technological/engineering design, organizational/managerial, or governance/control perspective in order to cover the architecture of the overall socio-technical system. This can be expressed in the DCP diagram (see Figure 3).

These three design-counterpart roles for investigators have been developing gradually over the past decades. Initially, with the development of technology, the technical investigator has matured, creating specialist approaches in many technological domains such as propulsion, structures, avionics, stability, and control. Although the domain of human factors has seen major progress over the last two decades, the notions that have been developed in this domain are not yet readily applicable for investigation purposes (Strauch, 2002; Dekker, 2006). Translating theories on human factors into investigation tools is progressing, developing notions on bounded and local rationality, naturalistic decision making theories, a blame-free view on human error, high reliability organisations, and resilience in organisational design. In the domain of governance and control, the development is in an even earlier phase: this domain is developing classification schemes on failure, but is not yet in a phase of developing general concepts and notions of systems governance and control. Consequently, a framework and toolbox of investigation methods for conducting accident investigations at a systems level is not yet fully developed. Designers need counterparts for the assessment of their designs. Such a role is provided by accident investigators.

Conclusions

Although the Reason and Rasmussen models may well serve risk management in the process industry, and nuclear power supply, there are doubts about their generalization toward the aviation industry. In practice, they are exposed to the risk of serving as reference metaphors for the benefit of risk communication and standards for generating generic, linear solutions. On methodological grounds, Reason's model shifts the focus from accident causation toward human error analysis, while Rasmussen's model replaces accident investigation by management control in a socio-technical systems context. Consequently, both models do not comply with the needs of accident investigation theory and practices and systems engineering design needs in the aviation industry. Consequently, engineering design methodology may provide an alternative for improving the safety performance of complex systems at a socio-technical level.

The potential for systems engineering design in providing safer solutions requires to

- identify inherent properties before they manifest themselves as emergent properties.
- deal with complexity and dynamics by focusing on functions rather than on factors.
- focus on design principles and properties rather than optimizing performance.
- introduce systems dynamics by synthesizing interrelations into accident scenarios.
- apply a proof of concept by testing solutions in a dynamic simulation environment.

Therefore, it is necessary to

- develop event scenarios separated from systems models.
- develop prototypes of safer solutions.
- create dedicated virtual systems models, representing their specific characteristics.
- facilitate testing and validation in these models, parallel to the real system. ◆

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Was It Really Pilot Error? A Case Study of an Indian Military Helicopter Accident

By Capt. Samir Kohli, Head of Safety, Saudi Aviation Flight Academy

***Capt. Samir Kohli** is the head of safety with Saudi Aviation Flight Academy, Riyadh, Kingdom of Saudi Arabia. He is an ex-Indian Navy helicopter pilot with more than 21 years of flying experience. He has dedicated the last 15 years of his life to aviation safety management systems and air accident investigations. He has investigated 12 military aircraft accidents and has stood in as "friend of the accused" (which is the military term for "defense attorney") in three military court marshals convened to try pilots charged with pilot errort (acquittal was won in two of these). He was also involved as the team leader in a study program commissioned to study 120 fatal aircraft accidents that occurred between 1960 and 1990 to identify the recurrent human factors and organizational issues that contributed to them.*

Figure 1

Figure 2

Somewhere in the Indian Ocean, July 2006.

Exercise Objective: To demonstrate combat readiness of the fleet (See Figure 1).

The sea

- Sea state 4 to 5.
- 10- to 15-feet-high waves.
- >30 knots winds.
- Constantly shifting wind direction.
- Long, low swell with an occasional violent motion.
- Generally confused seas and erratic waves.

The ship and the helicopter

The ship

Note the obstructions behind the helicopter as it comes in to land. (See Figure 3).

Figure 3

The commanding officer

- Ship had been undergoing modernization for last 4 years. The commanding officer had been in command for 3 of those 4 years.
- Possibly his last year in command.
- First time sailing with fleet since taking over command.
- Expected to be transferred out very shortly and this exercise was possibly his last chance to demonstrate "operational readiness" of the ship to the fleet commander.

The pilot

- Rank lieutenant commander.
- Eleven years' flying experience, 9 years as captain.
- An experienced pilot at sea and well trusted and respected by his commanders.
- The CFI in his basic training noted, "Tendency to pull back and

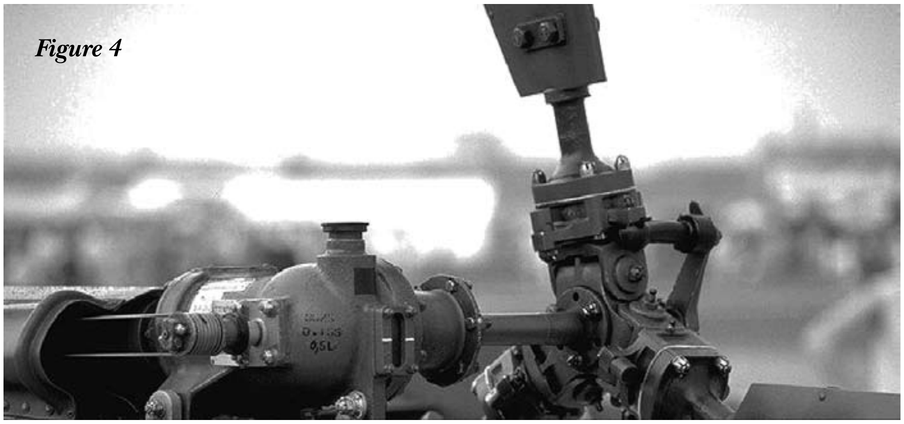


Figure 4

get into a nose-up attitude on landing and warned for the same."
• Involved in two "tail touch" incidents in the past with minor damage to the tail rotor on each occasion.

The copilot

• Young and serving his first afloat deployment post qualification to land on deck.
• Considered the pilot as a "role model" and had a lot of admiration for his achievements.
• Unquestioning obedience of the pilots orders at every stage during the deployment.
• Witnesses reported a "master-dog" type relationship between the two.

The mission

• At 0400 hours, message received for ship to launch helicopter 0700 to pickup the fleet commander (rank rear admiral) + five from another ship in fleet.
• The pilot's first reaction when told of mission—"These guys must be out of their minds!"
• At 0600, ship signaled, "Flight commander recommends weather not suitable."
• At 0655, ship signaled, "Helo ready for launch."
• Helicopter airborne at 0701.

The accident

• First trip uneventful.
• As it lifted for second trip, the fleet aviation officer asked pilot if he will accept four passengers.
• The pilot expressed his dissatisfaction, stating high all up weight and bad weather indicating need to have a higher reserve of power.
• Pilot objections overruled and ordered to prepare to accept four passengers as fighter aircraft were expected overhead any minute for a simulated strike.
• Helicopter arrived over landing area with four passengers, hovered for a few minutes, reportedly "danced at hover," swung violently, and crashed on its right side with the cabin protruding outside the ship over water.
• Two persons on deck received splinter injuries—one a minor splinter in the eye, the second two large pieces in his arm and chest (that was later extracted from his back, fortunately without damage to heart and lungs).

What happened?

• First report from the pilot: "The helicopter was unstable due to turbulence and deck movement. I maintained hover at 10 feet to try and synchronise with deck movement. Suddenly there was a violent movement of deck and as I tried to pull back **my tail rotor struck something. I lost directional control and spun.** I slammed down the collective pitch control to contain on deck. The landing was very hard, collapsing the right oleo and causing the machine to tip over (see Figures 4 and 5).

What happened?

The tail rotor was found separated from the helicopter but still attached to the tail gear box, found functional in factory.

What happened?

• The copilot insisted that the helicopter swung in three complete circles through left and that he saw the rear of the ship "at least thrice."
• Three witnesses insisted that the helicopter "swung to the right,


Figure 5

then left, then right again" before crashing on deck. Never swung in complete circle.

- The splinters in the eye, arm, and chest of the injured personnel identified to be parts of "main rotor blade balance weights." The two pieces extracted from the arm and chest of one of the injured formed a complete balance weight with serial number legible and traced to red blade.
- Both stated they were injured while helicopter was still "dancing in the air" and did not see it crash.
- One red pitch change rod found broken.
- Two blade spacer cables found broken, of which one was never found.
- Red rotor blade had a semicircular indentation of exact diameter of the tail rotor drive shaft.

The enquiry and verdict

- The enquiry conducted over 45 days found the pilot to be at fault for

—operating the helicopter outside the limits of the flight envelope.

—mishandling of controls leading to loss of the tail rotor due to strike and consequent loss of the helicopter.

- Recommended withdrawal of pilot from flying cadre, quoting also the previous two incidents of tail rotor damage.

The questions unanswered

- Why was the launch ordered in the given weather? What's the responsibility of the senior management (fleet commander and his staff)?
- What would be consequences for the pilot in event of refusal to launch under combat conditions?
- Why did the main rotor blade balance weight break away when the helicopter was still in air?
- What caused one blade spacer cable to break from both ends and go missing?

As the mess unraveled…

- Fleet commander:

—"…This was a war-like exercise. In military combat operations we have to take risks.

Yes, the circumstances were challenging.

—…I would have ordered disciplinary action for refusal to fly.

—…It was my personal decision to launch the helicopter in the given conditions.

If the action was wrong, I alone am responsible for it."

What actually happened

- Electron microscope examination revealed fatigue failure of the red pitch change rod.
- The pitch change rod ruptured at hover due to loading.
- Caused asymmetric cyclic pitch change of red rotor blade. Interpreted as "high turbulence" by pilot.

What actually happened

- A flapping blade also lags causing excessive strain on the blade spacing cables.
- The cable posts of red and blue blades broke under this strain and the cable flew off under centrifugal force (353 RPM), lost into the sea.

What actually happened

- The red blade flapped down to strike the tail drive shaft.
- The main rotor tip of the red blade broke.
- Splinters from the balance weight in the tip of the blade injured two personnel.
- The helo yawed side to side during this process. It most likely never spun.
- Pilots action of slamming down collective pitch was the best possible action at that stage, even if his diagnosis of the problem was wrong.
- Weakened tail drive shaft sheared off most likely on impact with deck.

Investigating ASIA

- **Accurate.** Weigh the evidence, don't count it! Even eyewitness statements can be wrong. The human eye sees what the mind believes.
- **Speedy.** Forty-five days to deliver an incorrect verdict? Interim verdict followed by detailed examination of evidence. Speed at cost of accuracy is not justified.
- **Independent.** Influenced by rank of the fleet commander?
- **Authentic.** Cost of error is another accident and more loss of life! ◆

Planning for Sea Search and Recovery Operations—A Small Investigation Agency's Perspective

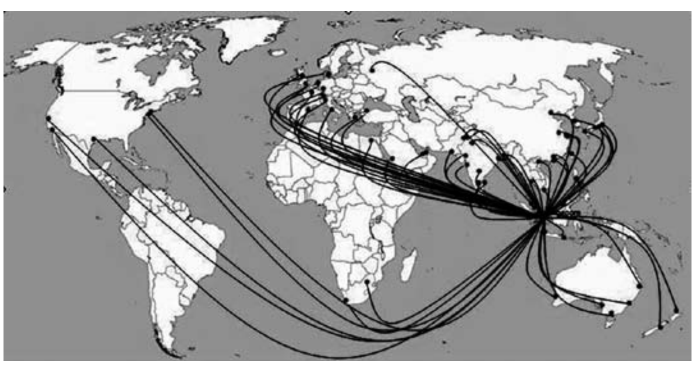
Prepared by the Air Accident Investigation Bureau of Singapore
Presented by Pang Min Li

Pang Min Li (Ms) graduated from the National University of Singapore in 2006 specializing in material engineering design. She worked for Singapore Technologies Aerospace and was involved in the design and production support on the Boeing 757-200 passenger-to-freighter conversion. She was posted to ST Mobile Aerospace in Alabama, USA, to serve as a liaison engineer for the prototyping of the converted B-757-200 freighter. Min Li gained experience in analyzing structure defects and verifying repair schemes. In May 2009, she joined the Air Accident Investigation Bureau of Singapore as an accident investigator.

Introduction

1 Singapore is a small country in Southeast Asia. It is surrounded by waters, and its only land link is with its neighbour Malaysia to the north in the form of two causeways. However, Singapore has very significant air carrier activities. Some 90 scheduled airlines operate at the Singapore Changi Airport, providing air connections to 200 cities in nearly 60 countries.

2 Among the 90 airlines, the seven national airlines of Singapore fly to more than 65 overseas destinations. Virtually all their flight routes involve flying over waters.



3 In fact, the departure and arrival routes for Singapore Changi Airport are over water as the airport is built on land reclaimed from the sea.

Changi Airport, located on reclaimed land on the eastern tip of Singapore.

4 Thus, a sea crash around Changi Airport of an aircraft during takeoff or landing is a distinct possibility. Changi Airport has taken this into account in its emergency response plan, in coordination with other government

AES's hovercraft (above) and fire boat (left).

response agencies such as the Police Coast Guard and the Maritime and Port Authority. The search and rescue and firefighting asset of the Changi Airport Emergency Service (AES) also includes two hovercrafts and a fire boat.

5 The depth of the sea water around Changi Airport is about 60 metres. Such shallow water should not present too much of a problem for the Airport Emergency Service in the search and rescue operation. While the Air Accident Investigation Bureau of Singapore (AAIB) does not have a lot of experience in the search and recovery of flight recorders and aircraft wreckage/debris, we believe that, with the assistance, if necessary, of the more experienced investigation agencies around the world, such search and recovery operation in shallow water will also not be too problematic.

6 The Air France Flight 447 crash in the Atlantic Ocean on June 1, 2009, highlighted a new concern for us. The unsuccessful attempts by the French Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) provided an impetus for the AAIB to review the way its investigators ready themselves for a sea crash.

7 Arising from the Air France accident, we asked ourselves the following questions:

- Are we able to direct and manage a search and recovery operation for an aircraft that has crashed into a deep ocean far away from Singapore?
- Do we have enough investigators to be deployed in the high seas

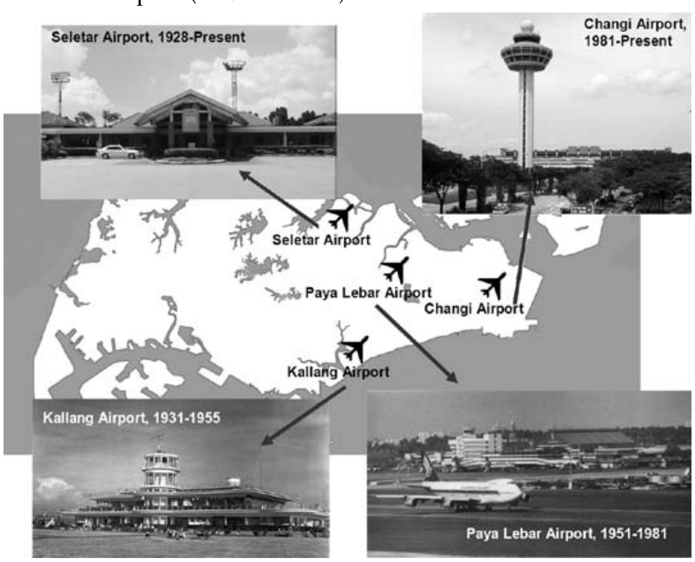
for a search and recovery operation?
• Are our investigators able to survive working in high seas for an extended period?
• Will we be able to muster the necessary manpower and equipment resources to conduct a sea search and recovery operation?
• Do we already have the basic equipment for a sea search and recovery operation?
• Do our investigators have sufficient training and knowledge for such sea search and recovery operations?
• Do we have the knowledge and experience to use the equipment or to devise a search pattern?
• Do we know beforehand which salvage companies have the capability that we may need?
• Do we know which other investigation agencies can help us in such a sea search and recovery endeavour?

8 This paper aims to share AAIB's considerations in the review and how the AAIB enhances its preparation to meet the challenges of a sea crash.

Airport development in Singapore

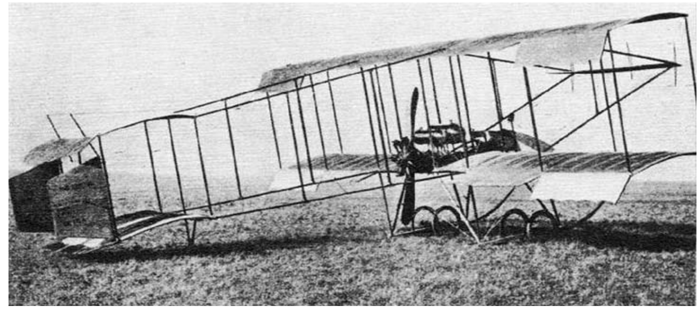
9 Despite being a small island, Singapore has nevertheless had an interesting history in airport development. Before the international airport at Changi became operational on July 1, 1981, Singapore had had three other civil airports:

• Paya Lebar Airport (1951–1981)
• Kallang Airport (1931–1955)
• Seletar Airport (1928–Present)

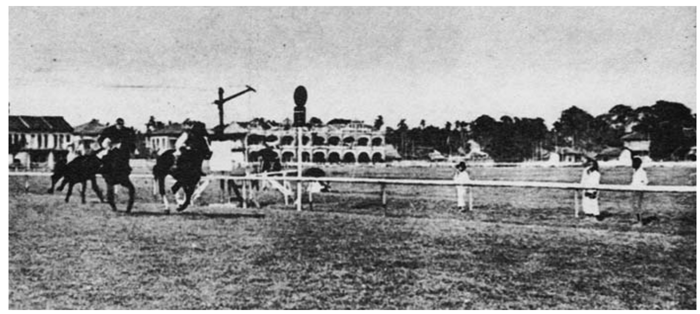


10 In the early years of the 20th century, flying was often regarded as a sport. In March 1911, Frenchman Joseph Christiaens became the first person in Singapore to perform a demonstration flight of a British-built Bistrol Box-Kite biplane at the Race Course (now Farrer Park). Eight years later on Dec. 4, 1919, Australian Ross Smith landed his Vickers Vimy in Singapore, as part of his pioneering flight from England to Australia. This was the first time an aircraft landed in Singapore from overseas.

11 After that, Singapore's civil aviation began to flourish and the first military and civil airport was completed in 1929 at Seletar to the north of the Singapore main island. Seletar Airport was built for aerial defence for the naval base on the northern shore of the island. Seaplanes used to anchor off Selatar. At that time, seaplanes that were equipped with floats appeared to be a versatile machine



Frenchman Joseph Christiaens became the first person in Singapore to perform a demonstration flight of a British-built Bistrol Box-Kite biplane at the Race Course (now Farrer Park, below).

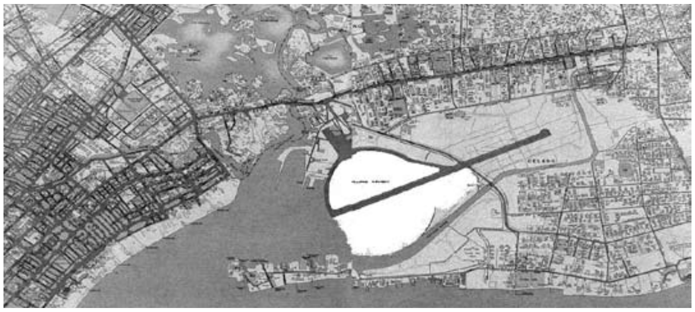


On Dec. 4, 1919, Australian Ross Smith landed his Vickers Vimy in Singapore as part of his pioneering flight from England to Australia—the first time an aircraft landed in Singapore from overseas.

where land-based aerodrome facilities were not available. With the completion of Seletar's landing facilities on dry land, more of the world's international flying pioneers were flying into Singapore on aircraft with wheels, not floats, and the first commercial flight (from Batavia, now Jakarta) landed in Seletar on Feb. 11, 1930.

12 However, the runways at Seletar Airport proved inadequate when aircraft grew larger and heavier. Sir Cecil Clementi, the governor of the Straits Settlements, selected the Kallang Basin as the site for a new airport. The location was near the City of Singapore and adjacent to a river, and could accommodate an aerodrome for landplanes and provide anchorage for seaplanes. Massive reclamation work began in 1932, and the Kallang Airport was completed on June 12, 1937. Seaplanes landed and took off on the adjacent Kallang River.

13 The advent of huge machines developed for World War II laid the foundation for the development of bigger and faster civil aircraft. And noisier aircraft, too. An airport further away from the city was needed. Thus, Kallang Airport was abandoned just 10 years after the end of the war, being replaced in 1955 by Paya Lebar Airport located



Kallang Airport on reclaimed land (highlighted in white).

at the northeastern part of the Singapore main Island. Although the airport was not immediately close to the Johor Straits to the north, it did have a water obstacle in the form of a river (Serangoon River) to the north of its single runway.

14 Paya Lebar Airport received heavier aircraft such as the Fokker F-27, Comet IV, Convair 880, Lockheed Electra, DC-8, and Boeing 707. Despite optimism that this would be Singapore's airport answer to the jet age, the single-runway Paya Lebar Airport had to cope with the pressure from new aircraft types and increasing traffic. Within a matter of years, there were numerous runway extensions, as well as additions and alterations to the arrival and departure halls.

15 By the mid-1970s, Paya Lebar Airport's capacity was already being stretched to the limit, and a decision was made in 1975 to construct a new civil airport at Changi on the eastern tip of the Singapore main island, where the new airport would be easily expandable through land reclamation. The Changi location is away from the densely populated areas and would entail arrival and departure flight paths over the sea. As such, complaints against aircraft noise would not be an issue, and ground casualties in the event of a crash during an aircraft's takeoff or landing would be very much mitigated. Again massive reclamation work had to be undertaken to build the Changi Airport, which became operational on July 1, 1981.

16 Thus, because the Singapore island is so small, the airports in use in Singapore in different periods all involve or involved operations over water. It was inescapable that air crash response had always to take into account a sea or underwater search and rescue scenario.

Earlier sea accident investigation experience

17 We did not research into whether there were any aircraft that had ditched or crashed into the Johor Straits or Kallang River in the early days of aviation in Singapore. But as early as 1975, Singapore had an experience in responding to aircraft ditching. On Sept. 17, 1975, a Convair CV-240 ditched into the Johor Straits, some 400 metres off the end of Runway 03 of Seletar Airport, when both of its engines lost power consecutively. The depth of the water was about 8 metres. The warm tropical water allowed the corrosion process to set in quickly. When the aircraft wreckage was recovered a few days later, extensive corrosion was noted. For example, localised corrosion of deep pits was found on the magnesium aircraft parts. For the propeller dome, the materials under the paint had corroded into a powder-like texture. The pressurised piston mechanism within the propeller dome also posed a hazard, especially when its integrity had been compromised by the corrosion. One of the lessons learnt from the recovery operation is the importance to recover the aircraft wreckage as quickly as possible, in order to minimise corrosion

The first day of dredging the crash site at the Musi River produced 100 bags of debris. (Picture by Tan Lai Hock of Lainhe Zaobao.

An aerial view of the search efforts on Musi River.

on the aircraft parts and reduce evidence loss.

18 Singapore investigators had to climb a very steep learning curve in underwater search operation when they represented Singapore as the State of Registry and the State of the Operator to participate in the Indonesian investigation of the plunging of the SilkAir Boeing 737 into the Musi River, near Palembang in the Indonesian island of Sumatra, on Dec. 19, 1997.

19 The Indonesian investigation was led by the National Transportation Safety Committee (NTSC). The crash site, at the mouth of the Musi River, was challenging, as there was strong tidal currents to contend with and the water was murky. Compounding this, the aircraft had virtually been pulverised during its impact with the water. Wreckage pieces were small, and they settled and got buried in the mud at the bottom of the river. Visibility underwater was so poor that divers searching for bodies or aircraft debris practically had to do so by touch.

20 At the Singapore end, the agencies and organisations that were mobilised in the aftermath of the crash included the Ministry of Transport, Ministry of Health, Ministry of Defence, Ministry of Foreign Affairs, Civil Aviation Authority of Singapore, Singapore Airlines (parent company of SilkAir), Singapore Airlines Engineering Company, etc. Singapore deployed two naval vessels, a Fokker 50, a Hercules C130 and two Super Puma helicopters to support NTSC's search operation. More than 90 divers from the Singapore Navy also took part in the underwater search. After a 2-week search attempt, a dredging company had to be called in to dredge out the debris. About 73% (by weight) of the aircraft debris was eventually recovered.

21 The Musi River search and recovery operation involved many

aspects, e.g., logistics, accommodation, salvage. The SilkAir accident made us a firm believer of the importance of prior interagency coordination and cooperation. The operation also drilled into us the importance of having adequate sources of funding to support such operation. The salvage cost was only a few million Singapore dollars, a tiny fraction of the cost of the TWA 800 or Swissair 111 case. Nevertheless, we believe airlines would do well to secure the capability to absorb such cost through, for example, the insurance coverage for their aircraft.

AAIB sea search capability enhancement

22 After its formation in October 2002, the AAIB contacted or visited the investigation agencies in Canada, France, Taiwan, the UK, and the U.S., which have a lot of experience in sea search of aircraft wreckage and flight recorders (e.g., through leading the investigations of TWA 800, Swissair 111, Flash Airlines 604, China Airlines 611 and helicopter crashes in the North Sea), in order to appreciate the tasks involved in a sea search operation. The AAIB also met with salvage companies to understand their capabilities and what they would need to perform salvage operation for the investigators.

23 AAIB investigators had their first taste of sea search when they were invited by the Indonesian National Transportation Safety Committee (NTSC) to help search for the Adam Air Boeing 737 that had gone missing over the Makassar Strait on Jan. 1, 2007. A team of divers from the Singapore Navy was also invited to join in the search.

AAIB investigators searching for the Adam Air B-737 flight recorders using ULB detectors.

24 For a week, the AAIB investigators were on the sea searching for the flight recorders using underwater locator beacon (ULB) detectors to try to listen for the 37.5 kHz pinger signals that should have been emitted from the ULBs associated with the flight recorders. They and the Singapore Navy divers were operating from a base ship, the Baruna Jaya IV (an Indonesia scientific research vessel). For the detection missions, they had to use rubber dinghies. A total of seven detection missions were conducted at multiple locations as assigned by the NTSC.

25 Listening for the 37.5 kHz pinger signals from the ULB was not as straightforward as it would appear. The sea condition, noise environment, etc., could make listening for signals a daunting and time-consuming exercise, not to mention the sea sickness that searchers may have to endure. The motion sickness was a torture that the investigators had to learn to endure and overcome. The feeling of nausea caused by the rocking motion of the sea currents made it very difficult for the investigators to concentrate on their task of listening for the signals.

26 Also, when the currents were strong, it was quite difficult to control or maintain the stability of the rubber dinghy. The drifting of the dinghy could affect the accuracy with which the location and direction of the signals might be recorded.

27 The Adam Air search mission exposed our investigators to the rigours of operating at sea, and they witnessed firsthand the challenges involved. With the depth of the waters in the Makassar Strait being about 2,000 metres, it was not surprising that the search from a dinghy using ULB detectors was not fruitful as the use of a ULB detector is generally limited to shallow water search. The recorders were eventually located by the U.S. Navy ocean survey ship Mary Sears using more sophisticated equipment. However, the experience was invaluable to the AAIB and strengthened AAIB's resolve to build up our underwater search and recovery capabilities and resources to an appropriate level.

28 The Adam Air search exercise also emphasised the need to have appropriate communication equipment for use in remote areas. As there may be areas that mobile services cannot reach, the use of walkie-talkies could be a good alternative for the search personnel to stay in communication with each other, with the base ship or with the operations command centre located on land.

29 Although the use of ULB detectors was not fruitful in the Adam Air case, one should remember that the French BEA investigators did succeed in locating recorders at a depth of more than 1,000 metres using ULB detectors in the case of the Yemenia A310 crash off the Comoros Islands on June 30, 2009, a demonstration of the French investigators' prowess in the use of ULB detectors. Therefore, honing of ULB detection skills can be an important part of an investigator's training.

Review post-AF 447

30 The Air France Flight 447 crash in the Atlantic Ocean on June 1, 2009, serves to remind the AAIB of the inherent difficulties involved in any sea search for aircraft wreckage and flight recorders. A sea crash of a Singapore aircraft, especially in international waters faraway from Singapore, will present a tremendous challenge for Singapore's emergency responders and accident investigators. One would recall that Paragraph 5.3 of Annex 13 to the Convention on International Civil Aviation places the responsibility of investigation on the State of Registry if its aircraft has crashed at a location that cannot be definitely established as being in the territory of any State, e.g., international waters.

31 The challenge arose from a multitude of factors. Mobilisation of resources (including the right equipment commensurate with the water depth) can be costly. The sea bed terrain may not be conducive for a straightforward search. The starting point for a sea search may be difficult to determine if the point of impact cannot be established fairly accurately. Thus, success of the search is not necessarily guaranteed. Furthermore, there will be logistical difficulties when the sea crash site is far from the home base.

32 Soon after the AF 447 accident, the AAIB set up a task force in July 2009 to develop and enhance AAIB's sea search operational capabilities. The task force reviewed the way the AAIB would tackle a sea search endeavour. It considered three main aspects: coordination, resources availability, and training. The task force identified the relevant domestic agencies and organisations, the types of resource needed for sea search and recovery, as well as the training needs of investigators and availability of training opportunities.

33 The review identified the following approaches:

- To draw up a deployment plan that can readily be modified to suit the circumstances.

• To strengthen coordination with relevant domestic agencies and organisations to enhance cooperation in the use of their resources and personnel in times of need.
• To acquire all the necessary sea charts.
• To acquire the necessary search equipment (e.g., ULB detector, GPS, compass) and train investigators in their use.
• To enhance the proficiency of Airport Emergency Service's divers in the use of ULB detectors.
• To take part in realistic sea search exercises.

Sea search deployment plan

34 No two accidents are the same. It will be difficult to have a one-size-fits-all plan to address all situations. Nevertheless, a basic plan will at least provide a framework to deal with the dynamic situation and enable more detailed plans o be derived quickly to suit a specific critical situation.
35 At this stage, the AAIB envisages dispatching and deployment two teams to respond to a sea search situation: a search and recovery team (SRT) and an investigation support team (IST). Each team has its own specific roles and responsibilities.
36 The SRT will be at the crash site to direct and oversee the sea search activities such as devising search patterns, on-site coordination with salvage companies on recovery of wreckage from waters, etc. The SRT will be comprised of the AAIB representatives and their advisers (who may include technical specialists of the airline concerned, hydrographic experts, etc.), divers, sea search advisers from a foreign investigation agency, etc.
37 The IST will be in charge of a land-based operations command centre, and its main duties are to provide logistical support to the SRT, to coordinate with other agencies, and to arrange for wreckage storage, identification, and reconstruction. The IST will be comprised of the AAIB representatives and their advisers (who may include technical specialists of the airline concerned, search and rescue specialists, pathologists, etc).

Coordination with relevant domestic agencies and organisations

38 Effective coordination with relevant domestic agencies and organisations is an essential factor to the success of any emergency response operation that a state has to mount. Communications and prearranged arrangements between the AAIB and other agencies will ensure smooth execution of plans and harmonise the ways in which the various parties respond and operate.
39 The roles and actions by the parties responding to an emergency event in Singapore (which include government ministries and departments, aerodrome operator, etc.) are embodied in an Airport Emergency Plan (AEP). For the AEPs of the Changi Airport and Seletar Airport in Singapore, the AEP includes a chapter on accident investigation that serves as a multilateral agreement on how these parties shall support the AAIB.

40 From the Maritime and Port Authority of Singapore, one of the emergency responding parties, the AAIB obtained hydrographic charts that cover the Singapore territorial waters, which are relatively shallow. The charts provide basic information such as water depth and sea bed features.
41 Some of the resources needed for a search operation in the event of a crash in Singapore waters or international waters can be of a very specialised nature, e.g., towed pinger locator, trained divers, surveying sonar, etc. The AAIB has been identifying and establishing contacts with providers of salvage and hydrographic services. Through meetings with them, the AAIB now understands better the capabilities and resources of these service providers and has also had a chance to peruse in advance a typical salvage contract. The AAIB has also looked into where wreckage may be stored, and talked to hangar owners and tentage companies to see if they have suitable facilities that can accommodate aircraft wreckage and protect it from the elements.

Mobilisation exercise

42 It is important to find ways to validate the coordination plans that have been devised. The aerodrome operator in Singapore regularly organises aircraft crash response exercise to test the readiness of the various agencies and organisations involved and to identify shortcomings in the coordination procedures in the AEP. Typically a total of two to three exercises are held every year, one of which would correspond to a sea crash scenario.
43 Typically, 300-400 participants will be involved in such an exercise, which gives the AAIB investigators an opportunity to interact with the Airport Emergency Service, the police, and the aerodrome and airline representatives.
44 For future sea crash response exercises, the AAIB plans to expand on the portion of the exercise dealing with search and recovery of flight recorders. Recorders will be dropped into the sea and investigators and divers will have to fish them out. This will add realism to the exercise and let other exercise participants gain a real appreciation of the coordination and time required for such search and recovery activities.

Acquisition of charts

45 The AAIB wants to be able to, when it is informed of a crash of a Singapore aircraft in international waters, determine quickly which states are or will be involved in the search and rescue operation. For this purpose, the AAIB needs to have a data system that can provide at least some preliminary information. The data system is comprised of flight information region (FIR) charts, hydrographic charts, and a simple contacts database.

Resources deployed for crash exercise.

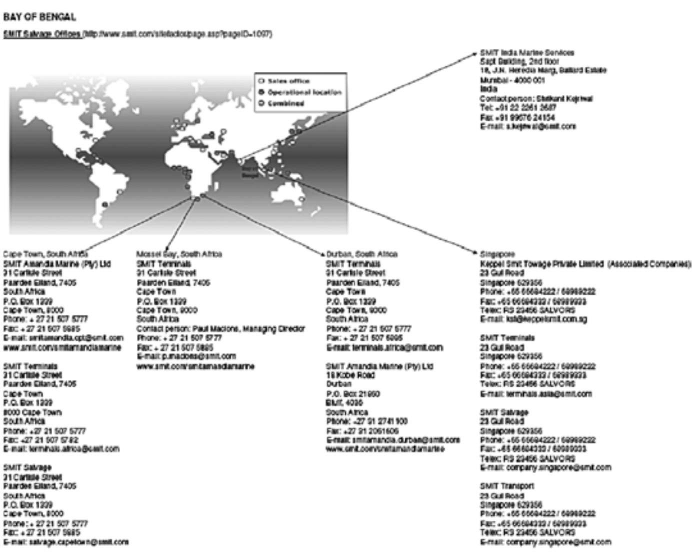
46 The FIR charts will be useful to the investigators to determine the search and rescue (SAR) authority with respect to the known or suspected crash location. These charts will also show the countries around the crash that may serve or as operational bases for the field investigation or for the search and recovery operations. The AAIB will contact the investigation authorities of these countries to solicit their support where necessary.
47 The hydrographic charts in respect of the crash area will provide maritime information of the area concerned and of the adjacent

coastal regions. The information may include the depth of the waters, tides and currents, seabed topography, etc. From the charts, investigators can quickly gain an idea of the terrain and depth of the sea crash area. Investigators can thus anticipate the types of search and recovery equipment that may be needed. This in turn will allow an estimation of the time needed for the search and recovery equipment to be mobilised and moved to the crash area.

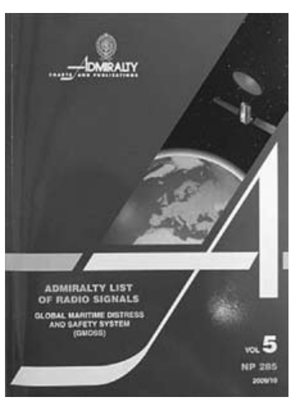
48 Hydrographic charts covering the entire world, in hardcopy or softcopy form, are available on a fee subscription basis. The cost can be quite substantial. The AAIB has opted for the alternative of obtaining from a local distributor of hydrographic charts an electronic catalogue of hydrographic charts available. The AAIB will select the charts needed for its search operation, and the local distributor can deliver to us the charts quickly. We will pay only for the charts thus ordered.

Hydrographic catalogue software containing worldwide hydrographic maps codes.

49 The contacts database is a simple one. The database aims to consolidate all the contact information with respect to SAR authorities[1], investigation agencies, Singapore's foreign missions, as well as the salvage companies (including information on their operational bases, capabilities and assets, and the location of the assets).



50 So far, data for the Bay of Bengal region have been organised. The AAIB will continue to expand the database to include data for the following regions, which together with the Bay of Bengal region should cover all the sea areas over which Singapore operators now fly:



The Global Maritime Distress and Safety System (GMDSS) publication.

- North Atlantic Ocean
- South China Sea (between Singapore and Taiwan)
- East China Sea (between Taiwan and Japan)
- North Pacific Ocean (between Japan and United States)
- Arabian Sea
- Indian Ocean (between Singapore and South Africa)
- Indian Ocean (between Singapore and Perth)
- Tasman Sea (between Australia and New Zealand)

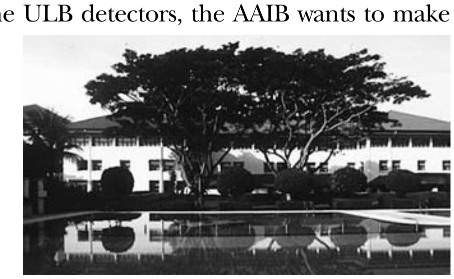
Acquisition of search equipment

51 The AAIB aims to own some basic equipment needed for search operation, if they are affordable, as part of its effort to enhance its investigation capability. This is so that while the AAIB waits for assistance from other agencies that have the equipment, it can at least launch some search effort. For example, while the Singapore Navy has ULB detectors, the AAIB acquired also two sets of ULB detectors. In addition, the AAIB acquired a ruggedised laptop that can be used at sea.

AAIB's handheld underwater acoustic locater.

Training AAIB investigators in the use of ULB detectors

52 Having acquired the ULB detectors, the AAIB wants to make sure that its investigators are proficient in using them. The AAIB organised training for its investigators at the training pool of the Singapore Aviation Academy (SAA). The training allowed the investigators to appreciate and understand the type of feedback and signals picked up by the ULB detectors.



SAA training pool.

53 Further training was also conducted at sea where an actual pinger beacon was dropped into the sea and the investigators were required to go search for the beacon by listening to the acoustic signals using ULB detectors.

Training of divers in the use of ULB detectors

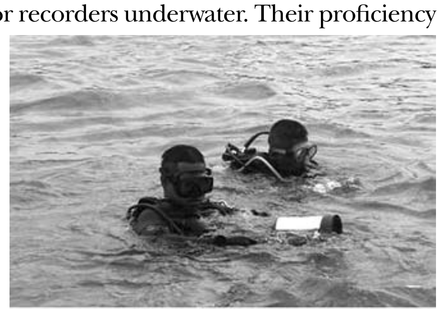
54 The AAIB investigators, who do not necessarily have diver qualifications, will search for pinger signals from the surface of the sea. At some stage, especially when a probable recorder location area has


AAIB investigators in training session.


Training session at sea with ULB and ruggedised PDA computer.


Familiarisation and practical training with the AES divers on the use of ULB detector.

been determined, it may be necessary to deploy divers underwater to try to locate the exact recorder location using ULB detectors.
55 The Changi Airport Emergency Service (AES) has divers among its ranks to carry out search and rescue tasks who can also support the AAIB in searching for recorders underwater. Their proficiency in the use of ULB detectors will of course be of importance to the AAIB. The AES divers are also eager to know more about the ULB detectors acquired by the AAIB. Thus, the AAIB organised training session with the AES divers to enable them to practise using the detectors. The divers provided valuable feedback on the practical problems encountered, such as the acoustic signal being received from all directions when they were very near the target pinger, strong current conditions, and the accidental adjustment of the frequency knob during the dive in low visibility.


Changi Airport Emergency Service divers in training.

56 Through the training session, the AAIB is able to understand the difficulties of locating the pinger in choppy sea conditions and the operational difficulties faced by divers in the use of handheld acoustic hydrophone to search for pinger signals underwater. Such training allows the AAIB to fine-tune its search procedures and explore other methods of listening for acoustic signal.

Improving search technology for recorders

57 The search difficulties in the case of the AF447 accident have raised questions about the adequacy of existing search technology for flight recorders installed on aircraft that crashed into deep water. Many of suggestions to improve the probability of a successful search for recorders have been surfaced, such as

- continuous or triggered air-ground transmission of data in the flight recorders.
- deployable recorders.
- extra lightweight recorders for installation in the vertical stabilizer.
- extension of the life of the battery on and the signal range of the ULB.

58 Another possible improvement in search technology is in the way the detection of signals using ULB detector and recording of coordinates/direction of the signals can be automated. Operating the acoustic hydrophone of the ULB detector is not as easy as it may seem. The hydrophone operator's task of listening for pinger signals is already made difficult by the many environmental factors. On top of this, he has to multitask, as he has to rotate the extension staff attached to the hydrophone, has to adjust the knob on the handheld receiver to increase/decrease the hydrophone's sensitivity, and also has to record the GPS location and bearing data when a signal is picked up. Therefore, it makes sense to automate the detection and recording of coordinates/direction of signals.
59 We understand that at least two investigation agencies are embarking on projects to use modern sound spectrum technology to help identify a valid 37.5 kHz signal. This will reduce the dependence on an investigator's listening skills, as visual monitoring of sound spectrum would appear to be easier. The hydrophone operator can then pay more attention to adjusting the orientation of the hydrophone, while keeping an eye on the spectrum display. When the spectrum suggests that there is a valid signal, then with possibly the click of a button by himself or by an assistant, the GPS location and signal bearing data can be recorded automatically. This will greatly increase the efficiency of the search process, and the hydrophone operator can work longer hours thanks to reduced workload.

Sea search exercises

60 Even with a decent operational sea search plan and with the acquisition of some basic equipment and the training of relevant personnel on the use of such equipment, the AAIB remains a strong believer of the need to gain practical experience in the mobilisation and organisation of a sea search and in the use of search and recovery equipment. The AAIB spares no opportunities to send its investigators to attend workshops and exercises on underwater search of recorders conducted by other investigation agencies in order to appreciate the tasks involved in a sea search operation. These workshops and exercises will enable its investigators to learn more about sea search and recovery of wreckage, and to tap others'

ECAC sea search exercise in Croatia in June 2009. From left: Recovering of wreckage from the sea, Croatian Navy divers preparing to go underwater.

expertise and experience. The AAIB is fortunate to have had the opportunities to take part recently in foreign sea search exercises in China, Croatia, and Taiwan.

61 In June 2009, the group of experts on accident investigation of the European Civil Aviation Conference (ECAC) organised a workshop on underwater recovery operations off the coast of Dubrovnik, Croatia, which included a sea search exercise. This is the first time that the AAIB had the opportunity to attend a very realistic underwater recovery exercise.

62 The AAIB participants were able to observe the deployment of the towed hydrophone array to detect the ULB signals. The towed hydrophone array (called a towed fish) belongs to the UK Air Accidents Investigation Branch and was transported all the way from the UK to Dubrovnik for the purpose of the workshop's exercise.

Towed hydrophone array (towed fish).

63 During a previous visit to the UK Air Accidents Investigation Branch, the AAIB had viewed pictures of the tow fish and reels of cables that could reach a depth of 300-500 metres (depending on the cable assembly configuration). So the ECAC exercise was an extremely valuable exposure for the AAIB participants to see for themselves how the tow fish and cables were actually used. They were able to witness firsthand how the tow fish and cables were deployed, how

The participants preparing the tow fish and the cables for deployment.

the search pattern was devised, how the search was monitored from a laptop display, how the search pattered was modified or adjusted in order to box up a probable location of the recorders.

64 In October 2009, the Office of Aviation Safety of the Civil Aviation Administration of China (CAAC) organised an air accident investigation simulation exercise. The exercise simulated the main phases of an air accident investigation such as initial notification of accident, appointment of investigator-in-charge, organisation of

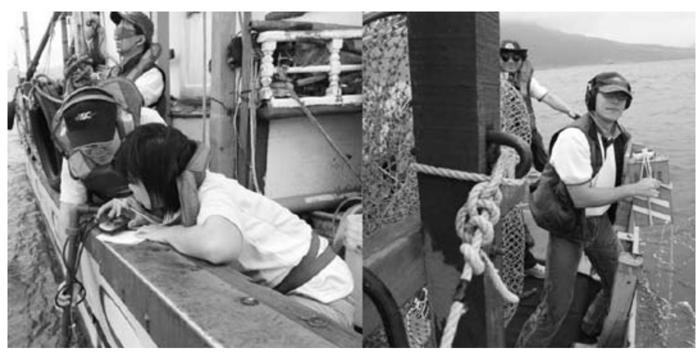
CAAC exercise in October 2009. From left: Attempting to locate the ULBs in a lake. AAIB investigators recording GPS positions for land exercise.

investigation team, crash site management, press conference, etc., and included a ULB search exercise in a lake.

65 The search exercise entailed finding the location of four ULBs that had been dropped into the lake. The AAIB investigators had the opportunity to practise their skills in rowing in inflatable dinghies and in listening for ULB signals. The AAIB investigators, together with other participants, also discussed and shared information on investigation equipment, ULB detection techniques and latest technologies.

66 In May 2010, the AAIB attended an underwater recovery for flight recorders exercise organised by the Taiwan Aviation Safety Council. The sea condition was rather rough, measuring six on the Beaufort scale, on the day of the exercise. The rough sea made the AAIB investigators appreciate the difficulties in performing a search operation. As the sea was rough, the engine of the boat had to be kept running in order to maintain course. Even with the engine running, the boat would still drift when hit by strong waves. The engine noise and the drifting made it very difficult to search for the pinger signals and obtain a precise bearing to the source of the signals.

67 The AAIB team experienced motion sickness after a while de-



Taiwan underwater search exercise in May 2010. From left: Listening for pinger signals and recording position information, retrieving flight recorder from the sea.

spite having taken some anti-motion sickness pills earlier. The motion sickness degraded human performance and thus affected the productivity of the search.

Attaching a rope to a part of the ULB detector.

68 Some of the lessons learnt from the exercises include

• To work out an initial plan beforehand and have a checklist to aid in planning a sea search. Although not all accidents are similar, the checklist will serve as a base line for the development of a better plan that would suit the situation.

- To plan for contingency funding and be prepared for a lengthy sea operation.
- To train investigators in ULB detection in different water conditions and environment (open sea, lake, swamp, salinity, etc.) as these can compound the difficulties for the pinger signal detection.
- To tie the hydrophone part of the ULB detector to a structure on the boat with a string. This will prevent losing the hydrophone in the event that the staff holding the hydrophone is broken by the strong sea current.
- To be prepared for motion sickness and not to drink or eat too much before going out to sea.

69 Some training in investigation techniques need not be done at sea. For example, investigators can hone their skills on land in the use of tools like GPS, compass with in-built clinometers, range finders, etc., before applying such skill in a real search endeavour.

Conclusion

70 Being a small investigation agency, the AAIB knows the difficulties that a small agency faces. With only limited resources, the AAIB may not be able to handle alone a major sea search operation for the flight recorders. Manpower and resources need to be roped in to ensure an efficient operation. Besides putting in place an intra-agency coordination and cooperation framework within Singapore, the AAIB will continue to learn from other air accident investigation agencies that have vast experience in underwater search and recovery of aircraft wreckage and flight recorders experience. The AAIB will tap their expertise and experience and enlist their specialists to assist us as advisers. In view of the possibly large expanse of sea area to be searched, more than a few ULB detection teams will be needed. The AAIB will invite additional teams from the Singapore Navy and other investigation agencies.

71 The experience from participating in others' underwater search and recovery exercises convinced the AAIB that besides devising a sea search deployment plan, it is important to gain as much practical experience as possible. The AAIB will continue to look for opportunities of practical training. A realistic sea search exercise can demand substantial planning efforts and resources. Nevertheless, the AAIB looks forward to more regional cooperation and interaction in sea search planning and operation, and perhaps also in the joint organisation of sea search exercises for flight recorders, so that investigation agencies in the region can help one another to enhance expertise and resources in sea search and underwater recovery efforts. ◆

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Endnote

1 A publication by the United Kingdom Hydrographic Office, titled "Global Maritime Distress and Safety System (GMDSS)," contains contacts for the SAR authorities.

Hazards at Aircraft Accident Sites: Training Investigators in Line with the ICAO *Circular 315 Guidelines*

By Nathalie Boston (Cranfield University), Graham Braithwaite (Cranfield University), and Sid Hawkins (AAIB)

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Sid Hawkins *photo and bio not available*

Abstract

ICAO Circular 315: Hazards at Aircraft Accident Sites (2008) provides guidance on the minimum standards of health and safety training to be provided to accident site responders and stipulates that recurrent training should be provided every 2 to 3 years. It builds on the training guidance of ICAO *Circular 298: Training Guidelines for Aircraft Accident Investigators* (2003) regarding training for accident site safety.

Developing a health and safety training course for accident responders in line with the guidance of ICAO *Circular 315* (2008) is a complex task, as the need for investigator protection must be balanced with the key investigation need to collect evidence. Training should be a mix of classroom-based education and practical onsite training using a simulated accident site, the benefits of which have been previously demonstrated. A simulation allows investigators to practice the skills needed to identify and mitigate site hazards while collecting evidence in a safe training environment.

This paper will outline the results of a pre-training survey of novice accident investigators that has shown that inexperienced investigators are more concerned with the risk posed by general health and safety hazards, such accident location and fire, and are less knowledgeable about potential aircraft-specific hazards such as composite materials and ballistic recovery systems. While general health and safety hazards may be encountered on aircraft accident sites more often than aircraft specific hazards, the knowledge of all hazards held by novice accident investigators or infrequent site responders needs to be extended. These results should be considered when developing training course and simulation content.

1. Background

Whilst the main focus of accident investigation is to prevent recurrence, investigators frequently finds themselves working on a site that can threaten their own welfare. There is no extensive list or long-running history of aircraft accident investigators becoming injured or ill on accident sites. However, there is concern that particular hazards on site may pose a problem to accident investigators and other site responders (e.g., ATSB, "Fibre composite aircraft-capability and safety" [2007]; FAA "First responder safety at small aircraft or helicopter accidents" online modules [2010]). Anecdotal evidence suggests that experienced investigators are identifying and managing hazards on site without consequence to either themselves or the evidence, but is this enough?

Several high-profile aircraft accidents highlight the variety of hazards that can exist. The 1992 El-Al B747F accident in Amsterdam became widely known for the suspected risk posed by depleted uranium on the site as well as the possible effects on the cargo. The 1999 Korean Airlines B-747F that crashed near Stansted Airport, UK, carried a mixed cargo that became potential hazards, including ammunition, carbon fibre fishing rods, explosive components for ejector seats, corrosive fluids and powder, and pharmaceutical products including radioactive isotopes. The impact formed a crater in the retaining wall of a man-made lake, which then had to be partially drained before site work could continue.

Accident sites will inevitably be attended by a wide range of first responders, from trained emergency responders such as aviation rescue and firefighting (ARFF), paramedics and police, to volunteers and airport/airline workers. Spectators are also common, especially if the accident is outside the airport perimeter. Whilst dedicated "on-airport" service personnel may well be trained to deal with aircraft specific hazards, their priority is to preserve life, which may well lead to a higher level of risk acceptance. For the emergency services that come from local municipal agencies or voluntary medical organisations such as St John's Ambulance and Red Cross, their specific knowledge of aircraft hazards will likely be less complete or less current. For airport / airline workers and other voluntary aiders, their knowledge is likely to be even less complete. As an industry, we pride ourselves on our excellent safety record. Inevitably, this can mean that experience dealing with "real" accidents can be somewhat limited.

As the rescue phase moves to recovery and investigation, so the players on site will change, along with the level of acceptable risk. Investigators will generally inherit a site where hazards have been evaluated in the context of life-saving and where the hazards will change over time, perhaps as wreckage is moved or weather conditions change. Taking "ownership" of an accident site brings responsibilities for themselves and the wide range of people who may need to access the site as part of the investigation effort.

In 1999, ICAO commissioned the Hazards at Accident Sites Study Group to "...compile a list of hazards peculiar to aircraft accident sites, develop relevant guidance materials and determine the associated training requirements for rescue personnel and accident investigators". The group was comprised of specialist health and safety professionals working within accident investigation organisations. The resulting work of this study group is ICAO *Circular 315: Hazards at Aircraft Accident Sites* (2008).

2. ICAO *Circular 315*

The intended purpose of ICAO *Circular 315* is "...to assist individuals to consider and apply effective occupational safety management practices both to their own activities and to the activities of the teams they work with or for which they are responsible." The circular specifies that "often, a balance must be struck between the requirements of the tasks and the need to make the performance of the task safe for the investigation and response personnel." Within the circular, an overview is provided of different types of hazards potentially present on site, and general risk management methods are discussed.

The Circular categorises onsite hazards into five overarching categories:

1. environmental hazards: accident location, fatigue, insects/wildlife, climate, security and political situation;
2. physical hazards: fire and flammable substances, stored energy components, pressurised gases, military and ex-military aircraft, recent safety equipment, pyrotechnics and explosives, and damaged and unstable structures;
3. biological hazards: general biological hazards and pathogens, and the local state of hygiene;
4. material hazards: metals and oxides, composite materials, chemicals and other substances; and
5. psychological hazards.

3. Historical perspective

Investigators have long been aware of the presence of hazards on site, but the exact nature of the hazards present, the extent of their presence on site, and the precise dangers that each hazard may pose to investigators collecting evidence is largely unknown.

One particular hazard that has been widely recognised on accident sites is blood-borne pathogens. Completion of blood-borne pathogen training prior to site entry is mandated in the USA by OSHA regulations, and some other nations also have similar requirements. The Canadian SASI blood-borne pathogen training programme is an example of how this particular area of hazards training can be tailored for aircraft accident investigator needs. However, the training guidelines in ICAO *Circular 315* suggest that the training for investigators is extended beyond simply considering blood-borne pathogens. Biological hazards are just one of the five categories of hazards identified within the Circular.

The hazards present on a modern accident site may be similar to the hazards that have always been present on a site, or they may be changing as the composition and operation of aircraft are changing. The number and types of people responding to a site may be limited through guidance and regulation, such as ICAO Annex 13 and the Australian Transport Safety Investigation Act 2003; but other than this, there is little chance for ensuring the competency of responders to the site.

Experienced investigators who have attended many sites may be able to immediately identify and assess potential hazards, and mitigate their consequences while still collecting all perishable and vulnerable evidence. In contrast, inexperienced accident investigators, or infrequent site responders, may not attend many sites, or a wide variety of non-comparable sites, and as a result their hazards identification and management skills may not be at the same level as that of the experienced investigators. This may result in inexperienced site responders becoming injured, or experienced site responders wasting time in supervising others on the site. With the decreasing accident rate, the number of sites to attend become fewer.

The best way to ensure safety and efficiency on the accident site, for all responders to the site, is to educate the responders in all aspects of investigation skills, including hazards identification and management. The form that this education and training takes is the focus of the research.

4. Heath and safety training of aircraft accident site responders

The health and safety training aims identified in ICAO *Circular 315* (2008) include

- "detailing the potential variable nature and scale of occupational health hazards experienced at aircraft accident sites;
- outlining any applicable State occupational health and safety legislation and its applicability to accident investigation activities undertaken by the state's aircraft accident investigators;
- providing an understanding of the occupational health risk management, risk assessment, and risk control processes associated with aircraft accident investigation operations;
- providing an understanding of the hazards and means of prevention of exposure to blood-borne pathogens that meet the requirements of state training standards;
- providing an awareness of the selection and use of personal protective equipment to meet the risks posed in aircraft accident investigation tasks; and
- providing an awareness of the effects and symptoms of psychological hazards associated with aircraft accident response activities."

The direct topics to be covered in a ICAO *Circular 315* compliant training course include "risk management, hazards associated with aircraft accident response, blood-borne pathogens, psychological reactions to aircraft accident response operations, site safety management, preservation of evidence, and protective clothing."

Training of accident investigators and other site responders may be completed internally within organisations, or through the use of external training providers. Training should specifically consider the job function that each individual will complete on a site so that the specific exposure they may have to particular hazards may be especially considered.

All investigators and responders coming to Cranfield complete 2 days of accident site hazards awareness training, whether part of an accident investigation course, or as a stand-alone Hazards and Evidence Awareness for Air Accident Responders course. Cranfield has trained a wide variety of site responders, including national accident investigators, airframe and engine manufacturers, operators, firefighters, and police. Delegates on the courses have a wide variety of experience on site and assist each other in understanding each group's (possibly competing) priorities and tasks to achieve on the site and the specialist knowledge that each organisation can provide to other responders around them.

Training is provided as a combination of classroom and practical teaching, using tabletop and site simulations, and practical experience in selecting and working in appropriate personal protective equipment.

Observations of delegates on the course suggest that, despite having just received classroom education on potential site hazards, many delegates rapidly forget everything they learn the instant they arrive on site, and the instinct to begin preserving and collecting evidence takes over. However, when the "initial excitement" has passed, investigators' appraisal of site hazards and appropriate mitigation measures or PPE selection, even if they have not previously attended an accident site, is conducted well. This suggests that a simple method of classroom-based hazards education can give investigators the information they need to conduct effective risk assessments.

What the course delegates do not do particularly well following classroom training only is using the PPE they have selected. When the procedures for putting on clean PPE and taking off contaminated PPE are only explained, the delegates performance of using this equipment on the simulated site is poor. Their actions are improved slightly having watched a practical demonstration, and are greatly improved when having practiced with the equipment themselves. One particular problem area is correctly wearing disposable dust respirators, which seems to create issues whether practiced before site entry or not.

When collecting evidence from the simulated aircraft accident site, investigators wearing PPE often comment on the additional stresses they feel. Standard evidence collection methods, such as photography and taking notes, may become harder than expected once in a high level of protective equipment, and potential problems with decontaminating used, non-disposable equipment such as cameras become apparent.

Wearing appropriate PPE through an exercise also gives investigators a better idea of how they may need to change levels of PPE throughout the day, whether to protect against the different hazards in different areas of site, as they take breaks, or as they encounter climate changes. Practicing with different levels of equipment, whether on a simulated site or within their own daily work environment, will allow the responders to become used to wearing the equipment, so that the evidence collection, rather than the equipment, can become the focus when attending a real accident site. This practice should include wearing single-use equipment, not just reusable equipment.

At the end of the course, each delegate is provided with a card stating their completion of hazards training (including compliance with OSHA blood-borne pathogen regulations). This card is valid for a 2-year period, which is within the standards suggested in *Circular 315*.

Circular 315 also recommends that training be conducted by "trainers who are knowledgeable and experienced in their subject as it applied to accident site operations." There needs to be awareness of a potential risk of bias toward teaching about particular hazards; training should give a balanced view of all potential current and emerging site hazards. The trainer should ideally be a safety professional with a wide knowledge of hazards, health, and safety management and accident investigation techniques.

5. Novice accident investigator perception of site hazards versus experienced accident investigators recognition of site hazards

The research considered two aspects of the awareness of hazards on aircraft accident sites: the novice investigator's perception of what hazards posed a risk on a site and the expert accident investigator's identification of hazards on sites they had attended.

One hundred and twenty one accident investigators attending basic accident investigation courses (as defined by ICAO *Circular 298* [2003]) at Cranfield University were asked to identify the five hazards they thought posed the most risk on an accident site. The survey was conducted prior to any other hazards training having taken place. The hazards identified by these investigators were categorised according to the hazard categories and sub-categories identified in ICAO *Circular 315* (2008). There were 20 categories in total used for analysis (see Section 2). The hazards identified by experienced investigators from a national aircraft accident investigation agency on accident and incident sites over a 6-year period were categorised in the same way.

The novice accident investigators identified

- damaged and unstable structures,
- biological hazards,
- fire and flammable substances,
- accident location, and
- chemicals and other substances

as the five hazards they perceived to pose most risk on aircraft accident sites.

Of the other 15 hazards categories, the group showed little knowledge regarding the hazards posed by stored energy components, fatigue, security, metals and oxides, recent safety equipment (such as ballistic recovery systems, etc.), local state of hygiene, and military and ex-military aircraft. Of the total 604 hazards identified during the survey of novice investigators, each of these categories was identified fewer than 10 times.

The indication from these results is that novice aircraft accident investigators are well aware of general health and safety hazards that would affect a person in any workplace, but they are not as aware of the aircraft-specific hazards that may occur on an accident site.

Experienced aircraft accident investigators identified

- aircraft location,
- biological hazards,
- damaged and unstable structures,
- composite materials, and
- fire and flammable substances

as the five most common hazards identified on sites.

Experienced accident investigators did not report encountering many examples of hazards posed by pressurised gases and explosives, radioactive hazard, cargo, psychological hazards, recent safety equipment, or the local state of hygiene.

6. Implication of these results on training course design

Although given in a different order, four of the five hazards that novice investigators perceive as most risky on site (aircraft location, damaged and unstable structures, biological hazards, and fire and flammable substances) are the ones experienced investigators identify most commonly on a site.

Novice accident investigators included risks from chemicals and other substances within their five perceived highest risk hazards, where experienced investigators identified it as only the seventh most commonly found on sites. Hazards associated with composite materials were reported by experienced investigators as the fourth most common hazard, but only seventh by the novice accident investigators.

The risk arising from cargo is identified by novices as quite high, but identified by experienced investigators infrequently. Conversely, novice investigators did not identify any risk associated with military and ex-military aircraft, whereas experienced investigators identified this in equal 11th ranking out of 20 hazards categories. The hazards posed by metals and oxides are listed by experienced investigators as the 8 most common hazard, while novice investigators responses rank these hazards as 15th most hazardous.

The hazards included as recent safety equipment and local state of hygiene are not recognised as greatly significant by either novice or experienced accident investigators.

By identifying the hazards that novice accident investigators are aware of, and perceive as a risk on an accident site, we can gather better knowledge about the general hazard identification skills that investigators have, and what hazards would be identified without further training. This can be used to optimise training time during the classroom education phase.

Within each of the categories, the hazards identified by novice investigators were quite general, where the hazards identified by experienced investigators were quite specific. It is suggested that training be tailored to include details about specific hazards within each of the categories that would provide better awareness of the range of hazards that may be encountered.

7. Conclusions

The results of this research suggest that to optimise the time and efficiency of an ICAO *Circular 315* compliant training course, five particular factors should be considered:

- After an overview of the general health and safety concerns from a site, a focus should be placed on reviewing aircraft-specific hazards. These will be the hazards that infrequent or inexperienced accident investigators are unaware of and could potentially catch them unaware on a site.
- Hazard management and mitigation measures should be trialed while completing simulated evidence collection tasks (or other tasks conducted by particular responders to the site). This will give site responders an opportunity to become familiar with some of the equipment they may use and identify any problems they may have completing their job on a site.
- How the threats on a site may change, with aircraft type, operation, location, etc. The particular threats should be considered for different areas, tailoring the information to the needs of particular responders. Also potential theoretical hazards should be considered, even if they have not necessarily been documented as having occurred on any accident sites yet.
- Broaden the range of those responders being trained to identify and manage hazards on the accident site. Experienced investigators do not need to spend their time on sites teaching novice investigators about hazards and supervising them on site. There is benefit in training other potential responders, possibly including emergency services, volunteer support organisations, as knowledgeable first responders may then be preserve perishable evidence earlier than investigators can get to it, without damaging other evidence on the site, or placing themselves in unnecessary danger.
- Finally, also give some consideration to the hazards that exist away from the accident site, both while conducting the accident (such as fatigue, personal security, and travel arrangements) and when analysing evidence away from the site.

Hazards are an inevitable part of every accident site, but they can be managed and all available evidence collected. With thorough consideration of the training aims of ICAO Circular 315 (2008) and capturing the hazards identification and management skills and knowledge of experienced accident investigators, novice site responders can be trained to successfully manage hazards from the first time on site. ◆

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Mental Health Aspects of Aircraft Accident Investigation: Protecting the Investigator

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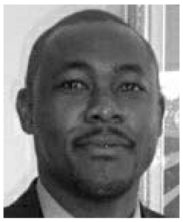

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Introduction and historical background

The crash site possesses many challenges for air safety investigators. The site must be surveyed to determine the degree of hazard, and entry/exit points must be established. Some of these challenges include, but are not limited to, hazardous materials, composite materials, serrated edged metals, environmental hazards, wild life, blood-borne pathogens, parachute systems, and aviation fluids (Wood and Sweginnis, 1995). Among these challenges, one has received very little attention, and that is the mental health and resiliency of the air accident investigator. Ussery and Waters, 2006 noted that mental health and resilience are proven tools for survival.

Aircraft accident investigators generally arrive at the scene of an accident after the emergency services personnel. However, there are instances where the investigators are exposed to the chaotic, traumatic, and emotional situations at the scene of accidents. While exposure to extreme psychological stressors does not always bring about negative reactions in aircraft accident investigators, there is empirical evidence that the exposure to these critical events does pose a challenge. Understanding the cases in which the investigators allow an event to become a traumatic stressor is important for diagnosis and to provide timely mitigation measures (Coarsey-Rader and Rockwood, 1993).

Medical author Dryden-Edwards (2004) described acute stress disorder as the anxiety and behavioral disturbances that develop within a month of exposure to extreme trauma. The symptoms of an acute stress disorder usually begin during or shortly following the trauma. Such extreme traumatic events include rape or other severe physical assault, near-death experiences in accidents, witnessing a murder, and combat. If the symptoms and behavioral disturbances of the acute stress disorder persist for more than a month, and if these features are associated with functional impairment or significant distress to the sufferer, the diagnosis is changed to post-traumatic stress disorder (PTSD).

In 1994, the American Psychiatric Association (APA) published a table of common symptoms of psychological trauma and post-traumatic stress disorder. This table described post-traumatic stress disorder as an emotional illness that develops as a result of a terribly frightening, life-threatening, traumatic, catastrophic life experience or otherwise highly unsafe experience. Individuals affected by post-traumatic stress disorder re-experience the traumatic event or events in some way and are likely to practice avoidance. This occurs when the individual tends to avoid places, people, or other things that remind them of the event. Sufferers may also experience hyper-arousal, a state of being highly sensitive to normal life experiences. Some may experience intrusive recollections of the event via flashbacks, dreams, or recurrent thoughts or visual images. Research suggests the circumstances of why some people develop post-traumatic stress disorder, while others are more resilient and able to cope and move on, is complicated and poorly understood.

Recently, the awareness of the psychological impacts of traumatic and critical events has increased and post-traumatic treatments have received considerable attention. This attention has brought greater interests in the events that are likely to lead to post-traumatic stress symptoms. Empirical evidence has found that post-traumatic stress symptoms may develop after a single exposure to a critical event. Coarsey-Rader (1995) posited that clinical procedures have been developed primarily for assisting first responders, military personnel and public safety employees, i.e., police, emergency management technicians (EMT), and firefighters with symptoms of acute distress. However, there is currently no specific program developed for intervention and prevention of distress experienced by aircraft accident investigators (Coarsey-Rader, 1995).

Purpose of research

The purpose of this research was to assess the traumatic effects of aircraft accidents on aircraft accident investigators. This has received very little attention since the primitive days of early aviation enthusiast and the Wright Brothers. Additionally, Coarsey-Rader (1995) found that there was no specific program developed to address the distress experienced by aircraft accident investigators. Ursano and McCarroll (1990), Raphael (1986), and Coarsey-Rader (1995) highlighted that aviation accidents are sometimes fatal and that aircraft accident investigators often experience graphic exposure to severe injuries, mutilated bodies, mass destruction, and the stench of burnt flesh.

This research examined the feasibility of an annual mental conditioning program for personnel involved in aircraft accident investigation. A methodical program may provide educational awareness topics that include (1) improving coping skills; (2) expectations at an accident site; (3) common stress related symptoms (disturbed sleep, headaches, fear, decreased appetite and anxiety); (4) changes in routine to avoid fatigue; (5) importance of teamwork, social and family life (Bilal et al., 2007); (6) importance of seeking assistance; (7) effective communication; and (8) understanding acute stress and post-traumatic stress disorder, and the risk factors and prevalence following exposure to trauma (Smith, Tremethick, and Clocklin, 2005). Strengthening the initial defense of the investigators may reduce the effects of exposure and stress.

Brief review of relevant literature

Post-traumatic stress disorder is not the only pathological outcome following traumatic events. Ursano, McCaughey, and Fullerton (1994), and Weisaeth (1994) posited that psychological responses to traumatic events vary depending on the types of disasters and victims. Birmes, Arrieu, Payen, Warner, and Schmitt (1999) suggested that persons who experience a major disaster and concomitant acute stress reactions are at an elevated risk for the subsequent development of post-traumatic stress disorder. Smith, North, McCool, and Shea (1990) reported that over half of the primary victims developed a psychiatric disorder within 4 to 6 weeks as a result of a jet crashing into a hotel. Chung, Easthope, Eaton, and McHugh (1999), and Taylor and Frazer (1982) noted that among secondary victims involved in the Mount Erebus air crash in 1981, one third experienced transient problems initially. One-fifth experienced transient problems after three months. Lopez, Piffaut, and Seguin (1992) indicated that a history of trauma may itself be a risk factor for depression.

Research from the International Critical Incident Stress Foundation (ICISF) indicated that more than 90% of individuals involved in a traumatic event would develop some type of adverse psychological effect. Kessler, Sonnega, Bromet, Hughes, and Nelson (1995) estimated that PTSD occurs in around 14% of those exposed to traumatic events. Raphael (1986) estimated that 30-40% of those who experienced a significant stressful event would go on to develop a significantly distressing reaction by one year post-impact. Bisson, Brayne, Ochberg, and Everly (2007) indicated PTSD rates tended to be higher among individuals more directly exposed to traumatic events. However, they also indicated that recent research suggested lower rates of problematic reactions than imagined as a result of marked human resilience in the wake of traumatic events.

Bledsoe (2003) posited that in general, through years of training and experience, mental health professionals learn to isolate their feelings and emotions from their professional work. However, it would be a difficult request to ask volunteers and non-mental health professionals not to become emotionally involved. Notwithstanding this consensus, empirical evidence has shown that on-scene traumatic stressors have indicated significant psychological distress among air accident investigators. Bilal, Rana, Rahim, and Ali (2007) indicated that denial of the impact of work on their well being and functioning may serve well until it fails. Then they must face up to their vulnerability. Coarsey-Rader and Rockwood (1993) found that more than 50% of accident investigators consistently ranked fatal accidents as producing above-average stress. In accidents where children are injured or fatally wounded, Cotter (2004) found that 70% of the respondents reported above average stress 50% reported being very stressed, and 20% reported these accidents as excessively stressful. Cotter (2004) attributed the above-average stress to identification with the victims, as many of the investigators were parents. On the other hand, in accidents where the investigators knew the deceased or injured crewmembers, Cotter (2004) found 62% of the respondents reported above-average stress, 40% reported the accidents being very stressful, and 22% reported the accidents as excessively stressful. These results were attributed to the investigators associating the similarities between their own lives and that of the victims.

Barboza (2005) highlighted that many people experience acute stress-related symptoms in the wake of traumatic events. However, only a few will develop acute stress disorder (ASD), post-traumatic stress disorder (PTSD), or both. Milano (2005) estimated that productivity typically decreases by 80% for 2 weeks after a crisis. Of the affected individuals, 8% required additional ongoing care. In cases where personnel may experience harmful or negative effects from exposure to traumatic and other critical events, structured and individualized professional clinical treatment should be administered.

Critical incident stress debriefing (CISD)

Jeffery T. Mitchell developed the critical incident stress-debriefing (CISD) model during the late 1970s to assist emergency responders to quickly recover from a traumatic incident. Cigrang, Pace, and Yasuhara (1995) indicated that this model has also been used as a preventative mental health intervention in the aftermath of aviation disasters. This model, referred to as the "Mitchell Model," is a formalized seven-phased group discussion pertaining to critical incident, disaster, or traumatic experience. The seven phases include Introduction, Fact finding, Thought, Reaction, Symptom, Teaching, and Reentry.

Post action staff support (PASS)

The post action staff support (PASS) is a variation of the critical incident stress-debriefing model and consists of three phases. Review, Response, and Remind/Review phases are described as combining the Introduction/Fact/Thought phases of the regular CISD. In the Review, phase the questions are designed to have members think about and discuss the critical incident stress management activities and their participation. The Response phase is described as combining the Reaction/Symptom phase of the regular CISD and works to elicit comments on the perception of the team members and any concerns they may have about their performance. The Remind phase correlates to the Teaching/Reentry phase of the International Critical Incident Stress Foundation (ICISF) model. This PASS model is used as an activity for team maintenance that can minimize the effect of the disaster experience on individuals within a team (Potter, n.d.).

Resiliency management (RM)

An alternative method of handling the element of post-traumatic stress is resiliency management (RM). It is similar to CISD with the exception of the elimination of the traditional debriefing components where the individuals relive graphic details. This is replaced with approaches designed to encourage natural recovery mechanisms and relationships of support. The evidence-based method that is employed provides practitioners with defensible, ethical, and effective post-crisis intervention services (Blythe and Slawinski, 2004).

Critical incident stress management (CISM)

Critical incident stress management (CISM) is another short-term method that is designed to reduce trauma symptoms and has been utilized in a number of first responder organizations such as police departments, fire departments, and hospitals. CISM is an integrated comprehensive, multi-component crisis intervention approach to critical incidents (Everly and Mitchell, 1996). Its purpose is to stabilize and mitigate acute psychological distress and to also prevent or mitigate any potentially adverse post traumatic symptoms associated with acute stress disorder (ASD), PTSD, and other manifestations of acute human crisis (Flannery, 1999). Some airlines have also adopted the critical incident stress program into their organizations. This is to educate members about critical incident stress and to help prevent the onset of PTSD among pilots and crewmembers following a critical incident or accident (Tompkins, 1997).

Crisis counseling (CC)

Crisis counseling (CC)is referred to as a continuum of individual and group interventions, designed to meet specific needs of people experiencing different levels of impact (Milano, 2005). The National Mental Health Information Center (NMHIC) has defined the crisis counseling program as an initiative that supports short-term interventions with individuals and groups experiencing psychological stress to large-scale disasters. These interventions involve the counseling goals of assisting disaster survivors in understanding their current situation, reactions, and assisting survivors in reviewing their options. It provides emotional support and encourages linkages with other individuals and agencies that may help survivors recover to their pre-disaster level of functioning (FEMA, 1993, p. 9).

Psychological first aid (PFA)

Psychological first aid (PFA) consists of a systematic set of helping actions aimed at initial post-trauma distress and supporting short-and long-term adaptive functioning. Designed as an initial component of a comprehensive disaster/trauma response, PFA is constructed around eight core actions: contact and engagement, safety and comfort, stabilization, information gathering, practical assistance, connection with social supports, information on coping support, and linkage with collaborative services (Ruzek et al., 2007).

Research design

Contact was made via e-mail with several industry professionals with a background in aircraft accident investigation, psychology, or mental health counseling. Invaluable information was obtained from the following professionals who were instrumental to the success of this research. The air safety investigators included Troy Jackson, senior air safety investigator of the Transport Safety Institute; Mary Cotter of the Ireland Aircraft Accident Investigation Branch; Professor Graham Braithwaite, Ph.D., Cranfield University; and Professor Frank Taylor now retired, formerly of the Cranfield University. The industry mental health counselor was Professor Amy Bradshaw, Ph.D., of Embry-Riddle Aeronautical University. The psychologists included Brenda Tillman, Ph.D., and Tania Glen, Ph.D., of the Readiness Group International LLC, and Carolyn V. Coarsey, Ph.D., of the Higher Resources, Inc.

This research examined the primary clinical treatment options that are applicable to individuals exposed to critical events and trauma during the discourse of their duties. A survey was created and utilized as the primary research instrument. The refined instrument contained 13 items. It was disseminated via electronic mail utilizing the daily flight safety information services of Curt Lewis and Associates LLC. The instrument was also administered to the delegates attending the ISASI 2009 seminar in Orlando, Fla. The survey questions were categorized into two distinct formats. The first category collected demographics such as gender, marital status, and employment affiliation. There were some closed-ended questions that required a "yes" or "no" response. The second category collected Likert Scale data based on the attitudes, opinions, and actual experience or behavioral responses of the investigators pre/post accident. Some questions also obtained information about coping skills, as well as social support following investigations.

The survey consisted of 233 participants (n = 233) that were contacted through the Curt Lewis and Associates flight safety mail list serve, and attendees of the ISASI 2009 seminar. The number of participants, their experience, and the number of exposures to critical events represented a broad spectrum of the aircraft accident investigation population.

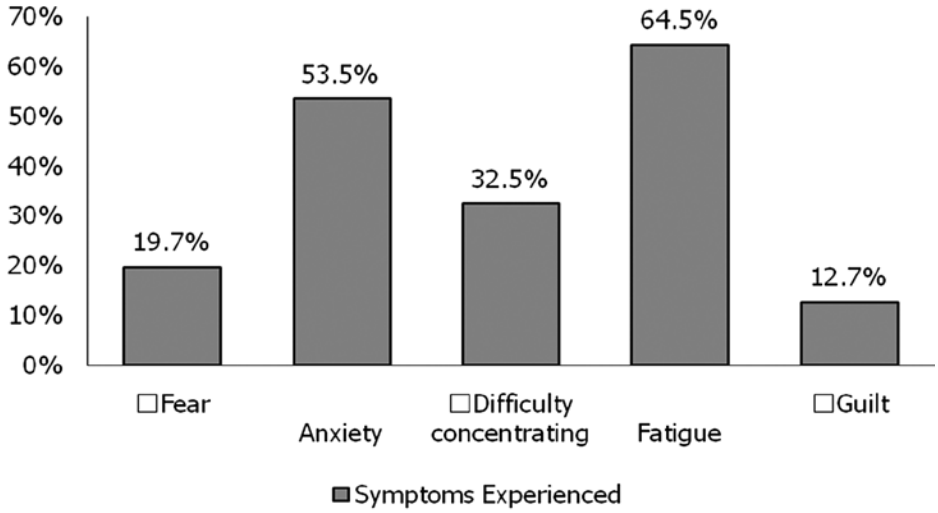

Figure 1. Symptoms experienced by participants.

Discussion of results

There was sufficient evidence in medical and psychological journals to demonstrate that a strong relationship exists between stressful life events and the emergence of a broad range of physical and mental health disorders (Ussery and Waters, 2006). Likewise, aircraft accident investigation is inherently psychologically stressful. The effects of unresolved stressors were manifested in a variety of symptoms expressed by the participants. This study was conducted with a sample of 233 participants of which 97.9% returned completed surveys and 2.1% returned incomplete surveys. Of the 228 completed surveys, 10.1% were females and 89.9% were males. These participants submitted responses to a 13-question survey instrument.

The results of the analysis indicated that the level of experience of the participants did not preclude them from the ill effects of exposure to trauma. The symptoms of anxiety, difficulty concentrating, fatigue, and multiple symptoms of anxiety/fatigue were reported in every experience category. Additionally, there were participants who reported experiencing all four symptoms simultaneously, in four of the five experience categories. The group with 15-19 years' experience was the only exception.

Fatigue, anxiety, and difficulty concentrating were the dominant symptoms manifested in the participants. The analysis revealed that 64.5% were fatigued, 53.5% experienced anxiety, and 32.5% experienced a difficulty concentrating. Among the other symptoms, 19.7% experienced fear, and 12.7% experienced guilt. (See Figure 1.)

Flannery (1999) also noted that individuals have a tendency to feel that asking for support is a sign of weakness and results in that person ignoring the side effects, which may have irreversible effects. This behavior may have contributed to the extent of the symptoms experienced among the participants. The results show that 31.6% confided in a colleague or sought professional assistance while 68.4% of the participants did not. One respondent indicated that other problems existed that contribute to the high percentage of individuals who did not find it convenient to confide in a colleague.

In response to a question dealing with voluntarily seeking assistance, 16.4% stated that they were very unlikely to voluntarily seek assistance, while 19.15% of the participants reported that they were unlikely to do so. On the other hand, 32% were likely to voluntarily seek assistance while 13.8% were very likely to do so. There were 18.7% who were undecided to seek voluntary assistance. These results indicate that there is significant resistance among the air safety investigators to voluntarily seek assistance even after experiencing the ill effects.

Of those who sought assistance, 50% did so within 1-3 weeks after the event, 27.8% did so between 1-6 months and 5.6% did so between 7-12 months post impact. There were 12.5% who reported seeking assistance one-year post impact. This indicates that some individuals may have been hesitant in seeking assistance while the distress remained persistent, problematic, or a limiting factor in the individual's performance. Others may have ignored the side effects and relied on their natural resilience before being overwhelmed by the psychological distress.

In response to a question on how the exposure to trauma affected the way the safety investigators related to their families, the options available were fear, anger, eating, caring, a change in routine and other symptoms. Participants were also given an opportunity to provide a brief explanation. Some participants expressed other symptoms that included the following: difficulty sleeping or sleeping disorders, reduced patience with others, valued time with others more, compartmentalization, depression, withdrawal, and lack of interest from fatigue. (See Figure 2.)

One participant reported, "Fear of death of family members or myself." Another participant reported that they "lost interest in committed relationships," while another reported that "no effect that I noticed. Perhaps you should also ask partners!" This was an important statement as 78.1% of the participants were married, 12.3% were single, 0.9% was engaged, and 2.6% were separated while 5.7% were divorced. Only one individual mentioned that the job might have been a contributory factor in their divorce. This

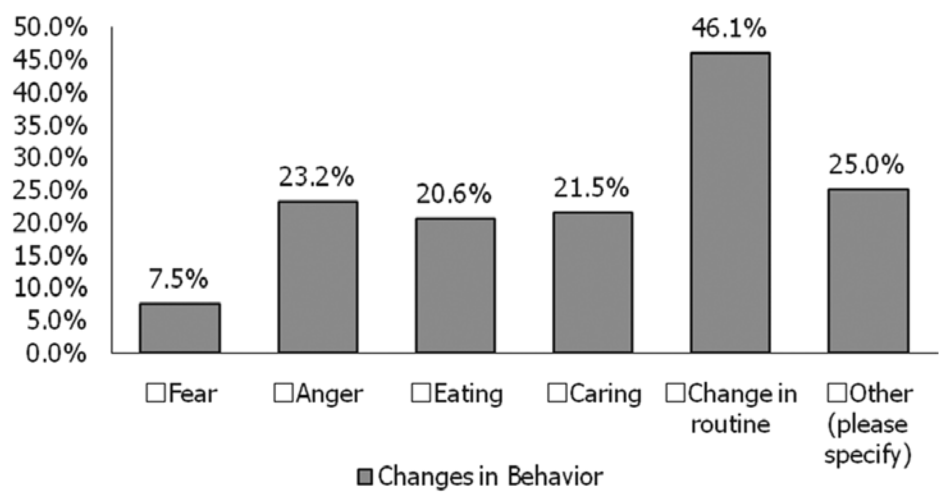

Figure 2. How participants related to their family post exposure.

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creates an avenue for additional research among the spouses or partners of air safety investigators to determine the ill effects of trauma in relationships.

There were individuals who struggled with activities they previously enjoyed. One individual expressed, "When I fly with my husband, I have difficulties with fear and anxiety due to the fact that accidents that I have investigated have been couples. At first I had eating problems, but those have gone away." There were several who reported, "Seeing the death of a parent and child strengthened my appreciation of my own life and family." Another individual stated, "Appreciation increased when the dust settled."

There was one who commented, "I am involved in accident investigation via critical incident response, the caring of the well-being of fellow crewmembers and accident investigators." There was another who reported that they encountered problems with eating when they reported, "No barbeques after dealing with burnt persons for awhile." This confirms the association of barbeque meats with the stench and sight of the burnt flesh at accident sites. One individual expressed, "Constant deployments of course take their toll.... I might say I have a constant wall up, but I rather just say I am used to getting shot at." There was one who reported, "It caused me to get extreme-chronic PTSD." While another expressed that "I wanted to quit my job!"

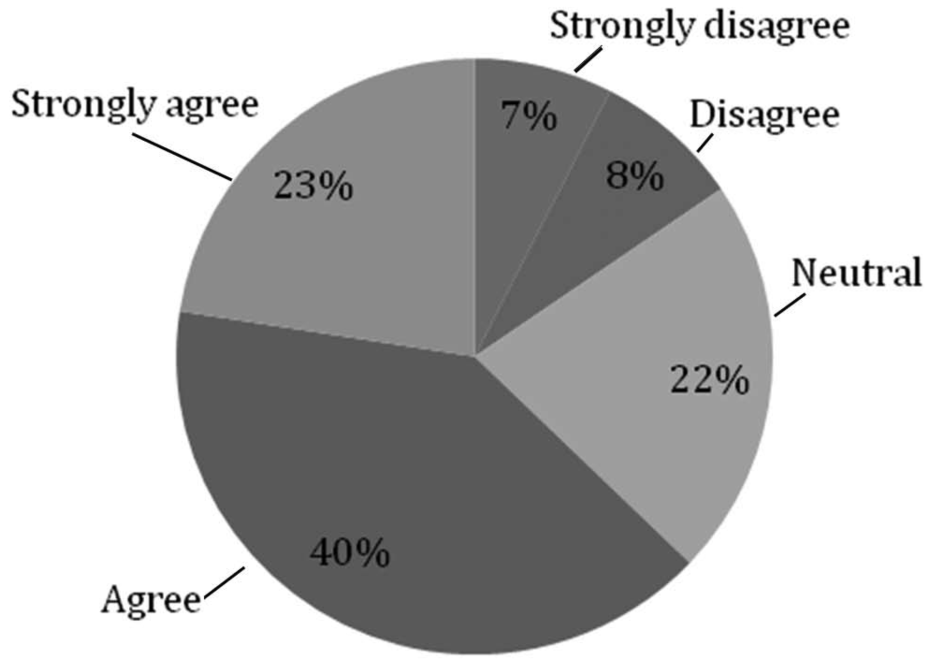

Figure 3. Likert Scale response to annual training program.

Some organizations have taken the initiative and have provided some form of pre/post accident stress/critical incident training for the air safety investigators. The results indicated that 3.6% provided "pre" accident training, 16.1% provided "post" accident, while 42% provided both pre/post accident training. The results also revealed 38.4% provided neither "pre" nor "post" accident training. These training programs must be evaluated for their effectiveness at providing conditioning or being capable of mitigating the ill effects of secondary trauma. Once proven adequate, these training programs should be continued and implemented across all air accident investigation units. One participant underscored budgetary constraints why pre/post accident stress training may not be offered at some organizations.

In the area of mandatory annual critical incident training programs, the responses showed that 40% agreed and 23% strongly agreed. On the other hand, 22% remained neutral, 7% strongly disagreed, and 8% disagreed. (See Figure 3.)

Conclusions

The purpose of this study was to take a deeper look into the mental health aspects of air safety investigation in an effort to ultimately better protect investigators. This research found that aircraft accident investigation is inherently psychologically stressful with fatigue, anxiety, and difficulty concentrating being rampant symptoms. Some individuals were hesitant in seeking assistance while the distress remained persistent, problematic, or a limiting factor in the individual's performance. Others ignored the side effects and relied on their natural resilience before being overwhelmed by psychological distresses. Others were forced into different programs by spouses and close friends who recognized differences in behaviors of affected individuals. This confirmed that there is significant resistance among the ASI population to voluntarily seek assistance even after experiencing the ill effects.

A comparison of the level of experience and the number of exposures did not preclude an ASI from the ill effects of exposure to trauma. Symptoms such as anxiety, difficulty concentrating, fatigue, and multiple symptoms anxiety/fatigue were reported in every experience category. Additionally, in four of the five experience categories, there were participants who reported experiencing all four symptoms simultaneously. The 15-19 years' experience category was the only exception. Some organizations have taken the initiative and have provided some form of pre/post accident stress/critical incident training for air safety investigators. The results revealed 42% provided both pre/post accident training while 38.4% provided neither "pre" nor "post" accident training.

This research concluded that regardless of the level of experience or the number of exposures to critical events, secondary trauma is harmful to ASIs. Concerns for the emotional and psychological health of these individuals should be given priority to mitigate or correct the ill effects. Strengthening the initial defense of the investigators may reduce the effects of exposure and acute stress.

Recommendations

This research was conducted to increase the awareness of the ill effects attributed to the exposure to trauma on air safety investigators. It was determined that there is a correlation between psychological distress among air safety investigators and exposure to traumatic events. In an effort to mitigate the ill effects of exposure to these events, and to encourage remedial action by the affected individuals and organizations on a whole, the following recommendations are proposed:

- Universities and other educational institutions preparing individuals for aircraft accident investigative techniques should incorporate mental health aspects and coping skills as subjects in their course content. This would promote mental conditioning, focus, and endurance during the execution of their duties.

• Build resiliency in current and future air safety investigators by helping them to master stress, build vitality, engage in emotion and focus of the mind through continuous education, training, good practices, and modifications in workplace culture.

• Air safety investigators should be encouraged to monitor their stress levels prior to, during and post accidents. In addition, ASIs should be encouraged to seek the appropriate care in a timely manner to minimize the ill effects.

• There were 178 married participants in this study. A follow-up study should be conducted among the spouses of the air safety investigators to determine the impact of the secondary trauma in their relationships. This could be accomplished by implementing a program for the spouses of air safety investigators to share information concerning the stress-related issues experienced and the mitigation measures that were applicable.

• Annual critical incident training program similar to the annual blood-borne pathogens training should be developed to provide standard mental conditioning for air safety investigators. ◆

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Investigating Accidents Related to Errors of Aeronautical Decision-Making in Flight Operations

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Yueh-Ling Hsu *is a professor in the Department of Air Transportation, Kainan University, Taiwan. (Photo not available.)*
Thomas Wang *is the acting managing director and head of the Flight Safety Division, Aviation Safety Council, Taiwan. (Photo not available.)*

Abstract
Aeronautical decision-making (ADM) is defined by the FAA (1991) as "a systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances." When faced with a problem requiring a decision, if a pilot recognizes there is sufficient time for making wide-ranging considerations, her or she will evaluate the dominant response option by conducting a mental simulation to see if it is likely to work. Jensen and Benel (1977) found that decision errors contributed to 35% of all nonfatal and 52% of all fatal general aviation accidents in the United States. Furthermore, Diehl (1991) proposed that decision errors contributed to 56% of airline accidents and 53% of military accidents. This research analyzes 51 accident reports obtained from ROC Aviation Safety Council (ASC) published between 1999 and 2008. Each accident report was independently analyzed using the Human Factors Analysis and Classification System (HFACS) framework (Wiegmann and Shappell, 2003). The presence or the absence of each HFACS category was evaluated from the narrative of each accident report. Where there were discrepancies in the categorization of an accident, the raters convened and resolved their observations. Statistical relationships linking fallible decisions in upper management levels were found to directly affect supervisory practices, thereby creating the psychological preconditions for unsafe acts and hence indirectly impairing the performance of pilots' decision-making, ultimately leading to 68% of accidents. The results show clearly defined, statistically described paths that decision errors at Level-1 with inadequacies at both the immediately adjacent and also higher levels in the organization. This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher managerial levels in the operation of commercial aircraft result in decision errors on the flight deck and subsequent accidents. To reduce the accident rate regarding decision errors in flight operations these "paths to failure" relating to these organizational and human factors must be addressed.

Keywords: Accident Prevention, Aeronautical Decision-Making, Human Errors, Human Factors Analysis and Classification System

Introduction
Flying a high-technology aircraft is not only an issue of skilled psychomotor performance but also real-time decision-making involving situation awareness, choice amongst alternatives and assessment of risk within a limited-time frame (Endsley, 1993 and 1997; Prince and Salas, 1993). Pilots must perform a wide array of tasks in addition to getting the aircraft from one point to another. As a result, pilots must learn to make decisions and develop judgment related to mission performance in addition to those decisions related to flying the aircraft. Aeronautical decision-making (ADM) has traditionally been viewed as an intrinsic quality or as a by-product of flying experience (Buch and Diehl, 1984). Pilots' situation awareness and risk management should be a key part of the aeronautical decision-making process that promotes aviation safety. However, Jensen and Benel (1977) found that decision errors contributed to 35% of all nonfatal and 52% of all fatal general aviation accidents in the United States between 1970 and 1974. Furthermore, Diehl (1991) proposed that decision errors contributed to 56% of airline accidents and 53% of military accidents.

Endsley (1997) suggested the key to effective decision-making in all of these cases rests in correctly understanding the situation. Experienced decision-makers consider a large number of cues in building situation assessments, and under certain specific circumstances, take actions that appear contrary to those prescribed by checklist. Larkin, McDermott, Simon, and Simon (1980) advised that problem-solving studies show fundamental differences between novices and experts in how problems are interpreted, what strategies are devised, what information is used, their memory for critical information, and the speed and accuracy of problem solving. Experts can see underlying causes and have more complex models of problems than novices. O'Hare (2003) reviewed aeronautical decision-making and made a conclusion that "it is difficult to think of any single topic that is more central to the question of effective human performance in aviation than that of decision-making." Current FAA regulations require that decision-making be taught as part of the pilot-training curriculum (FAA, DOT 61.125); however, little guidance is provided as to how that might be accomplished, and none is given as to how it might be measured, outside of the practical test.

Literature review

Aeronautical decision-making is defined by the FAA (1991) as "a systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances" (Hunter, 2003). Jensen's (1997) defined pilot judgment as "the mental process that pilots use in making decision." Both definitions implicitly include both process and outcome. Fischer, Orasanu, and Wich (1995) suggested that risk and time pressure are situational variables that further constrain the decision process, as risk and time pressure may call for an immediate response whether or not the problem was fully understood. Minimal risk levels and fewer time constraints, in contrast, permit additional diagnostic actions or the deliberation of options. Jensen, Guilke and Tigner (1997) suggested that risk management should be a key part of the decision-making process. Risk assessment feeds into decision-making in two ways: during the assessment of the precipitating threats and in evaluating potential courses of action. Janis and Mann (1977) proposed that a good decision-making process is one in which the decision-maker successfully accomplishes the collection of information about a wide range of alternatives, carefully assessed the risks and benefits of each course of action, and prepares contingency plans for dealing with known risks.

The processes of decision-making center around two elements—situation assessment, which is used as a precursor to generate a plausible course of action, and mental simulation to evaluate that course of action for risk management. If a pilot recognizes there is sufficient time for making wide-ranging considerations, her or she will evaluate the dominant response option by conducting a mental simulation to see if it is likely to work. If there is not adequate time, the pilot will tend to implement the course of action that experience (if any) dictates is the most likely to be successful. Klein (1993) found that whereas experts use a recognition-primed or perception-based decision process to retrieve a single likely option, novices were more likely to use an analytical approach, systematically comparing multiple options, and experience affects the processes of decision-making by improving the accuracy of situation assessment, increasing the quality of the courses of action considered and by enabling the decision maker to construct a mental simulation. Furthermore, Endsley (1997) defines situation awareness (SA) as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future." In the dynamic tactical environment, effective decision-making is highly dependent on situation awareness, which has been identified as a critical decision component (Endsley and Bolstad, 1994). Situation assessment is the process by which the state of situation awareness is achieved and is a fundamental precursor to situation awareness, which is itself the precursor for all aspects of decision-making (Nobel, 1993; Prince and Salas, 1997).

Tactical flight training has many aspects that challenge the quality and processes of pilots' inflight decision-making. In addition to the tasks and situations faced by the pilot of a civil aircraft, military pilots must perform a wide range of other tasks in addition to flying their aircraft safely. Their primary task may be to intercept offensive aircraft or to deliver weapons, troops, or equipment. Often the act of flying the aircraft per se in a hostile environment becomes a secondary task. As a result, military pilots must learn to make decisions related to mission performance in addition to those related to flying the aircraft *per se* (Kaempf and Orasanu, 1997). Flying advanced fighter aircraft has made increasing demands on pilots' cognitive abilities as the complexity of cockpit systems and the tactical situation has grown. There is now a requirement for decision-making training to be incorporated into tactical training programs. Furthermore, many accidents are either wholly or partially attributable to poor decision-making (Li, Harris, and Yu, 2005). However, at the present time, there is no formal training program available for military pilots making effective decisions under high pressure and in a time-limited situation.

Automated aids in the aviation industry are designed specifically to decrease pilots' workload by performing many cognitive tasks, not only including information processing, system monitoring, diagnosis, and prediction, but also controlling the physical placement of the aircraft. Flight management systems (FMS) are designed not only to keep the aircraft on course, but also to assume increasing control of the cognitive flight task, such as calculating fuel-efficient routes, navigating, or detecting and diagnosing system malfunctions. An inevitable facet of these automated aids is that they change the way pilots perform tasks and make decisions. However, the presence of automated cues also diminishes the likelihood that decision makers will either make the cognitive effort to process all available information in cognitively complex ways. Parasuraman and Riley (1997) describe this tendency toward overreliance as "automation misuse." In addition, automated cues increase the probability that decision-makers will cut off situation assessment prematurely when prompted do take a course of action by automated aids. Automation commission errors are errors made when decision-makers inappropriately follow automated information or directive (e.g., when other information in the environment contradicts or is inconsistent with the automated cue) that have begun surfacing recently as by-products of automated systems. Experimental evidence of automation-induced commission errors was provided by a full-mission simulation in the NASA Ames Advanced Concepts Flight Simulator (Mosier, Skitka, Heers, and Burdick, 1998).

Orasanu and Fisher (1997) investigated the five highest performance pilots and the five lowest performance pilots and found a tendency for high performance pilots to use low workload situations to make plans and collect more relevant information when compared with the poorer performing pilots. High performance pilots also demonstrated greater situation awareness. The key issues of a pilot's decision-making are time pressure and risk. For more than 30 years, the importance of aeronautical decision-making has been recognized as critical to the safe operation of aircraft. Jensen and Benel (1977) reported that the majority of fatal general aviation accidents was associated with decision errors. More recent studies (Shappell and Wiegmann, 2004) have also found decision errors have contributed to 45% of accidents in the USAF, and 55% in the U.S. Navy. Orasanu and Connolly (1993) have suggested that much 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. Maurino et al. (1995) suggested that it is important to understand how decisions made by people at the sharp-end (pilots) are influenced by the actions of the people at the blunt-end of their operating worlds, the higher managerial levels in their organizations. However, there is little empirical work formally describing the relationship between organizational structures, psychological pre-cursors of accidents, and the actual errors committed by pilots. Decision-making is a complex cognitive process and is affected by situational and environmental conditions (Payne, Bettman, and Johnson, 1988). Dekker (2001) proposed that human errors are systematically connected to features of peoples' tools and tasks and as acknowledged more recently, their operational and organizational environment. These latent failures are spawned in the upper management levels of the organization and may be related to manufacturing, regulation, and/or other aspects of management. As Reason (1997) noted, complex systems are designed, operated, maintained, and managed by human beings, so it is no surprising that human decisions and actions are implicated in all organizational accidents.

Method

Data: The aviation accident reports were obtained from the ROC Aviation Safety Council between 1999 and 2008. A total of 51 accidents occurred and had been completed investigation within this time period. There were 24 different types of aircraft involved in the accidents analysed, including commercial jets airliners (Airbus A300, A320, and A330; Boeing B-737 and B-747; McDonnell-Douglas MD-11, MD-82, MD-83, and MD90): private jets (Bombardier BD700): turboprop-powered aircraft (ATR 72-200, De Havilland Canada DASH-8-300, Fokker 50) and commercial helicopters (Bell UH-1H, 206, and 430; Boeing 234; Eurocopter BK117). Full copies of all these accident reports may be found on the ROC Aviation Council website (http://www.asc.gov.tw/asc_en/accident_list_1.asp).

Classification framework: The version of the HFACS framework described in Wiegmann and Shappell (2003) was utilized in this study. Level-1 of the HFACS categorizes events under the headings of "unsafe acts of operators" that can lead to an accident. This comprises four sub-categories of "decision errors," "skill-based errors," "perceptual errors," and "violations." Level-2 of HFACS is concerned with "preconditions for unsafe acts." This has seven sub-categories within it: "adverse mental states," "adverse physiological states," "physical/mental limitations," "crew resource management," "personal readiness," "physical environment," and "technological environment." Level-3 of HFACS is concerned with "unsafe supervision," which includes the four categories: "inadequate supervision," "planned inappropriate operation," "failure to correct known problem," and "supervisory violation." Level-4, the highest level in the framework, is labeled "organizational influences" and is comprised of three sub-categories: "resource management," "organizational climate," and "organizational process."

Research design: Two aviation human factors specialists coded each accident report independently. The analysts had previously been trained together on the use of the analysis and categorization framework to ensure that they achieved a detailed and accurate understanding of it. This training consisted of three half-day modules delivered by an aviation psychologist. The training syllabus included an introduction to the HFACS framework, explanation of the definitions of the four different levels of HFACS, and a further detailed description of the content of the 18 individual HFACS categories. Prior to undertaking the present study these analysts also undertook the analysis a total of 523 accident reports (Li and Harris, 2006, 2008). The presence (coded 1) or absence (coded 0) of each HFACS category was evaluated from the narrative of each accident report. Each HFACS category was counted a maximum of only once per accident, thus this count acted simply as an indicator of the presence or absence of each of the 18 categories within a given accident. Where there were discrepancies in the categorization of an accident, the raters convened and resolved their observations.

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 Kruskal's Tau (τ), which was used to calculate the proportional reduction in error (PRE). Tau (τ) has the advantage of being a directional statistic. The lowest level categories of decision error in the HFACS was designated as being dependent upon the categories at the higher level in the framework, which is congruent with the theoretical assumptions underlying HFACS. The value for Tau (τ) 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. Also, odds ratios were applied to calculate 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. Finally, the inter-rater reliabilities were assessed using Cohen's Kappa and percentage rate of agreement to indicate acceptable reliability between raters.

Results

Sample characteristics

In total 321 instances of human error, describing the underlying causal factors of the 51 accidents, were recorded using the HFACS framework (see Table 1). "Decision errors" were involved in 35 of accidents (68.6%) as the highest category of HFACS framework. Initial results found that acts at the level of "unsafe acts of operators" (Level-1) were involved in 109 (33.9%) of instances; the "preconditions for unsafe acts" level (Level-2) was as a causal factor in 81 (25.2%) of instances; the "unsafe supervision" level (Level-3) was involved in 74 (23.1%) of instances; and the "organizational influences" level in the HFACS model (Level-4) was involved as a factor in 57 (17.7 %) of instances. It must be noted in the following analyses that the percentages quoted refer to the percentage of times that an HFACS category was implicated in the sequence of events leading up to an accident. However, in most instances many more than just a single factor were implicated in an accident sequence, hence the percentages quoted sum to more than 100% across the results section as a whole.

Inter-rater reliability

Prior to resolution of discrepancies in coding between the raters, the inter-rater reliabilities, calculated on a category-by-category, basis were assessed using Cohen's Kappa. There are 10 categories the

HFACS Category		Frequency	Percentage	Ordinal	Cohen's Kappa	Inter-rater Reliability (Percentage Agreement)
Level-4, Organizational Influences	Organizational process	25	49.0	6	.415**	70.6%
	Organizational climate	6	11.8	16	.457**	86.3%
	Resource management	26	51.0	5	.113	56.9%
Level-3, Unsafe Supervision	Supervisory violation	24	47.1	7	.295*	64.7%
	Failed correct a known problem	8	15.7	14	.287*	70.6%
	Planned inappropriate operations	9	17.6	12	.316**	70.6%
	Inadequate supervision	33	64.4	2	.261*	66.7%
Level-2, Preconditions for Unsafe Acts	Technology environment	12	23.5	11	.105	70.6%
	Physical environment	24	47.1	7	.606***	80.4%
	Personal readiness	7	13.7	15	.441***	80.4%
	Crew resource management	24	47.1	7	.499***	74.5%
	Physical/mental limitation	3	5.9	17	.086	80.4%
	Adverse physiological states	2	3.9	18	.480***	96.1%
	Adverse mental states	9	17.6	12	.225	70.6%
Level-1, Unsafe Acts of Operators	Violations	30	58.8	3	.485***	76.5%
	Perceptual errors	14	27.5	10	.549***	78.4%
	Skilled-based errors	30	58.8	3	.493***	76.5%
	Decision errors	**35**	**68.6**	**1**	**.529*****	**80.4%**

* *Note that the percentages in the table will not equal 100% because in many cases more than one causal factor was associated with the accident.*

Table 1. Frequency, Percentage, Ordinal, and Inter-rater Reliabilities of each HFACS Category for All 51 Accidents Between 1999 and 2008

Kappa values in excess of 0.40, which is regarded as being acceptable (Landis and Koch, 1977). For the remainder of the categories, though, the Kappa value failed to achieve this level. Below 0.40 is regarded as a poor level of inter-rater reliability. However, Cohen's Kappa has several weaknesses as an index of inter-rater reliability. Low observed frequencies can distort Kappa values, deflating its value where there is actually a very high level of agreement. Cohen's Kappa becomes unreliable when the vast majority of observations fall into just one of the categories, and there is also a high percentage of agreement between raters in this category. In such a case, Cohen's Kappa will be low as the statistic is based upon expected probabilities calculated from the marginal observed totals. Kappa does not take in to account raters' sensitivity and specificity and becomes unreliable when raters' agreement is either very small or very high (Huddlestone, 2003). As a result, inter-rater reliabilities were also calculated as a simple percentage rate of agreement. These showed reliability figures of between 56.9% and 96.1%, indicating acceptable reliability between the raters (see Table 1). Decision error has 0.52 of Kappa value, and 80.4% percentage rate of agreement for inter-rater reliabilities.

Indirect path of association between latent failure and active failure

Analysis of the strength of association between categories at HFACS Level-4 “organizational influences” versus Level-3 “unsafe supervision” indicated that of a possible 12 relationships, three pairs of associations were significant ($p<0.05$). “Organizational process” was significantly associated with “inadequate supervision,” “planned inappropriate operations,” and “supervisory violations” at Level-3. Inadequate supervision is more than 27 times more likely to occur when there are organizational level issues associated with poor “organizational process.” The strength of association between categories at Level-3 “unsafe supervision” versus Level-2 “preconditions for unsafe acts” indicated that of a possible 28 relationships, six pairs of associations were significant ($p<0.05$). These were “inadequate supervision” at Level-3 versus “CRM,” “adverse mental states,” and “personal readiness” at Level-2; “planned inappropriate operations” with the “physical environment” and “CRM,” and “supervisory violation” versus “personal readiness.” Of these comparisons, it can be seen that poor “personal readiness” was more than 11 times more likely to occur in the presence of “inadequate supervision” at the higher level. Similarly, CRM was more than 9 times more likely to occur in the presence of “inadequate supervision” at the higher level.

Direct path of association between upper categories and decision errors

Analysis of the strength of association between categories at Level-4 “organizational influences,” Level-3 “unsafe supervision,” and Level-2 “preconditions for unsafe acts” versus “decision errors” at Level-1 “unsafe acts of operators” directly indicated that of a possible 14 relationships, 9 pairs of associations were significant ($p<0.05$). The following categories: “organizational process” (Level-4); “inadequate supervision,” “planned inappropriate operations,” and “supervisory violations” (Level-3); “adverse mental states,” “physical/mental limitations,” “crew resource management,” “personal readiness,” and “physical environment” (Level-2) were significantly associated with “decision errors” at Level-1. Of these comparisons, it can be seen that “decision errors” were more than 15 times more likely to occur in the presence of “CRM,” more than 13times more likely to occur in the presence of “planned inappropriate operations,” and more than 4 times more likely to occur in the presence of “organizational process” at the higher level.

Discussion

It can be seen from the data presented in Table 1 that “decision errors” is the key point of human factors in flight operations related to the highest percentage (68.6%) of accidents among 18 categories, and the majority of HFACS categories had large enough numbers of instances of occurrence in the data set to allow reasonable confidence in the pattern of results obtained. The findings are accord with previous researches conducted by Jensen and Benel (1977), Diehl (1991), Li and Harris (2006 and 2008). All categories also exhibited good levels of inter-rater reliability calculated by percentage agreement. These were as good as, or in excess of, the levels reported in previous studies (e.g., Wiegmann and Shappell, 2003; Gaur, 2005; Li and Harris, 2005 and 2008).

Reason (1990, 1997) proposed that latent conditions promoting unsafe acts are inevitably present in all systems. The original decision on how to allocate resources made at the highest levels in the organization may originally have been based on sound commercial arguments but such inequities can create safety problems in other, operational parts of the system. The analyses in this paper clearly show that inadequacies at HFACS Level-4 "organizational influences" had associations with further inadequacies at HFACS Level-3 "unsafe supervision." The category of "organizational process" is a particularly important factor at this highest organizational level. Poor "organizational processes" were associated with "inadequate supervision," "planned inappropriate operations," and "supervisory violations" at the level of "unsafe supervision" and hence directly were ultimately at the root of decision errors resulting in accidents. 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. A similar pattern of results was also found in the analysis of 523 ROC air force accidents previously reported by Li and Harris (2006, 2007). Moreover, this research proposes that not only categories at Level-2 have a direct influence on pilots' decision-making, but also categories at HFACS Level-4 "organizational influences" and Level-3 "unsafe supervision" have a direct influence with Level-1 pilots' decision-making (see Figure 1).

Figure 1 reveals that the category of "organizational process" at Level-4 was the key factor in HFACS framework. "Organizational process" refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment of standard operating procedures and formal methods for maintaining checks and balances between the workforce and management. Inappropriate in "organizational process" practices have particularly influenced pilots' decision-making at Level-1 and inadequate supervision," "planned inappropriate operations," and "supervisory violations" at Level-3. The role of supervisors is to provide their personnel with the facilities and capability to succeed and to ensure the job is done safely and efficiently. The category "inadequate supervision" refers to a supervisor's failure to provide professional guidance, failure to provide proper training, failure to track the qualifications, lack of accountability, and loss supervisory situational awareness; "planned inappropriate operation" was created as a category to account for failures such as poor crew pairing, failure to provide adequate briefing time, risk outweighing benefit, and excessive workload; "supervisory violations" are reserved for those instances when existing rules and regulations are willfully disregarded by supervisors, such as authorizing an unqualified crew for flight, failure to enforce rules and regulations, violation of procedures, and inadequate documentation. Moreover, all of these three categories at Level-3 not only have a direct influence regarding to pilots' decision-making, but also have significant association with "adverse mental states," "physical/mental limitations," "crew resource management," "personal readiness," and "physical environment" at Level-2. Finally, all of these five categories at Level-2 have a direct influence regarding pilots' decision errors. The category of "adverse mental states" was created to account for mental conditions that affect performance, such as loss of situational awareness, task fixation, distraction, and mental fatigue due to stress; "physical/mental limitations" refers to those instances when operational requirements exceed the capabilities of the individual at the controls, such as visual limitations, insufficient reaction time, information overload, incompatible physical capabilities and a lack of aptitude to fly; "crew resource management" was created to account for occurrences of poor coordination among personnel, such as coordination between and within the aircraft, as well as with ATC, maintenance, or other support personnel; "personal readiness" refers to when individuals fail to prepare physically or mentally for duty, as individuals are expected to show up for work ready to perform at optimal levels. A breakdown in "personal readiness" includes failures to adhere crew rest requirements, overexertion when off-duty, self-medicating, and inadequate training; "physical environment" refers to both the operational environment and the ambient environment, such as weather, altitude, terrain, lighting, vibration, and toxins in the cockpit.

Reason (1990) suggested that human behavior is governed by the interplay between psychological and situational factors. The finding of this study shows five categories at Level-2 (latent/active failures), "adverse mental states," "physical/mental limitations," "crew resource management," "personal readiness," and "physical environment" had a strong statistical relationships with the active failures of pilots' decision errors at Level-1 (see Figure 1). Reason (1990, 1997) has suggested that there is a "many to one" mapping of the psychological precursors of

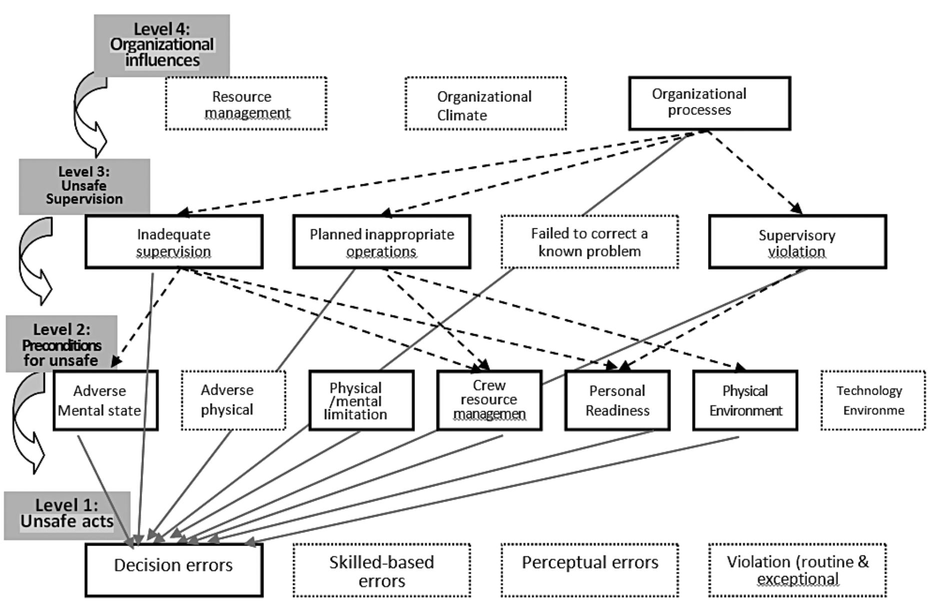

Figure 1. Paths between categories at the four levels in the HFACS framework showing the significant associations with decision error using Chi-square ($\chi 2$) and Goodman and Kruskal's Tau (τ) for the data derived from 51 accidents reports by ASC between 1999 and 2008.

unsafe acts and the actual errors themselves, making it difficult to predict which actual errors will occur as a result of which preconditions. The results of this study using the HFACS framework support this assertion. There are statistically significant associations between causal factors at the higher organizational levels, psychological contributory factors and decision errors made by pilots (see Figure 1). It can even be suggested that poor organizational processes at the highest levels in the organization result in poor supervisory oversight, which themselves lead to inappropriate preconditions for unsafe acts resulting in making inappropriate decision in flight operations. However, some prudent considerations need to be taken when interpreting the statistical relationships presented within Figure 1. In a few categories, the frequency counts are moderately 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. Nevertheless, the results of this study of civil aviation accidents occurring in the ROC show a remarkable similarity to the study of military accidents conducted in the air force of the same country.

Although there is no relevant research regarding direct influence on cross levels of HFACS so far, this research indeed shows the strong association of cross level influence between categories at Level-4 and Level-3 to decision errors at Level-1. Aviation accidents always caused by a series of human factors and these factors from organizational influence to unsafe acts of pilots are closely connected to each other. The results of this study reveal further discovery comparing with the HFACS theory proposed by Wiegmann and Shappell (2003) "each higher level in framework will directly affect the events in the lower level." For example, Oct. 31, 2000, a Singapore airlines B-747-400 (SQ-006) crashed on Runway 05-R, which is partially closed, while taking off from Taoyuan International Airport. In the meantime, the airport is hit by the skirt of a typhoon and covered in a strong downpour. The airline had 20 flight crews and 159 passengers. The following fire damaged the whole aircraft and caused 83 deaths and 39 serious injuries. According to the accident investigation report, the pilot should have been be able to tell the physical environment from runway and taxiway light, central light (the middle line of N1 glide sign and Left 05 Runway), and the different light structure, PVD (para-visual display) that the aircraft was not on the centerline of Runway 05-L. However, the pilot's decision-making ability and situation awareness are potentially affected by the time pressure of taking off before striking typhoon, strong wind, low visualization, and wet and slide runway condition. And all these potential factors led the pilot to taxi to Runway 05-R, which is maintaining and caused the accident. Classify this accident by HFACS. Level-1 "decision error" is comprised of many issues, such as entering the wrong runway, ignoring the PVD message, and adopting 30/hr crosswind limit (adopted wet runway standard instead of slough one). "Decision errors" of pilot taxiing onto wrong runway and taking off are directly affected by the strong wind, heavy rain, low visualization with typhoon, time pressure of taking off before being hit by typhoon, attention on central light of taxiway, sign and light facility; HFACS LEvel-2 consisted of "physical environment," "adverse mental states," and "crew resource management." Besides, the accident was also affected by company's procedure, rule, training, and supervision, which belongs to HFACS Level-3 "inadequate supervision," and Level-4 "organizational process." In terms of ignoring the PVD message, which corresponds to Level-1, the pilot's decision errors are directly connected to the company's policy. In the company's document, there is no regulation about PVD, which is verified in the B-747-400 flight handbook by Singapore Civil Aviation Administration, and there is no relevant PVD procedure to guide pilots regarding how to confirm runway position with PVD under low visualization condition. Besides, there is no handling procedure, training, and supervision for pilots by airlines while PVD is malfunctioning. These factors are related to Level-4 "organizational process" and Level-3 "inadequate supervision" across Level-2. Therefore, refer to SQ-006, it illustrates that events at Level-1 can be directly affected by events at Level-2; moreover, it is also possible that they are directly affected by Level-3 and Level-4 without Level-2 or Level-3. This research is aimed at providing a new direction for flight safety administration and the investigation unit for future reference in developing accident prevention strategies for flight operations.

The causal factors of accidents relevant to decision errors are usually underestimated and even misunderstood, as there were many accidents caused by inadequate decision-making of pilots are attributed to pilots' violations (Li and Harris, 2008). "Decision-making" is a rather complicated cognitive process that not only affects by physical, mental, flying condition, and technical environment, but also is affects by organizational management and supervisory class. In fact, "decision-making" is like any other flying skill that can be learn and promote flying safety (Jensen and Hunter, 2002; Klein, 1993; Prince and Salas, 1997). Therefore, designing the relevant training strategy according to these factors to enhance the quality of a pilot's decision-making is the top priority for flight safety administration and airlines.

Conclusions

Aeronautical knowledge, skill, and judgment have always been regarded as the three basic faculties that pilots must possess. The requisite knowledge and skills have been imparted in academic and flight training programs and have subsequently been evaluated as part of the pilot certification process. In contrast, judgment has usually been considered to be a trait that good pilots innately possess (Buch and Diehl, 1984). The advent of improved accidents investigation technology, such as cockpit voice recorders, along with a more systematic review of accident statistics, has produced a growing realization of the significance of pilots' decision errors in aviation mishaps (Diehl, 1991; Li and Harris, 2006, 2007 and 2008). The introduction of new technology has motivated the military and airline to put greater emphasis on the role of the pilot as a manager and decision-maker. Thus, an attempt has been to improve decision skills and to better understand the underlying causes of judgment errors. However, "decision-making" in training program is short of relevant research and regarded as a by-product of flying experience. This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher managerial levels in the operation of commercial aircraft result in decision errors on the flight deck and subsequent accidents. The results show clearly defined, statistically described paths that relate errors at Level-1 (the operational level) with inadequacies at both the immediately adjacent and also higher levels in the organization. This research draws a clear picture that supports Reason's (1990) model of active failures resulting from latent conditions in the organization. To reduce the accident rate regarding decision errors in flight operations, these "paths to failure" relating to these organizational and preconditions of human factors must be addressed. ◆

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The Use of Commercial Satellite Imagery in Aircraft Accident Investigation: Results from Recent Trials

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Introduction

In the majority of aircraft accidents, the wreckage is easily located and is accessible to investigators; however, there are notable exceptions. The loss of Air France Flight 447 over the Atlantic Ocean in 2009 and Adam Air Flight 574, which crashed near Indonesia in 2007, show the difficulty that can be experienced in locating aircraft wreckage. Similarly, the RAF Nimrod, which crashed in Afghanistan in 2006, and UTA Flight 772, which broke up over the Sahara Desert in 1989, both show that wreckage can be difficult or even impossible to access due to either political or geographical constraints.

For these reasons, there has been an increasing interest in the use of general aerial imagery for the location and subsequent analysis of aircraft accidents. In more populated areas, this may come from police, air ambulance, or even news helicopters, but again, this will be absent in more remote regions. Some agencies and organisations may have arrangements that allow access to imagery from military satellites, which may have different capabilities than commercial satellites. Following the loss of Flight 447, a request was made for the U.S. government to use satellite technology to assist in the search for wreckage. However, there are often issues surrounding the priority of acquiring this imagery and its subsequent access and use in the civilian domain. As a result, attention has turned to the use of commercial satellite imagery for accident location and investigation. This paper evaluates the current state of the art focusing on the needs and priorities of an accident investigation and reporting upon live als conducted in Cyprus in 2009.

Commercial satellite imaging

The availability and use of commercial satellite imagery has grown markedly in recent years with no better demonstrator than the ubiquitous *Google Earth*. However, acquiring this imagery on demand is not cheap, and therefore it is useful for investigators to know what can potentially be achieved by this technology. For example, it would be helpful to know whether, say, a flight data recorder can be identified by a particular satellite before spending many thousands of pounds acquiring the image to order. Whilst the published specifications of the imaging satellite can provide some of this information, they are not the whole picture!

There is a wide range of satellites offering images in the visible spectrum, all with different resolutions and characteristics. Table 1 shows some of the higher resolution satellites and the best resolution available from each. This indicates the smallest dimension that can be resolved and hence a lower number is better. Resolutions are shown for both panchromatic images (black and white) and multispectral (colour and other bands). Clearly, the panchromatic resolutions are much greater than the multispectral. One useful concept when dealing with satellite imagery is that of ground sample distance (GSD), which is the size of area on the ground represented as a pixel at nadir (i.e., overhead). As the viewing angle changes from directly overhead, i.e., increasing off-nadir angle (ONA), the available resolution reduces.

Satellite	Panchromatic (m)	Multispectral (m)
OrbView-3	1	4
IKONOS	0.82	4
EROS-B	0.7	-
QuickBird	0.61	2.44
WorldView-1	0.5	-
WorldView-2	0.46*	1.84*
GeoEye-1	0.41*	1.64*

Table 1. Available Resolutions of Commercial Satellites
**Subject to restrictions, see below.*

Satellite	Resolution (m)
RADARSAT-2	3
COSMO-SkyMed	1
TerraSAR-X	1

Table 2. Available resolutions of Commercial Radar Satellites

Whilst satellite resolutions continue to improve, the distribution and use of imagery from U.S.-owned satellites at better than 0.50 m GSD panchromatic and 2.0 m GSD multispectral is subject to prior approval by the U.S. government. Without this approval, images at resolutions better than 0.5 m will be resampled to give 0.5 m resolution. Whilst this approval may be granted in the case of accident investigation and resolutions will continue to improve, it is at least feasible that resolutions better than those currently offered will not be available in the near future.

One useful technique aimed at maximising the information available from electro-optical (EO) imagery is that of pan-sharpening, which can often be specified when requesting the imagery. This involves fusing the colour information from a multispectral image with the geometric information from the panchromatic image, essentially yielding a high-resolution colour image.

Commensurate with this growth in EO satellites has been an increase in the availability of commercial radar imagery, albeit at slightly lower resolutions. Table 2 shows three of the commercial radar satellites available and their associated resolutions. EO satellites are unable to image through thick cloud, whereas radar does not suffer from the same limitation. This is particularly relevant when considering that poor weather is a factor in many accidents.

In general when obtaining satellite imagery of a particular location, it is possible either to purchase a pre-existing "library" image or to task the satellite to acquire a new image. Clearly, whilst library imagery is useful for planning, recovery, visualisation, etc., it offers little to support the process of investigating the accident. Therefore, if up-to-date imagery of the accident site is required, it will be necessary to task the satellite to acquire specific imagery. The speed with which this can be done depends on a number of factors including budget, priority, and satellite orbit. However, as a general guideline, the minimum time it would take to task a specific image, from point of request to having the image, would generally be between 1 and 2 days.

Imaging satellites are scientific instruments with a wide range of parameters that need to be specified before acquiring an image. An analogy can be drawn with SLR cameras where there are many modes and settings, some of which will drastically affect the outcome of the image. Whilst it is beyond the scope of this paper to discuss the specifics of acquiring an image, parameters that can be adjusted include file type, imaging mode (related to imaged area and resolution), datum and projection, post-processing, dynamic range, etc. It should be noted that just like the zoom lens on a camera, most satellites can image a range of areas (e.g., 5k m x 5k m, 10 km x 10 km, etc.) but that an increase in area will often lead to a reduction in resolution.

Once an image has been acquired, it is usually delivered as a digital file. Dependent upon the size of the imaged area, the file size involved can be significant, e.g., 1GB for a 10 km x 10 km image, which has implications with respect to file handling. The majority of current handheld devices will not deal with a file of this size. An additional complication arises from the file format. Whilst it is often possible to specify the delivered format, the default format can be, say, the National Imagery Transmission Format (NITF) rather than the more common TIFF or JPEG. This means that the processing chain should also be considered when acquiring imagery as specialist software may be required to view the image. In some cases, further post-processing is required before anything resembling an image is produced.

These points are not raised to discourage the investigator, but rather to highlight the need to prepare for the possibility of a need to utilise imagery in the future. Attempting to understand the different satellite parameters should not be done whilst searching for a lost aircraft. Therefore, it may be appropriate for a representative to engage with a satellite imagery provider to establish a "standard" set of parameters and a processing workflow before it is needed in anger.

Trial configuration

In order to assess the potential utility of satellite imagery in aircraft accident investigation, a trial was conducted in which known targets were set out and imaged. The trial was conducted in collaboration with the UK Ministry of Defence (MOD), the UK Air Accidents Investigation Branch (AAIB), and the Defence Science and Technology Laboratory (dstl). Cyprus was chosen as a location for the trial due to the generally clear skies and the availability of open space.

Three test sites were set up: the first used accident-damaged aircraft components (metallic, carbon fibre, and mixed materials) in representative terrain, and the second used a helicopter door and tail boom floating at sea. The third site consisted of a grid of objects of various sizes and materials including metal squares ranging from 0.5 m x 0.5 m to 4 m x 4 m and real wreckage, all for use as a "testcard" for the satellite. These sites offered an array of problems at the more challenging end of wreckage location and plotting. Clearly, finding an intact 50 m fuselage will be easier than a 4 m x 4 m square panel. All three sites were also surveyed by the Joint Aircraft Recovery and Transportation Squadron (JARTS) using differential GPS mapping.

Two images were acquired of the site; an electro-optical image from the QuickBird satellite and a radar image from the TerraSAR-X synthetic aperture radar satellite (courtesy of infoterra GmbH).

The QuickBird image was of a 10 km x 10 km area, taken with a 0.6 m (panchromatic) and 2.4 m (multispectral) ground sample distance at an average off-nadir angle of 3°. The file was supplied in NITF 2.1 format with a file size of 960MB. The image was requested at "assured" tasking level for a time window of Aug. 17-21, 2009, and was acquired on Monday, August 17, at 08:42 GMT. (This is relevant because painting of the target was completed at approximately 10:00 GMT; comparison of Figures 1a and 1b show that the orange 4 m x 4 m orange square is only three-quarters completed and the other two "orange" squares are unpainted and not raised!) The file was viewed using GeoGenesis Lite, a free NITF viewer from IAVO. The commercial cost of tasking this image, given the assured tasking level and relatively narrow acquisition window, would be in the region of £10,000.

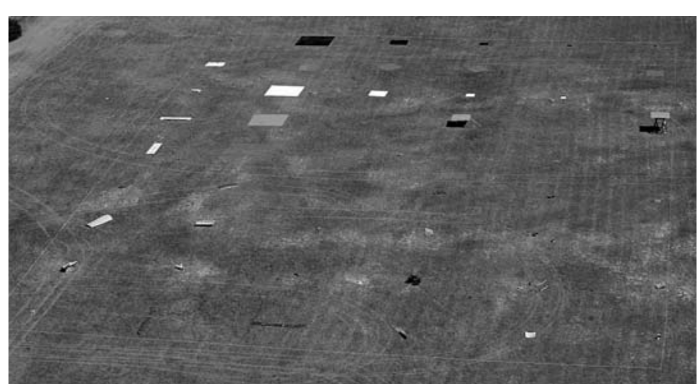

Figure 1a. Handheld image from helicopter of the grid.

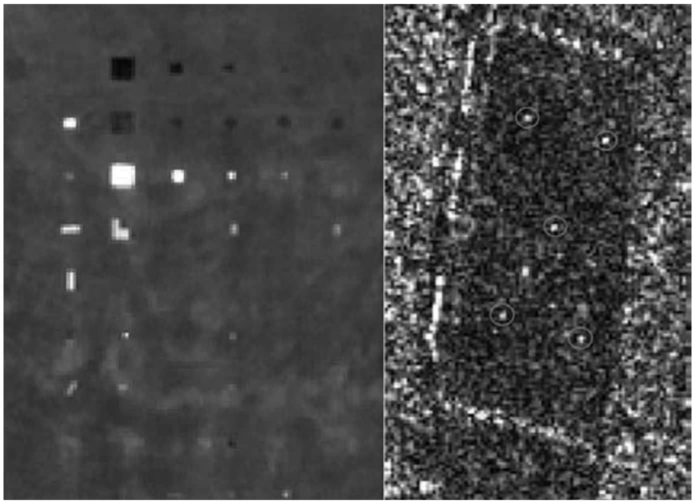

Figure 1b. Commercial satellite image (left). Figure 1c. Radar image of the of the grid (radar reflectors circled) (right).

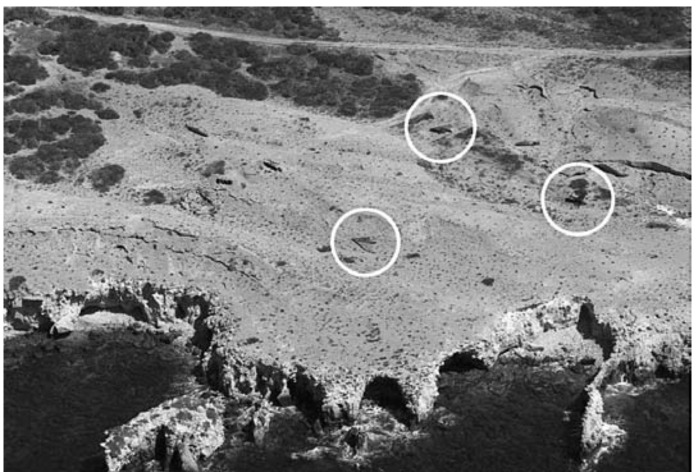

Figure 2a. Handheld image from helicopter of the Harrier site. (Both wings and tailplane circled.)

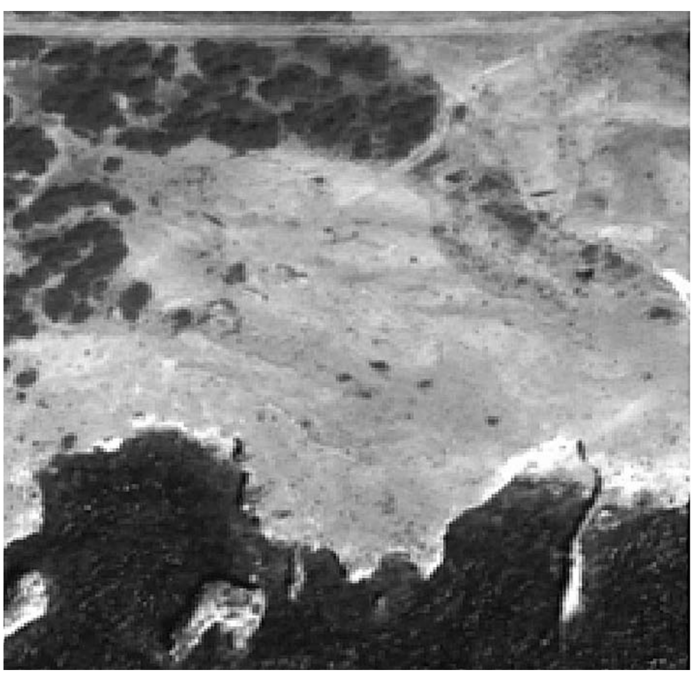

Figure 2b. Commercial satellite image of the Harrier site.

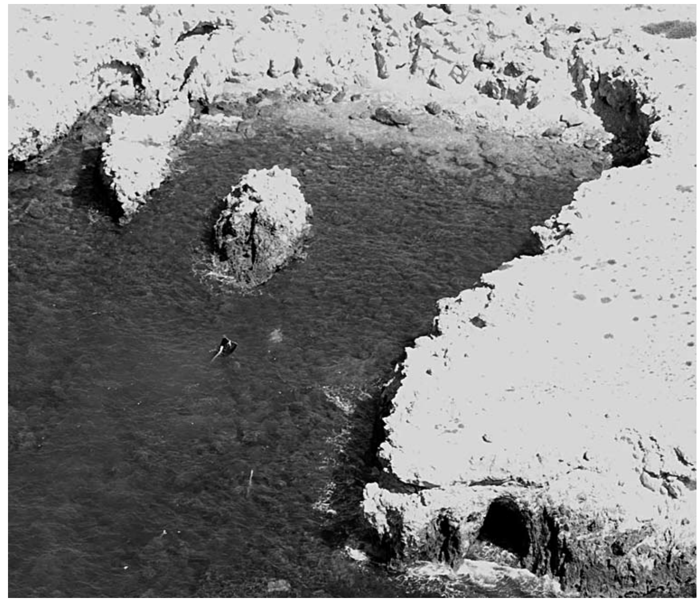

Figure 3a. Handheld image from helicopter of the sea site.

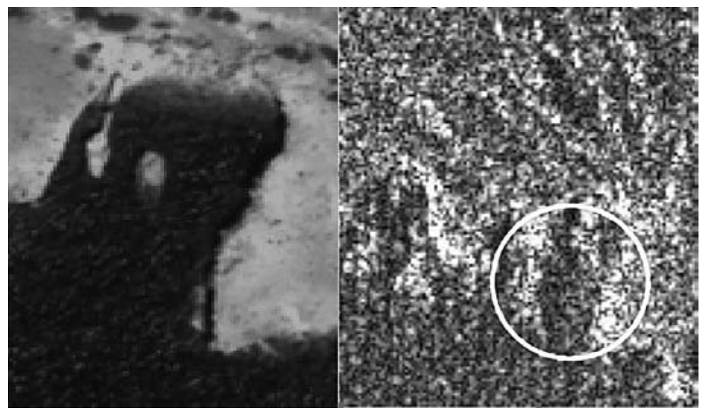

Figure 3b. Commercial satellite image of the sea site (left). Figure 3c. Radar image of the Harrier and sea sites (sea site circled) (right).

The TerraSAR-X image was acquired of a 10 km x 10 km area in "spotlight" mode giving a 1m GSD. However, by the nature of its operation, the preferred range of acquisition angles for this satellite is 20° to 55° with the trial image being acquired at 48°. This acquisition angle results in a reduction in resolution to approximately 1.5 m. The file was delivered as a Complex SAR image and was approximately 220MB in size. Analysis was performed using Radar Tools, an open source application. The commercial cost of tasking this image would be in the region of £7,000.

Figures 1-3 show handheld imagery of the three sites taken from a helicopter, corresponding pan-sharpened electro-optical images extracted from the QuickBird image and two images extracted from the TerraSAR-X image.

Analysis

Each of the items in the grid was analysed for interpretability by examining the image and deciding whether it was distinct from the background, i.e., whether there was "something there." No attempt was made to interpret the detail of the item.

Of the 50 targets that were in the grid, 20 were clearly visible, 7 were marginal, and 23 were undetectable. The clearly visible targets included a 2 m x 2 m black square; a 1 m x 1 m white square; a tail panel and a bulkhead (each 2 m x 1 m approximately). The marginal targets included a 1 m x 1 m black square, a 0.5 m x 0.5 m white square, a canopy section and a pair of seats. Those targets that were deemed undetectable included a 0.5 m x 0.5 m black square, a 4 m x 4 m Perspex square, a helicopter rotor blade, and a flight data recorder.

These results highlight the other factors that impinge upon the interpretability of an image. Whilst the panchromatic GSD of 0.6 m gives an indication of the results that might be available, the results are also heavily affected by other factors such as the surrounding area, object colour, viewing geometry, etc. It is interesting to note for example, that the 2 m x 2 m black square is clearly visible occupying approximately 4 pixels by 4 pixels, but also is the 1 m x 1 m white square occupying 2 pixels by 2 pixels, whilst the 1m x 1m black square is considered marginal. Because of the colours present in the surrounding area, a white pixel is much higher contrast than a black pixel, making it more prominent.

In order to test the geolocational accuracy of the satellite image, 20 items were chosen from the grid, the location of the item's centre was estimated and the coordinates noted, as displayed by the software based on the geographical information embedded within the image. These coordinates were then compared with the surveyed data.

Comparing the coordinates for absolute accuracy (i.e., comparing merely the precise coordinates) the average error was 10.25 m for the easting and 3.56 m for the northing with a maximum error of 10.80 m and 3.7 5 m, respectively. Assessing the relative accuracy (i.e., the distance between items) the average error was 0.20 m for the easting and 0.08 m for the northing with a maximum error of 1.05 m and 0.23 m, respectively.

Given the distances involved from sensor to object and the potential errors due to pixellation and centre estimation, these accuracies are exceptional. Notwithstanding the issues of interpretability above, a typical maximum error of 20 cm would be deemed more than accurate enough for wreckage plotting from a distance.

One technique that is often referred to in imagery analysis is that of change detection. This involves taking a "before" image and comparing it to the "after" image in order to highlight any differences. This can either be done manually or in software. The manual approach may be as simple as viewing the two images on the screen simultaneously and moving around them in a synchronised way looking for differences or anomalies. Whilst this method is labour intensive, it can be extremely effective.

The software approach uses algorithms to compare the before and after image. However, this technique works most effectively when using "matched" images, i.e., images taken from the same sensor, at the same resolution, with the same geometry with only differences of interest present. Clearly, since the next accident location is unknown, the likelihood of matched imagery being available is low. Therefore, automated change detection was attempted on the QuickBird image of the grid, with an image from the GeoEye satellite providing the reference from which to detect change. Whilst it would be possible to adjust the detection parameters in order to highlight the areas of known change, the point of using this technology is to detect change where it is unknown. Therefore, the change detection was performed using standard parameters.

A piece of software called Matisse, written by dstl, was used in an attempt to detect change. After performing the change detection, one of the panels in the grid was highlighted by the software as the most prominent change in an area of 700 m x 700 m around the grid. Expanding this to a 4 km x 3 km area resulted in the software highlighting the same panel as being one of the 50 most prominent changes in the scene.

Clearly, this technique will not be used as a totally automated process, but rather as a way of highlighting possible areas of interest to an imagery analyst. Therefore, given the results above, it is feasible that an analyst may be able to process the changes highlighted in, say, a 10 km x 10 km scene in a day although as the algorithm ranks possible detections, the more highly ranked a find is, the more likely it will be found by the analyst early in the process.

Examination of the radar image of the grid highlights some of the difficulties of working with radar. The five radar reflectors (laid out like the face of a die) are visible and circled in Figure 1c, as are some of the other components including the tail plane. However the resolution is such that each item occupies no more than one pixel in size. This makes it very difficult to interpret the image.

Figures 2a and 2b show the Harrier site. Whilst the bright blue parachute in the top left hand corner of the image is clearly visible, comparison of the two images clearly highlights the difficulties in distinguishing the wreckage from the surrounding scrubland. The wreckage visible in this image includes both wings, the rear fuselage and both drop tanks from a Harrier. There are also many other smaller parts in the images, such as pipes and a nose gear leg, but these are only visible from the helicopter image when zoomed and are not visible on the satellite image.

Figures 3a and 3b show the helicopter and satellite image of the sea site. The handheld image shows a helicopter tailboom floating in the water and a red door on the beach. However, it is not possible to distinguish any of the wreckage from the surrounding land or the sea. Similarly, the resolution offered by the radar image in Figure 3c, coupled with the noise and returns from the surrounding area, make it impossible to identify any wreckage and difficult to even identify the local geography.

Practical example

On April 10, 2010, a Tupolev 154 aircraft crashed near Smolensk, Russia, killing all 96 people onboard including the Polish president. Satellite imagery of the accident site was acquired from the World-

Figure 4a. Wreckage trail and surrounding area.

Figure 4b. Wreckage trail enlarged.

View-2 satellite and archived. This imagery was then provided to Cranfield courtesy of DigitalGlobe for research purposes.

WorldView-2 is a high-resolution multi-spectral satellite and is one of the most recent commercial satellites available. It was launched in October 2009 and is capable of producing high-quality images with a resolution 0.46 m for panchromatic and 1.84 m for multispectral. In addition to the traditional red, green, and blue bands, it also offers two near-infrared bands, a red-edge band, a yellow band, and a coastal band. Using the latter band, WorldView-2 has the ability to perform bathymetry (measurement of depth in water).

The image in Figure 4a clearly shows the wreckage trail in the top right corner. It also shows the vehicles, tents, and access routes being used by emergency services and investigators. It is clear from this figure that at this resolution, a trained analyst could easily identify this wreckage trail as the location of an accident. However, this image represents an area of approximately 150 m by 100 m. Clearly, at this magnification, the analyst time taken to manually search, say, 20 km by 20 km would be considerable, although not completely impractical.

Figure 4b shows the same image zoomed on the wreckage trail with the rear section of the aircraft in the centre of the image. Other footage of the accident site suggests this piece is of the order of 10m in length, which is consistent with the number of pixels depicting it. However, unfortunately, this is clearly a high-energy accident resulting in significant destruction of the aircraft, and hence it is difficult to distinguish many other parts of the aircraft.

Although satellite imagery had no role to play in the analysis of this specific accident, it provides a valuable proof of concept, particularly because it uses one of the highest resolution commercial satellites available, WorldView-2.

Concluding remarks

The growth in commercial satellite imagery means that access to imagery is widely available. However, as the discussion has outlined, the tasking and acquisition of this imagery is not trivial, with a wide range of factors and parameters to be taken into account. It would be prudent for organisations who may wish to acquire commercial satellite imagery to make contact with an imagery provider in order to establish their typical requirements in advance of requesting imagery. This is particularly important if imagery is required quickly, say, in response to an accident at sea where buoyancy may be time-limited.

Commercial satellite imagery is not yet of a quality to replace ground imagery or handheld imagery taken from a helicopter. However, the results of this trial and example have shown that there is potential utility in commercial satellite imagery for both wreckage location and wreckage plotting in specific situations. However, there are a wide range of factors affecting performance that are outside the control of the investigator including wreckage and scene colour, wreckage size, acquisition geometry, etc. The perceived risk of a wasted collection posed by these factors will obviously depend upon the situation faced by the investigator.

Future plans for research in this area include further trials into higher resolution multispectral satellites and the possible use of radar and hyperspectral sensors for detection of fuel and oil patches for location of accidents at sea.

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Close Cooperation in Investigations Has Improved Technical Partnership

By Michael Guan, Director of the Investigation Lab, Aviation Safety Council, Taiwan, and Christophe Menez, Head of the Engineering Department, Bureau d`Enquêtes et d`Analyses, France
(Recipients of the Award of Excellence for best seminar paper)

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Christophe Menez *graduated in 1998 as an engineer from the Ecole Polytechnique after an internship at the California Institute of Technology. He received a masters degree in aeronautics from the French National Civil Aviation School (ENAC) in 2000 after a one-year exchange with Sydney University. He worked for the French Civil Aviation Directorate (DGAC) for 3 years and joined the BEA in 2003, where he became head of the Engineering Department at the beginning of 2006. He has participated on site in a number of international investigations, including the Flash Airlines B-737 (January 2004, Sharm el Sheikh, Egypt) and the Armavia Airbus A320 (May 2006, Sochi, Russia). He is also involved in European working groups such as EASA's EFRPG.*

Introduction

About the ASC and its laboratory

Compared to Australia, Europe, and North America, aviation safety investigations and safety studies in Taiwan started to develop in the relatively recent past, about 20 years ago. The Aviation Security Council (ASC) was established in May 1998 as an independent government agency in Taiwan, ROC, responsible for the investigation of civil, public, and microlight aircraft accidents and serious incidents (Aviation Occurrence Investigation Act 1, 2), as well as issuing safety recommendations directly to the premier and following them up. Since its creation, the ASC has investigated 68 occurrences, among these 33 cases involving large transport aircraft (MTOW > 15,000 kg) and encountered many technical difficulties and challenges.

The ASC investigation lab, with a staff of six persons, is in charge of providing technical support to aviation occurrence investigation. This includes but is not limited to site survey, flight recorder reaout, flight path reconstruction, radar data and GPS data processing, performance analysis, and visualization. The lab also undertakes underwater location of wreckage, structural examinations, and failure analysis.

ASC Investigation Occurrence

	CVR	FDR/QAR	ANI	GPS/Radar	Total
2006	2	4	4	2	12
2007	2	4	5	2	13
2008	4	5	4	4	17
2009	5	2	1	6	14
2010.07	2	5	1	0	8

Technical Assistance

	CVR	FDR/QAR	ANI	(GPS/RDR, GIS, DB)	Total
2006	5	14	5	(0, 6, 3)	33
2007	5	6	7	(0, 22, 8)	48
2008	0	22	8	(9, 8, 18)	65
2009	5	33	6	(2, 3, 10)	59
2010.07	1	32	3	(15, 4, 6)	61

Figure 1. Summary of flight data readouts.

The ASC investigation lab has been involved in several foreign investigations, for which the ASC appointed accredited representatives. In addition, in order to build experience in flight recorder readout and analysis, the ASC also provides technical assistance for other agencies. In 2009, the ASC investigation lab worked on 10 CVR and 35 FDR/QAR, 7 animation sets, and 21 sets of GPS/radar data and satellite map superposition. The detailed list is shown in Figure 1.

About the BEA and its laboratory

The BEA (Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile) is the French body responsible for technical investigations of civil aviation accidents and incidents; it was originally created shortly after World War II. Following the dispositions of ICAO Annex 13 and the European directive for accident investigations, a French law (Law 99-243 of March 29, 1999) brought changes to the status of the BEA and confirmed the independence of safety investigation.

The Engineering Department of the BEA, comprising a staff of 25 people, is in charge of providing technical support to investigations in various fields. It is made up of two divisions: the Recorders and Avionic Systems Division, which undertakes work on flight recorders, avionic systems, radar data, and performances analysis, and the Structure Equipment and Engines Division, which is in charge of wreckage, engine and metallurgic examinations.

The Engineering Department is usually involved in investigations conducted by the BEA, as well as investigations abroad for which the BEA has appointed an accredited representative as per Annex 13 requirements. It also provides technical assistance to other states conducting an investigation, when, for example, they do not have the capacity to read out flight recorders. In 2009, the Engineering Department worked on 75 flight recorders, 97 electronic devices (half of these being certified avionics equipment), 33 sets of ATC data (radar and communications), 40 wreckage examinations, and 27 metallurgical examinations. Investigators from the Department also take part in examinations performed outside of the BEA's facilities.

Common issues which both agencies face

Any state willing to conduct investigations under the SARPs of ICAO Annex 13 *shall [standard 5.4] have independence in the conduct of the investigation and have unrestricted authority over its conduct, consistent with the provisions of Annex 13.* The state must be well prepared to manage the conduct of accident investigations, which by their very nature always occur in different contexts, require qualified staff with experience, significant financial resources, the ability to ensure coordination between participants, most of the time on an international level, the status to ensure independence, and clear rules regarding interactions with the judicial authorities.

Among these requirements, the agency conducting the investigation should have enough technical capacity and knowledge to perform examinations or supervise them so that it can comply with the standard 5.6 stating that *the investigator-in-charge shall have unhampered access to the wreckage and all relevant material, including flight recorders and ATS records, and shall have unrestricted control over it to ensure that a detailed examination can be made without delay by authorized personnel participating in the investigation.*

The provisions of Annex 13, which relate to participants in an investigation, often result in having several states working together, though they may have very different experience in conducting an investigation, different resources, and be faced with the challenge of overcoming cultural differences and language barriers. The ASC and the BEA have had to work together in such contexts and in doing so tried to make an efficient and complementary use of each others experience and capabilities. However cooperation, forced on us by circumstances, has been extended to a longer term technical partnership, which is presented in the next part of the paper.

Cooperation and technical partnership

Investigation into an ATR 72-200 accident in Taiwan in 2002

On Dec. 21, 2002, an ATR 72-200, a cargo flight number GE791 to Macau, departed from Taipei at 01:05 local time (UTC+8). During cruise at FL180 with autopilot engaged and airspeed around 200 knots, prolonged exposure to severe icing conditions forced the crew to continually activate the airframe deicing. Ice accretion caused a loss of control of the aircraft, which crashed into the Taiwan Strait near Penghu Islands, with both pilots missing (see Reference 1).

The ASC immediately formed a team to conduct the investigation to which, in accordance with article 84 of Taiwan Civil Aviation Law and ICAO Annex 13, the BEA was invited to participate to represent the state of manufacture, assisted by advisors from the ATR 72 manufacturer. The BEA sent five investigators to participate in the on-scene investigation and the underwater searches, and provided

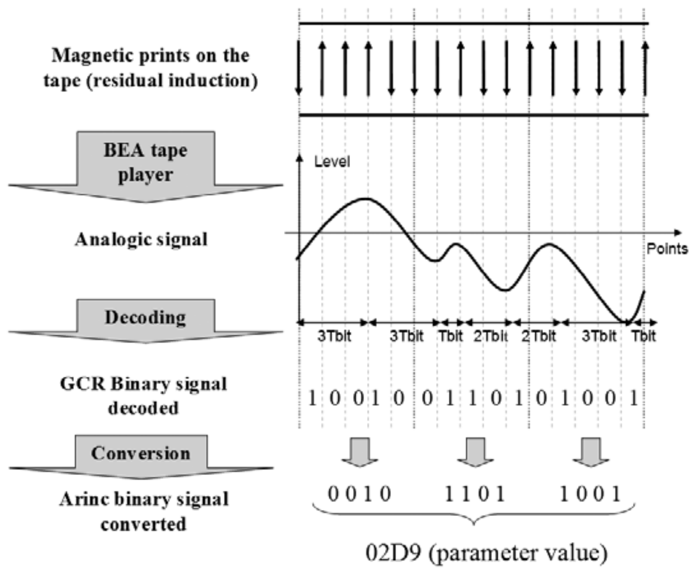

Figure 2. F800 readout principles.

technical assistance to the ASC regarding some of the technical issues encountered during the investigation: the retrieval of the flight data from the damaged magnetic FDR (Loral F800), icing performance analysis, and the identification of audio warnings.

The flight recorders were both recovered 22 days after the accident and transported to the ASC investigation laboratory for disassembly and readout. The CVR readout required careful cleaning because of water penetration in the protected module of the recorder, but the tape was read out successfully. For the FDR tape, from whose casing a lot of water flowed out during opening, a detailed examination showed some discolorations and wrinkles on the tape, especially the portions exposed to the outside or in contact with the mechanism, including some severe wrinkles near the end. The ASC used a modified NAGRA-T recorder to play back the FDR tape and then used the Recovery Analysis and Presentation System (RAPS) to translate the original wave signal into engineering data. However, due to the severe wrinkle damage on the tape, the last 7 seconds of the accident flight recording could not be retrieved using RAPS.

In order to recover this important data, the BEA proposed to read out the tape again, using a dedicated tape reader associated with decoding software, both developed by the BEA investigators (see Figure 3). In magnetic FDRs, the data are recorded by transforming the binary signal coding for the parameter's values into an analog signal, since the magnetic tape cannot directly record a binary signal; during the readout the signal waveforms recorded on the tape are converted back into the binary coding for the parameter values. In addition to that, for the Loral F800 model, before being converted to analog, the binary signal is first modified with a code called GCR to transform a series of four bits into corresponding series of five bits, therefore increasing the size of the file. When the recorders are read (see Figure 2), errors in the readout of the tape result in creating series of bits that do not exist in the GCR system, thus enabling investigators to locate problems on the magnetic tape and locally correct the conversion. Using the BEA's tape reader and decoding software, it was possible to decode and validate the 7 last seconds of the recording that were missing at the first readout.

With the help of the BEA, the ASC conducted a full flight simulator (FFS) at ATR and analyzed data related to previous similar

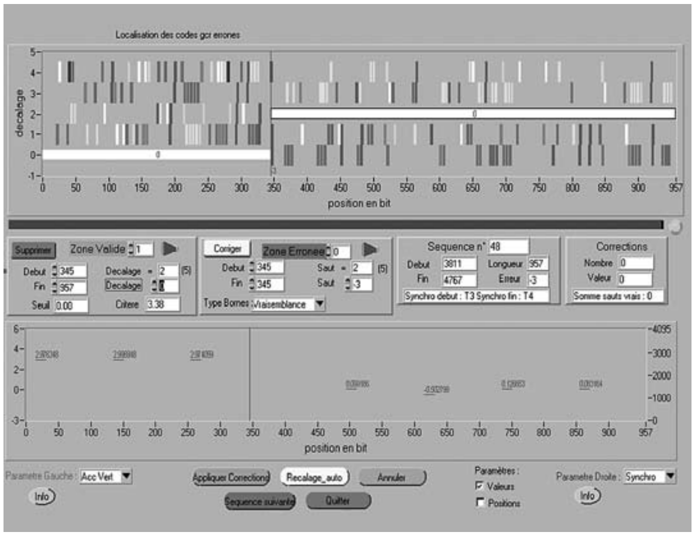

Figure 3. BEA software for F800 readout.

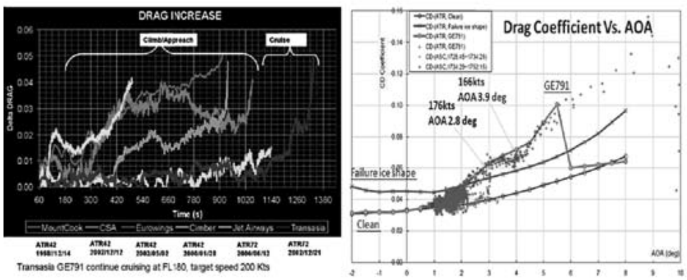

Figure 4. Results of GE791 icing performance analysis.

ATR 42/72 occurrences involving severe icing conditions. Performance analysis indicated that the accident aircraft's drag increased 4 minutes prior to autopilot disengagement and reached a value of +170% of drag in normal flight condition (see Figure 4). Ten seconds before the roll upset, the longitudinal and lateral stability were greatly affected by the significant quantity of ice that had accumulated on the wings. Prior to autopilot disengagement, the aerodynamic behavior of the aircraft (lift/drag) was degraded by about 40%. Based on the recorded data from the CVR, FDR, and performance analysis, the ASC concluded that the GE791 had probably encountered severe icing conditions that were worse than the icing certification requirements of FAR/JAR 25 Appendix C (see Reference 1, Reference 2).

Sharing technical resources

After this experience of working together the ASC, which was a relatively young investigative agency at this time, was interested in learning more about investigative tools used at the BEA, among them the tool developed for F800 magnetic tape readout. The BEA offered to have investigators from the ASC spend some time in its Engineering Department; this was the beginning of a technical partnership between the two organizations.

Work related to aviation occurrence investigations is of a kind that often requires tools that are not commercialized on a wide scale, which require some specific training and experience to be used efficiently, or which have simply not yet been developed at the time of the investigation. One example of this is the field of flight recorders. Accidents are still rare enough that no one, including investigative agencies, has ever dealt with all the possible problems that can be

Figure 5. Readout of corroded memory chips from a flight recorder.

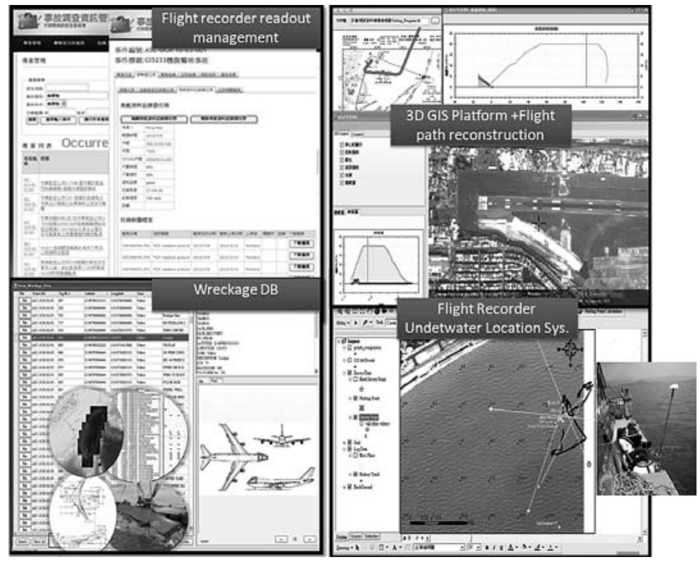

Figure 6. Major analysis modules of the OIMIS.

encountered in reading out a damaged flight recorder. Manufacturers offer training for the investigation community in order to better understand the way recorders work and the major checks and operations to be performed during readout (investigators from the ASC and the BEA have, for example, followed a common session of such training at L3 Communication and Honeywell). These training courses are very useful, even essential, and they complement the experience of the investigative agencies that deal on a regular basis with damaged flight recorders in which in certain cases special techniques have to be applied to solve a readout problem. Difficulties have often been encountered with magnetic tape recorders, and even if new technology recorders are more reliable, difficulties still arise at times. In 2009, for example, the BEA had to deal with a flight data recorder whose electronics board had been exposed to severe corrosion due to prolonged water immersion, and the investigators had to apply specific techniques to read out the memory chips one by one and reconstruct the binary file (see Figure 5).

The cooperation between the ASC and the BEA has continued for many years. This includes formal seminars organized between the two agencies in Taiwan in 2003, 2007, and 2009. The BEA very much appreciates the interest that the ASC has shown to newly developed tools and the capacity of the ASC laboratory to develop new tools as well.

Recently, for example, important engineering developments at the ASC include the Occurrence Investigation Management Information System (OIMIS), the Engineering Failure Analysis System. (EFAS), and the "TRK2KML" program, which uses Google Earth

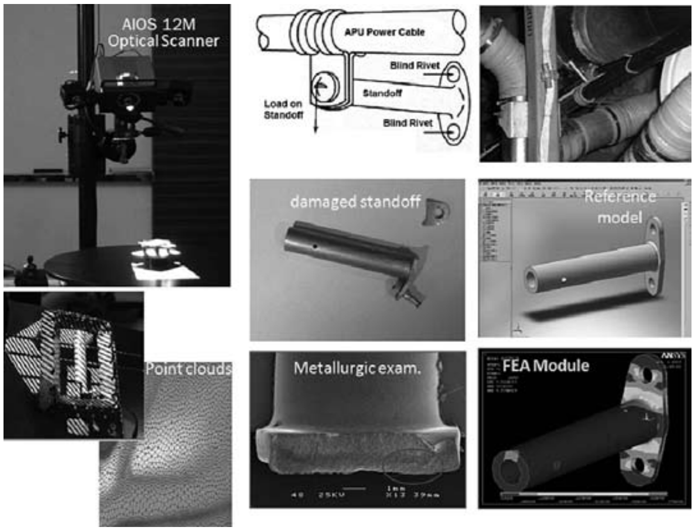

Figure 7. Operational procedures of the EFAS.

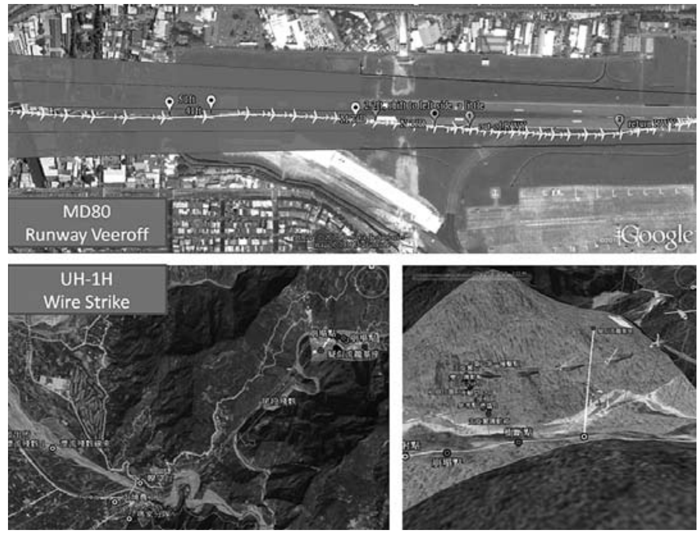

Figure 8. Flight paths of two cases: an MD-80 runway veer off and an UH-1H wire strike.

as a data visualization tool. Some specific features are summarized below.

• The Occurrence Investigation Management Information System (OIMIS), which integrates multi-data sets (ground scars, wreckage distribution, CVR/FDR data, radar tracks, SIGMET charts) into a 3-D GIS, to visualize the sequence of events of the occurrence. It contains four analysis modules: flight recorder readout management, flight path reconstruction, wreckage database, and flight recorder underwater localization system (see Figure 6, Reference 4).

• The Engineering Failure Analysis System (EFAS), a system that use a precise optical scanner and Finite Element Analysis (FEA) program assistance to determine the root cause of structure failure modes (see Figure 7, References 5 and 6).

• For considerations of cost effectiveness, accurate mapping, and fast presentation of the sequence of events of an aviation occurrence, the ASC has developed the TKM2KML program to visualize flight paths on Google Earth, which is available and free for worldwide investigators (see Figure 8, Reference 7).

Like the NTSB in the U.S., the AAIB in the UK, and the MAK in Russia, the BEA has developed its own software for decoding and analyzing flight data, a tool called LEA. This choice comes from the fact that tools available commercially for airlines to perform flight analysis do not exactly correspond to the needs of investigators. An airline analyzes the safety risks associated with a large number of flights, whereas an investigative agency concentrates on one particular event and often wants to perform detailed calculations on the data, such as the calculation of parameters not originally recorded by the airplane. In 2008 the BEA and the ASC decided to install the LEA program at ASC facilities in Taiwan, which was effective in April 2009. The ASC thus benefits from being able to freely use a tool developed by the BEA, but the BEA also benefits from it by receiving feedback from the ASC that will help to improve the software.

Now that the ASC is a more experienced investigative agency, it is also taking an active part in providing solutions to problems encountered by investigators. Recently, the ASC has developed a partnership with Garmin (through its branch in Taiwan) to get assistance with the readout of damaged GPS units and the decoding of files extracted from memory chips on these units to use them as a source of data for investigations. This partnership includes the development of an investigation kit to recover data from damaged Garmin portable GPS receivers (GPS MAP 96/96C/196/296/396/495/496). Using this partnership with Garmin, the ASC has helped the BEA to decode some of the files that had been extracted from Garmin GPS units at BEA's avionic laboratory. For some of the most recent units, the data are encrypted and can not easily be decoded without technical assistance from the manufacture. (For more details about issues related to the extraction of data from damaged electronic units, see Reference 3.)

However, ASC's contribution to the safety community outside of Taiwan is, of course, not limited to the BEA. After benefiting from contact with more experienced investigative agencies, the ASC is willing to play a role in turn within the international safety investigation community.

Beyond the bilateral partnership

Accident investigator recorder meeting (AIR)

In 2004 the AAIB, the ASC, the ATSB, the BEA, the BFU, the NTSB, the TSB, and other national investigative bodies initiated an annual Accident Investigator Recorder (AIR) meeting to share experience in technical fields such as the handling and readout of damaged recorders, flight data analysis, flight path reconstruction, avionic systems examination, and underwater recovery. Most of the investigative agencies take part in this annual meeting, which one of them hosts each year, and have the opportunity to compare each other's way of solving technical issues encountered during investigations, as well as to decide common action from the group for future solutions. This group is also a good place to discuss regulatory activities because several members participate individually at various levels (ICAO, the FAA, EASA) and define harmonized positions when needed.

Shortly after its creation, the group felt the need to have a dedicated website for exchanging data and continuing discussions between each annual meeting. The ASC proposed to set up this website (http://irig.asc.gov.tw) and continues to maintain it.

Conclusion

Conducting Accurate, Speedy, Independent, and Authentic investigations requires knowledge, financial resources, dedicated tools, and the capacity to adapt to the specificities of each occurrence.

In order to raise the level of their investigative capabilities, agencies usually get training from manufacturers or other training courses provided by investigation agencies. These training courses can be very beneficial but are insufficient for investigators, since there are always differences between theories and a real occurrence.

The ASC was once a young investigative body and could gain benefits from help from more experienced agencies such as the BEA, which was confronted with a large number of occurrences. Today the ASC is also providing help to the safety community and is giving technical assistance in several fields such as flight recorder readout. Bilateral and regional cooperation between safety agencies is necessary. We believe that sharing information and techniques is valuable, even though it implies a greater effort of adaptation to each other's culture and requires some language barriers to be overcome.

Building technical partnerships and exchanges between aviation safety investigation agencies, through MOUs (memorandums of understanding) or through multilateral groups, is an effective way of overcoming the limitations in resources or technical capabilities, as well as sharing difficulties encountered during investigations in order to work together to design suitable tools to overcome them. Investigators will always need to work with manufacturers, airlines, and experts from various fields; however, the only way for investigative agencies to be able to perform truly independent investigations is to maintain a good level of expertise and modern technical capabilities. ◆

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Terrain Profile Analysis Using Radar Altimeter Data from FDR

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Umberto Irgang *Photo and bio not available*

Abstract

Accidents and incidents that occur during takeoff, initial climb, and final approach have been raising major concern in commercial aviation in recent years. Investigation of such occurrences requires that all the data available from the FDR (flight data recorder) are used so that the involved circumstances are completely clarified. This paper describes a technique developed at the Embraer Air Safety Department that combines radio altimeter data from the FDR and topographic data from the terrain the aircraft has flown over. By using the radio altimeter and pressure altitude parameters recorded in the FDR, it is possible to determine the terrain's topographic profile, which can then be compared with the terrain's actual profile obtained from SRTM (Shuttle Radar Topography Mission) data. This comparison allows for the refinement and/or validation of a rough trajectory obtained from less accurate means, such as an assumed sequence of geographical coordinates. The determination of the trajectory with respect to the ground is a key factor for the comprehension of several types of occurrences. The technique revealed to be especially useful to confirm trajectories when other FDR parameters such as ILS (instrument landing system) deviations and GPS (global positionings) coordinates are unavailable. After the technique description, a case study of an investigation supported by Embraer using terrain profile analysis is presented.

Introduction

In the recent years from 1999 through 2008, 56% of fatal accidents occurred during either takeoff, initial climb, final approach, or landing phases, according to Boeing's statistical summary of commercial jets (Boeing, 2009). These figures indicate that every organization in the industry somehow involved with accident investigation must be prepared to investigate that class of accident. Fortunately, more parameters are being recorded in the FDR as a consequence of more stringent requirements, increased systems integration, and memory availability. This allows for more detailed analyses, improving the investigator's work when it comes to determining the contributing factors of the occurrences. On the other hand, thousands of older generation aircraft are still in operational use and thus are subject to be involved in accidents. These aircraft represent a challenge for flight data analysts as a restrictive set of parameters is recorded in the FDR, making it more difficult to draw conclusions from the information available. Furthermore, even new generation aircraft fitted with solid state recorders are subject to the shortage of important parameters due to external factors. An example of that is the lack of ILS deviation parameters on approach and landing accidents that occur on airports that are not equipped with this system. This study has resulted from a runway excursion accident with these circumstances with an airplane manufactured by Embraer, which participated in the subsequent inquiry providing support to the investigation authority. The lack of geographic coordinates and ILS parameters in the FDR motivated the development of a technique that relies on altitude parameters to draw the terrain contour of the region the aircraft has flown over. By comparing the terrain profile obtained from the FDR parameters with the actual terrain contour obtained by topographic data, it was possible to "link" the aircraft trajectory with the ground, i.e., determine the touchdown point on the runway. Several other studies have addressed the subject of trajectory reconstruction (Machado, 2009), but in this case, the available parameters would not allow the determination of the aircraft position with respect to the ground. It is important to mention, however, like any other flight data analysis technique, this one must be applied when accident circumstances are suitable for it and its results should be cross-checked with every other source of information available so that it does not lead to wrong conclusions.

In order to explain the technique, this paper begins with a description of the determination of the terrain profile from the FDR parameters. Then, it discusses the determination of the actual topographic profile from the SRTM data. Next, the process of comparison of both terrain profiles is described. Finally, the case study which motivated the development of the technique is briefly presented followed by a discussion of the usage of the technique for validation of trajectories obtained by FMS (flight management system) coordinates.

Terrain profile—altitude parameters

This section describes the determination of the terrain profile from altitude parameters recorded in the FDR, hereafter referred to as *altitude profile*. Basically, there are two distinct sources for altitude information on a commercial aircraft recorder: static pressure altitude and radio altimeter, according to airplane flight recorder specifications (FAA, 2010). Pressure altitude is the height of the aircraft above sea level derived from the measurement of the static pressure assuming a standard atmosphere (Collinson, 1996). The value of the static pressure is associated with a pressure altitude value by means of the ISA (international standard atmosphere) model. On its turn, the radio altimeter measures height above terrain by means of electromagnetic waves that are transmitted toward the ground. This device transmits a radio signal that is reflected from the ground and measures the time delay to the reflected return signal (Helfrick,

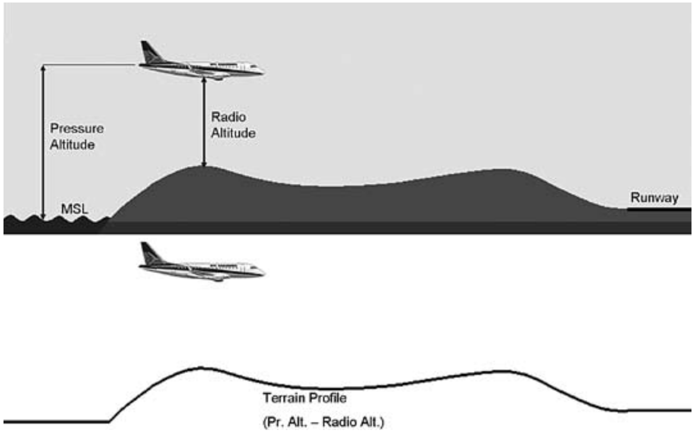

Figure 1. Determination of the terrain profile by subtracting the value of the radio altitude parameter from the pressure altitude parameter.

1995). Commercial aircraft equipped with both systems are required to record both pressure and radio altitude parameters in the FDR (FAA, 2010). Usually, the pressure altitude parameter is greater than the radio altitude parameter, except when the airplane is operating on an aerodrome located below mean sea level. Therefore, the simple subtraction of the radio altitude from the pressure altitude yields the terrain profile. The principle is illustrated in Figure 1. As the pressure altitude measures the aircraft altitude with respect to a predetermined reference (usually the sea level) whereas the radio altimeter measures the aircraft altitude with respect the terrain beneath, the subtraction results in the terrain profile. For the scope of this technique, the numeric value of the terrain elevation is not critical, but its shape is so that it can be compared to the actual topographic outline later. It is important to mention that the radio altitude parameter is required to be recorded up to the elevation of 2,500 ft above ground (FAA, 2010). Therefore, the altitude profile cannot be determined when the airplane is flying above that.

Shuttle Radar Topography Mission

The Shuttle Radar Topography Mission was an initiative to obtain a high resolution digital elevation model of the earth. The project was a joint endeavor of NASA (the National Aeronautics and Space Administration), the National Geospatial-Intelligence Agency, and the German and Italian space agencies, and flew in February 2000. It used dual radar antennas to acquire interferometric radar data, processed to digital topographic data at 1 arc-sec resolution (USGS, 2004). The space shuttle Endeavour was equipped with the radar system and flew during 11 days around the planet. Although the data were originally collected with 1 arc-sec resolution, the results were made public with either 1 or 3 arc-sec resolution. Only the United States territory is available with the higher 1 arc-sec resolution. The rest of the planet is presented with 3 arc-sec data. In practical terms, 1 arc-sec data correspond to a distance of approximately 30 meters between adjacent samples, whereas 3 arc-sec data correspond to a distance of approximately 90 meters. Elevation data are presented on thousands of tiles, with each tile covering a square area of 1 latitude degree in width and 1 longitude degree in height. Each tile is formatted as a two-dimensional array whose elements are 16 bit signed integers (USGS, 2004). Figure 2 presents a schematic view of a portion of an SRTM tile of 1 arc-sec resolution. Each SRTM tile is a file with the HGT extension.

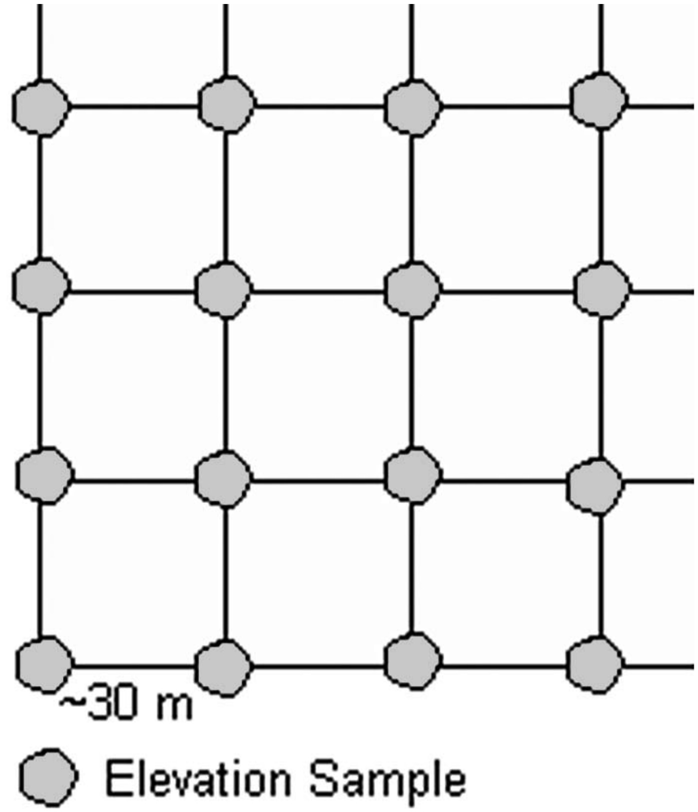

Figure 2. Schematic representation of a 1 arc-sec resolution SRTM tile.

SRTM data also contain occasional voids due to several different causes, such as shadowing, phase anomalies, or other radar-specific reasons. Elevation voids are flagged with the value -32768. Naturally, the presence of data voids is a factor that might impair the use of the terrain profile technique.

Terrain profile—SRTM

In order to determine the terrain profile from the SRTM data, it is necessary to know the final approach trajectory in terms of geographical coordinates (i.e., only latitude and longitude parameters). These coordinates can be considered the projection of the actual aircraft trajectory onto the ground. In other words, this projection is a rough trajectory that will be used to obtain a valid trajectory. The projected trajectory is necessary so that it is possible to look inside the SRTM file and then determine the terrain elevation of each of its coordinates. The resulting elevation data makes up the SRTM terrain profile.

However, the technique would not be necessary if these aforementioned coordinates were known in the first place. Fortunately, for the cases in which few parameters are available, it is relatively easy to determine a sequence of latitude/longitude pairs that correspond to the flight phase whose profile one wants to determine. For flight phases in which the aircraft is aligned with a runway (either in final approach or initial climb), it is simply necessary to determine a sequence of geographical coordinates that correspond to the prolonged runway centerline. To calculate these coordinates, it is possible to use the so-called *great circle distance* equations starting from an arbitrary point located on the runway centerline. Figure 3 depicts a sequence of coordinates showing the prolonged centerline. The distance between the points depends on the resolution of the SRTM data being used.

For the cases in which the aircraft is not aligned with a runway, it

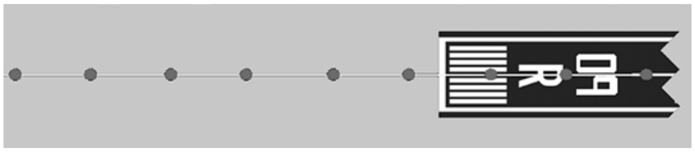

Figure 3. Sequence of geographical coordinates (in gray dots) defining the prolonged centerline calculated from a point on the runway. This sequence can then be used to calculate the SRTM terrain profile.

is possible to find a reference on the ground that might be related to the aircraft trajectory, such as a VOR/DME station that the aircraft was using as a navigation aid. In theses cases, determination of the coordinates might be more difficult because more complex calculations are required.

Once the coordinates have been determined, it is necessary to determine the elevation of each of the coordinates by looking into the SRTM file. The tile that contains the phase of flight must be used. As it was described, the SRTM file is a grid composed of elevation samples separated by 1 or 3 arc-sec of degree. As the trajectory coordinates do not necessarily coincide with the points in the SRTM grid, it is necessary to either interpolate the elevation samples or find the nearest match in the SRTM grid. For the purposes of this technique, the nearest match approach proved to be adequate. Figure 4 presents the SRTM terrain profiles of two distinct airports. The one above is the terrain profile obtained by extending runway 17/35 centerline toward the south at Mariscal Sucre International Airport (SEQU), Quito, Ecuador (3 arc-sec resolution). The one below is the terrain profile obtained by the extension of Runway 05/23 centerline toward the northeast at Yeager Airport (KCRW), Charleston, W.Va. (1 arc-sec resolution). It is possible to notice that the 3 arc-sec resolution profile presents sharp edges where the relief is irregular. That effect is a consequence from the lower 3 arc-sec resolution and is a factor that hampers analyses in regions outside the United States. Furthermore, in the 3 arc-sec profile, it is possible to notice the presence of the aforementioned data voids between 0 and 4 km from the runway. The occurrence of voids, however, is not restricted to lower resolution data only.

In addition to low resolution data and presence of data voids, other circumstances may cause SRTM profiles not to bring useful information to be compared with the altitude profile. SRTM data do not render the best results when applied in regions with characteristics of flat terrain or flights above the sea. Additionally, as the SRTM data were originally collected in the year 2000, many relief aspects may have changed since then as many of its characteristics are subject to human activities or environmental processes (e.g., the construction of new buildings, earthquakes, etc.).

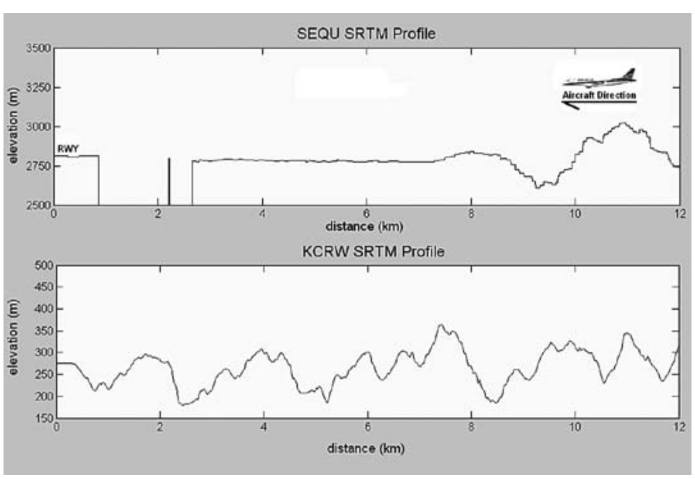

Figure 4. Comparison of two different terrain profiles. Above, profile from 3 arc-sec resolution SRTM data. Below, profile from 1 arc-sec resolution data. On both plots, the runway is located in the leftmost section of the graph.

Comparison of terrain profiles

Once both SRTM and radio altimeter profiles have been determined, it is necessary to plot them both as a function of the horizontal distance from a given reference. Plotting the SRTM profile as a function of distance is quite simple, as the geographical coordinates of the elevation samples are known, and consequently the distance between them can by obtained by great circle equations. In order to obtain the distances between the elevation samples of the altitude profile, it is necessary to consider the aircraft ground speed registered in the FDR. By taking the ground speed in consideration, it is possible to determine the horizontal distance between the elevation samples obtained from the altitude parameters. One point is chosen as the distance reference and from that point, the next points are calculated, one after the other. By integrating the groundspeed parameter in time, it is possible to obtain the traveled distance between two elevation samples. Figure 5 presents the process of calculating the horizontal distance between the elevation samples so that the altitude terrain profile can be plotted as a function of that distance. An important aspect to consider is the timing between samples of the involved parameters, as the integration process depends on the association between the ground speed and the altitude parameters. For example, if the sample rates of these parameters do not match, it is necessary to carefully select which samples will be used in the integration process. Otherwise, the analysis accuracy might be deteriorated. It is important to mention that the horizontal distance is not necessarily a distance measured along a straight line. Even if the trajectory is curvilinear, the method is still applicable because the elevation profile is a sequence of terrain elevation samples measured

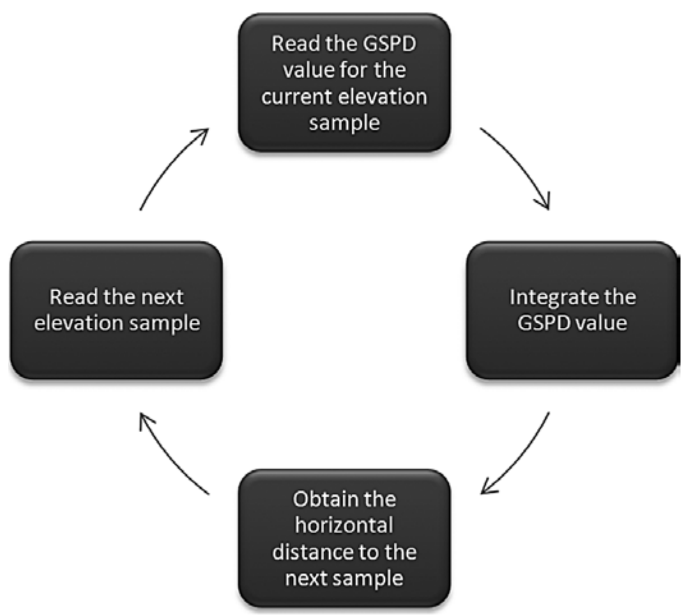

Figure 5. Process of determination of the horizontal distance. GSPD is the ground speed parameter.

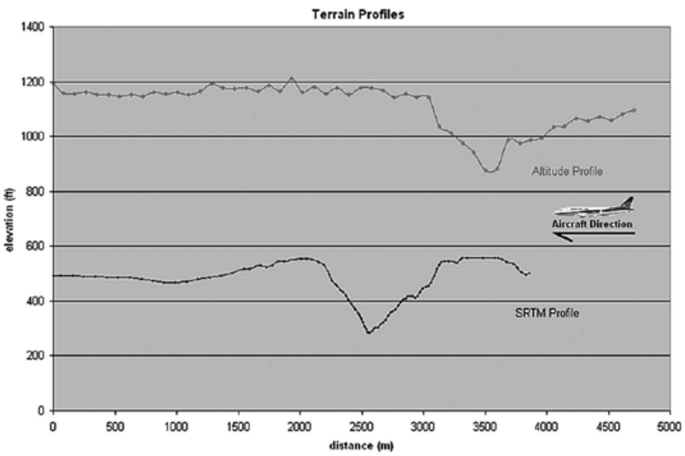

Figure 6. Comparison of altitude and SRTM profiles of the occurrence flight. It is possible to observe that both present similar features which are displaced from each other.

along a sequence of points that are necessarily aligned. Therefore, only the distance between samples matters, not the relative bearing between them. The importance of the horizontal distance lies on the fact that it defines if the altitude profile seems distorted ("stretched" or "shrunk") when compared with the SRTM profile.

It is possible, however, that the ground speed parameter is not available in the FDR. In that case, it is necessary to use the recorded airspeed, making the appropriate wind corrections.

Once the horizontal distance between the altitude samples is determined, the profiles are plotted and that plot will reveal that both of them present similar relief features, such as hills and valleys. As the SRTM profile was assumed to begin in an arbitrary point (see section "Terrain profile—SRTM"), it is likely that the profiles will be displaced from each other. That displacement will define the horizontal distance from the arbitrary point and the actual point. For example, during a landing, the altitude profile might begin in the point in which the aircraft touches the ground, and the SRTM profile begins in the touchdown aiming point, located approximately 1,000 ft from the runway threshold. In this case, the displacement between both profiles corresponds to the distance between the arbitrary point in the SRTM profile and the actual touchdown point on the runway.

Case study—runway excursion

This case study describes how the terrain profile technique was applied in the investigation of a runway excursion involving an Embraer aircraft. The approach took place during adverse weather conditions. The occurrence aircraft did not record latitude and longitude parameters. Furthermore, although the airport did have ILS antennae, the corresponding frequency on the navigation radio was not set by the flight crew. Therefore, the ILS deviation parameters were not available for analysis as well. Moreover, although the aircraft did record the groundspeed parameter, it was not possible to use this parameter to determine the touchdown point because the FDR recording ceased while the airplane was in motion. On the other hand, the occurrence took place on an airport with hilly terrain nearby the runway and this motivated the development of the technique. Both altitude and SRTM terrain profiles were determined following the steps described in the previous sections. The chosen arbitrary point where the SRTM profile begins was the touchdown aiming point, whereas the point in which the altitude profile begins is the instant in which the aircraft air/ground logic indicated the aircraft had landed. Figure 6 presents both profiles.

Observation shows that the profiles are very similar in shape but are displaced from each other. It is possible to notice that the terrain features occur "before" in the SRTM profile. That is, for a given terrain feature, its horizontal distance from the origin is smaller for the SRTM profile. This is an indication that the arbitrary point in which the SRTM profile begins is located forward (in the direction of the runway threshold) the point it should actually be. By comparing the profiles, it was determined that they were displaced by 1,036 m. That discovery showed that the aircraft actually touched down approximately 4,400 ft from the runway threshold of a 9,700-ft runway and ultimately helped investigators to better understand the occurrence and the involved factors.

Trajectory validation

So far it was discussed how the terrain profile analysis can be used for trajectory determination. However, even for the cases in which more parameters are available and the trajectory is known, the technique can be a useful tool for cross-check of the data. For example, cases in which FMS latitude and longitude are available in the FDR, the altitude and SRTM profiles can be plotted together in order to ensure that these geographic coordinates do not present displacement error in the direction of motion. Figure 7 presents the comparison of both profiles using this technique during the landing of an E-Jet at Sao Jose dos Campos Airport, Brazil. It shows that the profiles match, and thus the trajectory error is smaller than the SRTM data resolution of 3 arc-sec, approximately 90 m.

Conclusion

This paper presented a technique based on the comparison of terrain profiles obtained from two different sources. The technique proved to be useful in the investigation of a runway excursion in which the FDR data alone did not allow for the determination of the touchdown point. The merit of the technique, therefore, lies on its capacity to correlate the aircraft trajectory with the ground when the available data do not allow it based on other analyses. Furthermore, it was discussed how the technique can be used to perform a validation of trajectories obtained from other FDR parameters.

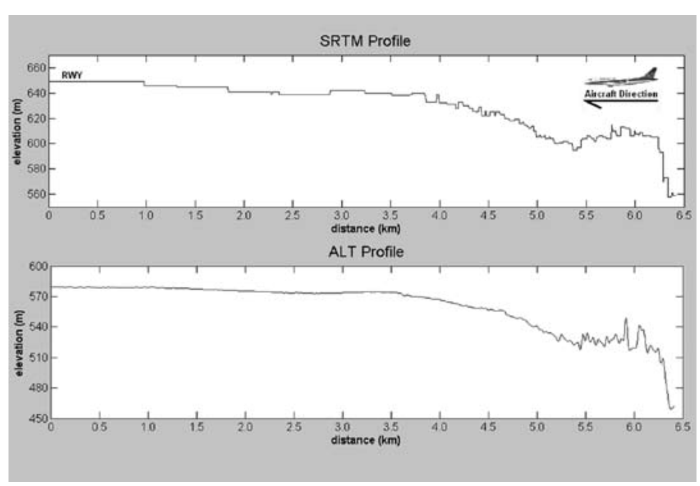

Figure 7. Comparison between SRTM and ALT terrain profiles. It is possible to notice that both present the same relief features without displacement. The runway is located in the leftmost section of the plot.

On the other hand, the tool also has its restrictions. As mentioned, the SRTM profile does not provide adequate information when applied on regions of flat terrain or water. Moreover, the altitude profile cannot be determined when the aircraft reaches 2,500 ft above ground level. All these restrictions must be considered carefully prior to drawing any conclusions from the application of this technique.

Nevertheless, as investigators are more and more required to timely respond to occurrences with accurate conclusions, it is always desirable to have an additional means to extract useful information from flight data, further enhancing their ability to adequately investigate incidents or accidents. If applied correctly, this tool is a step in that direction.

Acknowledgments

The authors wish to thank ISASI for the opportunity to share the basic ideas of this technique that hopefully might be used in future investigations and help to increase aviation safety. Additionally, thanks to the Embraer Air Safety Department staff and ITA (the Brazilian Aeronautical Institute of Technology) for their constant support. ◆

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Useful Human Factors Investigative Techniques: A Case Study of a Fatal King Air Accident in Canada

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Abstract

In the aftermath of an occurrence, investigators are frequently faced with a flood of data, and they need good methods to collect and analyse relevant information. Using the investigation of a fatal King Air accident (TSB A07C0001) as a case study, this paper discusses several useful methods for investigating human factors.

Initial investigation identified many crew deviations from standard operating procedures, and investigative scope expanded to look at organizational factors. Examination of the 4 Ps (philosophy, policies, procedures, practices) and an informal flight crew survey embedded in interviews subsequently revealed that the deviations were widespread adaptations that were not known to supervisors. Investigators used multiple time lines to understand events at the crew and organizational levels.

Investigators applied the local rationality principle in an attempt to overcome hindsight bias. The analysis divided conceptual constructs (crew resource management, situational awareness, and safety management systems) into smaller components to support analytical arguments for the existence of safety deficiencies.

Introduction

On the evening of Jan. 7, 2007, a commercial Beech King Air medical evacuation flight inbound to Sandy Bay, Saskatchewan, abandoned its landing attempt, but the aircraft did not climb sufficiently and collided with trees beyond the end of the runway. While all four occupants evacuated the aircraft, the captain died of injuries before rescuers arrived. Two passengers (medical technicians) were seriously injured, and the first officer had minor injuries. The aircraft was destroyed by fire.

This paper focuses on investigative methods, and some information about the occurrence is used to illustrate these methods. For full details of the occurrence, see the investigation report [1] available on the TSB website.

Examination of the wreckage revealed no indication of pre-impact anomalies. A cockpit voice recorder (CVR) was recovered from the wreckage and proved to be an important information source.

Subsequent review of the CVR, aircraft records, and initial interviews revealed the aircraft had operated normally throughout the flight. Consequently, the investigation focussed on human and environmental factors. This paper addresses only human factors; please see the investigation report regarding environmental factors.

We quickly became aware of multiple instances of flight crew practices that varied substantially from the procedures and policies of the air operator company. We decided investigative assistance was necessary, and an investigator from the TSB Human Performance Division was assigned. With this addition to the investigative team, we continued to review the CVR and conduct interviews.

First, we verified and documented the variation of crew practices on the occurrence flight from policies and procedures. At the end of this process, we were concerned that the variations in practices could extend beyond the occurrence crew. Consequently, we expanded the scope of the investigation to examine organizational factors in more detail.

Interview survey

One month after the accident, we interviewed seven pilots who operated the company's two King Air aircraft. We also interviewed the pilots' supervising managers.

Using the record of variant crew practices from the occurrence flight, we developed an informal survey of 13 questions to examine pilot knowledge of and compliance with the company's procedures and policies. This was consistent with TSB investigative guidance to examine the 4 P's of philosophy, policies, procedures, and practices.

The survey was conducted by asking questions at appropriate times during interviews. Interview subjects were not aware of the survey, and the sequence and timing of questions varied between interviews. The interviews were conducted by operations and human performance investigators, and were recorded and transcribed. From the transcripts, we developed a survey summary. The following are two examples of the responses to survey questions.

First, the company frequently had flights operating on short runways much like the one involved in this occurrence. We needed to know the extent to which pilots used aircraft performance data. The survey summary showed that most of the pilots interviewed did not make landing performance calculations required by policy, while some others rarely did so. (See Table 1.) This information led directly to a finding as to causes and contributing factors that the crewmembers did not assess the aircraft performance and did not identify runway length as a threat.

Position	Answer
Training Captain	Performance charts not used.
Training Captain	Performance charts not covered in ground school.
Captain	Performance charts not used.
First Officer	Used charts during training, rarely used them since.
First Officer	Used charts during training, rarely used them since.
First Officer	Not asked.

Table 1. Survey Summary—Landing Performance Calculations

Second, the Sandy Bay aerodrome did not have any instrument or visual vertical guidance system for pilots and also did not have any communications facilities. Consequently, company policies and procedures prohibited straight-in approaches and required pilots to visually inspect the runway before landing. We needed to know whether pilots were aware of and complied with these policies. The survey summary showed that half the pilots interviewed were not aware of this prohibition, and the remainder reported flying straight-in approaches when prohibited (see Table 2).

Position	Answer
Training Captain	Aware of policy. Thinks compliance good with occasional intentional deviations in visual conditions.
Training Captain	Likes to circle, but has done straight-in approaches.
Captain	Unaware of policy. Flies straight-in approaches if winds known.
First Officer	Unaware of policy. Thinks decision is at captain's discretion.
First Officer	Unaware of policy.
First Officer	Aware of policy. Thinks compliance is good with occasional intentional deviations.

Table 2. Survey Summary—Straight-in Approaches

This interview survey proved to be a very effective data collection method. Formatting the data in a summary documented the extent of pilot non-compliance, which supported our finding that substantial and widespread deviations from standard operating procedures had developed and persisted within the company's King Air operation.

During interviews with flight operations managers, investigators also asked questions regarding supervisory practices and knowledge of pilot compliance with policies and procedures. This revealed that supervisors were unaware of the pilot practices that deviated from policies and procedures.

While the interview survey was very useful, one negative consequence was that it substantially increased investigative workload, because many more interviews were conducted compared to other TSB investigations of similar occurrences.

Time lines

A timeline is a useful tool to help investigators understand why people did what they did. According to Dekker, "If you want to begin to understand human error,…a good starting point is to build a time line."[2]

Establishing and documenting a sequence of the occurrence events is part of the TSB's integrated safety investigation methodology (ISIM)[3], and is a normal TSB investigative function. ISIM is embedded in the TSB's transportation investigation information management system (TIIMS) through the use of a number of software tools for documenting and analysing time lines.

In this investigation, high-quality data from the CVR enabled development of a detailed occurrence sequence of events. However, not all events were recorded on the CVR, and many safety issues involved events that should have happened but did not. The occurrence time line was used to integrate events identified from all sources, and to identify times when the non-events should have occurred. The occurrence time line was extremely useful in determining the sequence of events, and aided us in understanding the flight crew's behaviour in the context of the many underlying factors.

In addition to the events during the accident flight, the investigation also examined events at two organizational levels: the air operator company and the regulatory oversight agency. Time lines were developed to establish the sequence of events within both of these organizational levels, and to help investigators understand the inter-relationships between the levels.

The organizational time line for the company was useful in that it organized supervisory activities into chronological order, again with linkages to underlying factors. This enabled a cross-reference to the crewmember time lines, helping investigators to better understand the company's supervisory capabilities and limitations.

The organizational time line for the regulator helped document events we had identified in chronological order. However, this time line was of low resolution and dealt with events that had occurred up to 2 years previously. The limited number of events we identified were specific to investigative areas of interest, and, to investigators, these events took on the appearance of a linear chain of events. In reality, these events were far from linear. Hundreds of other events we did not know about created a complex organizational context. Within this context were the selected events we studied.

Our recommendation is to use such a time line with caution regarding hindsight bias, and to work to understand the overall organizational context.

Conceptual deconstruction

Portions of the analysis in the investigation report discussed three broad concepts: crew resource management, situational awareness, and safety management systems. We were unsuccessful in our initial attempts to develop convincing arguments to support our findings in these areas. This resulted from describing how the occurrence events indicated problems with each concept as a whole, with investigators expecting that our findings were, to a large extent, self-evident. However, as Dekker [4,5] points out, we had made a "leap of faith" by using the categories as labels, and we had not clearly demonstrated that the facts led to our conclusions or that the problems identified had contributed to the occurrence.

Once the draft report had been reviewed externally, it was obvious from reviewer comments that our initial analysis needed to be revised. The approach taken was to deconstruct each of these three broad concepts into smaller, more manageable components.

Crew resource management (CRM)

First, we will discuss crew resource management (CRM). The definition of CRM that we used is the use of all human, hardware, and information resources available to the flight crew to ensure safe and efficient flight operations. In this occurrence, amongst the information resources available to the crew was extensive operational risk management guidance in the company's flight operations manual and standard operating procedures.

Canada requires that flight crews operating airline category aircraft with 20 or more passenger seats must receive CRM training. However, crews operating smaller aircraft, such as the King Air, are not required to receive such training. The Commercial Air Services Standards[6] of the Canadian aviation regulations lists eight CRM components for which training must be provided to airline category pilots. Several of these components were used in the revised analysis to better describe the problems that existed on the occurrence flight and within the company's King Air operation. This paper will discuss the CRM components of problem solving, and decision-making.

Problem solving is a CRM component listed in the training requirements. When this portion of the analysis was revised, we used a number of examples of crew behaviour as premises to support our argument that their problem solving was ineffective.

The destination of the occurrence flight was a 2,880-foot gravel runway. Post-accident calculations showed the landing distance on a bare level paved surface was 1,600 feet, resulting in a touchdown zone length of 1,280 feet. However, compacted and loose snow contaminating the runway would increase the landing distance and reduce the touchdown zone length.

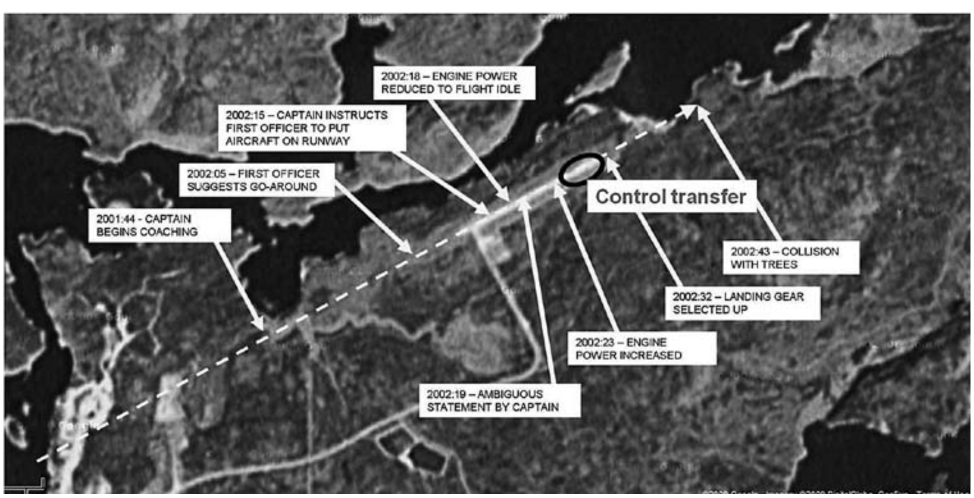
Although company procedures required pilots to make pre-flight aircraft performance calculations and to consult landing charts for contaminated runway operations, the occurrence crew did not make any landing performance calculations. Both pilots had previously flown into Sandy Bay without incident, and they likely expected this flight to be little different from previous flights. Additionally, the interview survey of other pilots showed they, too, did not normally conduct aircraft performance calculations. We concluded that pilot practice across the company's King Air operations was to base expectations of aircraft performance on past experience.

The occurrence crewmembers did not assess the aircraft landing performance or identify runway length as a threat. Consequently, they did not discuss and agree on a point at which a safe landing was no longer possible, and they were unprepared to make an informed and timely go-around decision as a crew.

Decision-making is a second listed CRM component for which training is required. We again used examples of occurrence crew behaviour to enhance our argument that decision-making was ineffective.

One example occurred during the after-start check, when the captain designated the first officer as the pilot flying for the leg and the first officer concurred. This was contrary to one company policy requiring the captain to be pilot flying on the first leg of the day, and a second policy requiring captains to conduct landings on runways shorter than 3,500 feet. The investigation could not determine why this decision was made. A result of this decision was that the less experienced crew ember was the pilot flying for the approach to Sandy Bay.

A second example of ineffective decision-making is the occurrence crew's conduct of the final approach and go-around. These portions of the flight also serve as an example of ineffective crew problem solving. The crew was conducting a non-precision instrument approach with the first officer flying the aircraft. Both crewmembers acquired visual reference with the runway about 4 miles from the threshold. Subsequently, the captain identified that the aircraft was high on the approach and began coaching the first officer. The first officer made an unassertive suggestion that they conduct a go-around, but the captain rejected the suggestion and continued coaching the first officer into the landing flare. In the flare, the captain decided to initiate a go-around, but his communication of this decision to the first officer was non-standard and did not have the desired effect of triggering the correct sequence of go-around actions required.



All of these examples had been included in the factual section of the initial draft report. However, discussing them in the revised analysis in the context of specific CRM components provided a more convincing argument to support our conclusions that the flight crew exhibited ineffective CRM and that the ineffective CRM contributed to the occurrence.

Situational awareness

A second broad concept the investigation examined was situational awareness.

The company was working toward, but had not yet received, regulatory approval to conduct GPS approaches. The company's aircraft were equipped with GPS certified for instrument approaches, and flight crew training was being developed. The occurrence crew used the GPS to provide distance-to-go to the aerodrome identifier waypoint, and this practice was also used by the company's other King Air pilots.

However, the geographic coordinates of an aerodrome identifier waypoint are those for the aerodrome geometric centre. In Sandy Bay, this point was the centre of the runway, equidistant from both ends of the runway.

We wanted to assess the effect on flight crew situational awareness of using GPS distance-to-go to the centre of the runway rather than the threshold. The actual distance to the threshold was about ¼ nautical mile less than the distance to the aerodrome waypoint coordinates, and our hypothesis was that this may have contributed to the aircraft being high on the final approach.

We used a model of situational awareness described by Brunelle [7], wherein the concept is divided into five elements. We focused on the spatial/temporal element, in particular the ability of the crew to anticipate the projected flight path of the aircraft.

We concluded that the crewmembers were likely unaware of the ¼ mile difference between the depicted GPS distance and the distance to the runway threshold. We were unable to determine whether this contributed to the aircraft being high on final approach. However, both crewmembers had visual contact with the runway for at least 2 minutes before the landing attempt, and the captain did identify visually that the aircraft was high on approach and take corrective action. Therefore, the crew was able to accurately predict the projected flight path of the aircraft during the final approach.

Our examination of situational awareness did not extend beyond this issue. However, the ability to divide the overall concept into smaller elements helped investigators to determine that the use of GPS distance-to-go had not contributed to the occurrence.

Safety management systems (SMSs)

A third broad concept we examined was safety management systems.

In 2005, the Canadian aviation regulations were revised to require specified organizations to implement safety management systems (SMSs). The occurrence air operator company was required by the new regulations to have an SMS because it operated three airline category aircraft. Implementation of the SMS was being done in four phases under the oversight of Transport Canada.

The regulations and Transport Canada guidance material divide a safety management system into six components. Three of the components are further divided into elements, for a total of 17 SMS elements.

In January 2007, at the time of this occurrence, the company was in phase 2 of implementation. During phase 2, amongst other SMS elements, the company was implementing a non-punitive reporting policy; a reactive reporting system; and reactive investigation, analysis, and risk management processes. Proactive processes would be implemented during phase 3. The company did not have a fully functioning SMS and was not required to have one until the completion of phase 4, in September 2008.

We limited our examination of the company's SMS to only those elements being implemented during phase 2.

We determined that the company's immature SMS had not detected some previous occurrences involving the accident crew, or many underlying factors identified as contributing to the accident. From this, we concluded that the company's reactive reporting system was not yet functioning.

In November 2006, 6 weeks before the accident, the company's SMS did detect and investigate a regulatory infraction involving the accident crew. We examined the reactive investigation, analysis, and risk management processes used by the SMS in this instance.

We determined that the company's investigation was well documented but was limited in scope. The company SMS analysis focussed solely on the crew and did not identify underlying supervisory and operational control deficiencies. Short-term corrective action taken by the company was an immediate suspension without pay of 2 weeks for the captain and one week for the first officer. Long-term corrective action included both a safety directive to flight crews regarding the numerous flight operations regulatory violations incurred by the company and pilot meetings to be held at each base to discuss the violations.

Follow-on action was to be a line check of the crew to assess compliance with regulations and standard operating procedures. The captain and first officer were scheduled to fly together only once in December 2006 following their suspensions; consequently, the company intended to conduct a line check in January 2007 but had not yet scheduled it when the accident occurred.

The company's SMS was immature and still under development, and this was reflected in the SMS investigation of the November 2006 incident. We concluded that the company's safety management system was not yet capable or expected to be capable of detecting, analyzing, and mitigating the risks presented by the hazards underlying this occurrence. This finding was listed with "Other Findings," which are intended to clarify a point of ambiguity or controversy. This issue had not contributed to the occurrence.

We were also interested in the company's use of punitive suspension from duty when an SMS non-punitive reporting system was being implemented. Our investigation revealed that, in the fall of 2006, a consultant audited the company's operations and found, in part, that the company's management response to repeated flight crew regulatory infractions was insufficient and recommended that the company implement a disciplinary policy. The company initially used unpaid suspension from duty as punishment, with a subsequent revision to fines of 10% of monthly salary for a first offence and 20% of monthly salary for a second offence, with no suspension from duty. Within 2 months of implementation of this policy, six company pilots had been disciplined, including the accident crew.

Our investigation determined that use of punitive action can substantially impair safety reporting systems. We made a finding as to risk that, in an SMS environment, inappropriate use of punitive actions can result in a decrease in the number of hazards and occurrences reported, thereby reducing effectiveness of the SMS.

The ability to divide the overarching SMS concept into smaller, more manageable elements proved to be quite helpful to our investigation. We were able to more effectively demonstrate that the facts supported our conclusions.

Local rationality

Hindsight bias strongly influenced initial attempts to understand the many deviations from policies and procedures that occurred during the accident flight. At that time, the focus of the investigation was on explaining what should have been done but was not. This approach influenced the analysis and findings in the initial draft report. When external reviewers provided comments on the draft report, it became clear that revisions were necessary.

During the post-review phase, our focus shifted to explaining why the crew behaved as they did, rather than pointing out what they should have done but did not. To help us do this, we applied the principle of local rationality. [8]

That is, people do not go to work with the intent of causing an accident. Their decisions and behaviour make sense to them in the context of their knowledge, circumstances, and goals. Although there may be limited information available, their situation may seem ambiguous, or they may have multiple conflicting goals, they make the best of what they have in order to get their work done.

Our challenge was to understand the world as the crew perceived it, in order to understand how they made sense of the situation. We used this approach to revise the analysis of the transfer of control that occurred during the go-around.

Procedures for clear and consistent verbal communications prevent confusion between pilots as to who has control of the aircraft, and the company had a control transfer procedure that was standard throughout its fleet.

However, the investigation revealed that the captain and first officer occasionally used a non-standard transfer of control practice that varied substantially from the procedure specified in the standard operating procedures. This practice resulted from the captain's mistrust of the first officer's ability to land the aircraft.

During previous flights, the captain had taken control of the aircraft from the first officer on numerous occasions, sometimes doing so using the phrase in the standard operating procedures, "I have control," sometimes using non-standard verbal phrases, and sometimes without making any verbal statement. In instances when the captain took control without making any verbal statement, the first officer's practice was to release the controls upon sensing pressure from the captain's control inputs.

Our problem was that the captain had been fatally injured, and we were unable to confirm he had, in fact, taken control from the first officer during the go-around. In the initial draft report, our analysis of this control transfer was inconclusive. Applying the principle of local rationality helped us to revise our analysis.

As previously discussed, the flight was high on final approach, the first officer was pilot flying, and the captain coached the first officer into the landing flare. The captain decided to initiate a go-around and communicated this decision to the first officer with a non-standard and ambiguous statement.

Having advised the first officer of his intent to conduct a go-around, the captain would have expected the first officer to advance the power levers. However, because the captain's statement was non-standard and ambiguous, the first officer was unsure of the captain's intentions, and did not initiate the go-around by advancing the power levers. Four seconds after communicating his go-around decision, the captain, likely feeling a sense of urgency by now, advanced the power levers himself.

The captain almost certainly took this action because it was clear to him that they could not land safely on the remaining runway, and the first officer had not responded to his communication of his go-around decision.

We examined four possible scenarios of aircraft control during the go-around:

- The first officer was in control.
- Both pilots were attempting to control the aircraft.
- The captain was in control.
- Neither pilot was in control.

Immediately after the captain had advanced the power levers, the first officer perceived pressure on the control column and observed the captain's hand on the control column. Believing the captain was taking control without making any verbal statement, as had occurred on previous flights, the first officer released the control column, also without making any verbal statement, using the non-standard practice they had employed on previous flights.

The first two scenarios listed above did not occur because the first officer released the control column.

On previous flights, the captain had taken control from the first officer both on approach and during landing. Given the captain's mistrust of the first officer's ability to land the aircraft, the lack of response from the first officer to the captain's ambiguous go-around communication, and the fact that the remaining runway was insufficient to land safely, we concluded that it was very likely that the captain did take control from the first officer and became the pilot flying for the remaining 20 seconds of the flight.

We also concluded that the scenario in which neither pilot was controlling the aircraft was very unlikely.

The conclusions we reached in the revised analysis made sense to us in the context of the crew's local rationality. These pilots did things for reasons that made sense to them at the time, given their circumstances, knowledge, and goals.

Conclusions

- Conducting a survey within interviews proved to be a very useful means of obtaining information.
- Use of a time line was very helpful to analyse and understand the occurrence sequence of events and underlying factors. An organizational time line for company managerial activities was also helpful.
- The regulator time line was of low resolution but was useful to establish chronological sequencing. However, it actually introduced confusion because of the inability to portray the complex organizational context within which decisions and actions were taken. Such a time line should be used with caution.
- Arguments regarding deficiencies in concepts such as CRM may not convince the reader. Dividing the concepts into smaller components will provide a trail to your conclusions that the deficiencies existed and contributed to the occurrence.
- The principle of local rationality helped us to understand why the flight crew's decisions and actions made sense to them, and to avoid the negative effects of hindsight bias. ◆

Endnotes

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2 Dekker, S. (2006), The Field Guide to Understanding Human Error, Ashgate, Aldershot, UK.
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Effects of Mental Stressors During Flight on Prosodic Features of Speech And Autonomic Nervous Responses

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Outline

This study examined the relationship between vocal indices and physiological indices of pilots subjected to mental stressors during flight to determine the optimum voice indices for estimating psychological stress.

Introduction

Pilots operates an aircraft with maintaining situational awareness while processing multimodal information, such as visual, auditory, somatosensory, tactile, and olfactory information. Particularly, modern pilots must have highly cognitive abilities including meta cognition and self-monitoring, to play an important role as system programmer, system monitor, and system administrator, not to speak of a good decision-maker who has a good flying skill, which has been crucial ability of the pilot from their incunabula, in their activities. A series of these information processing activities can be done by automatic process for a typical procedure through daily training and experience, and done by pattern matching strategy for relatively easy decision-making matters. It enables pilots to save their cognitive resources. However, in case of unusual emergency, or event which can cause a mishap, the pilot is obliged to decide under highly cognitive workload situation, where the pilot should select the most appropriate solution, while gathering information and considering another solution within limited time under stressful situation in peril of his life.

An estimation of the pilot's emotion during a series of events is necessary to analyze psychology and behavior of the pilot involved in such situations, as well as information of an aircraft system and its maneuver. However, available information is limited, even if the aircraft has an FDR (flight data recorder) or CVR (cockpit voice recorder). In the event of mishap or emergency event of an aircraft that has no FDR or CVR, the sole clue for psychological analysis is the voice of the pilot, that is a radio communication recording between pilot and air traffic controller, HUD (head-up display) VTR of the aircraft, or another aircraft, for example.

Kuroda (1986) reported that an estimation of pilot's stress by voice analysis is an effective method to estimate stress level during emergency situations of real operation. Many researchers tried to examine and reveal adequate voice index for stress level estimation, not only in space and aviation field, but also in defense and jurisdiction; a number of research areas need further investigation (Hansen et al., 2000). Especially, the research related to the relationship between voice indices and physiological indices is required.

Results of previous studies

The glottis movement is innervated by the Xth brain nerve, the vagus for 90%. The vagus has mostly inhibiting functions, controlling activity locally, but does influence nearly all parts of the body, as the parasympathetic part of the autonomic nervous system (Johannes, Salnitski, Gunga, and Kirsch, 2000).

The superior laryngeal nerve controls the cricothyroid muscle, which relates to the fundamental frequency rise by the glottis extension, and the recurrent laryngeal nerve controls the other Intrinsic laryngeal muscles.

Numerous researches have been done from 1960s in the space and aviation field. In 1965, the voice during A.A. Leonov's extravehicular activity outside the Voschod-2 was investigated as information of mental state of a cosmonaut. In 1978, the voice of S. Jaehn during preparation and different flight phases was investigated for voice pitch, formant, and intonation. Due to this kind of research, F0 have been found to indicate higher significantly under mental and physical stress situation of the extreme conditions of space mission.

In Japan, the Aeromedical Laboratory of the Japan Air Self Defense Force started to investigate the voice change characteristics during emergency situations in 1970s, and proposed the VSSR (Vibration Space Shift Rate) index by analyzing the voice, and deliberating the relationship between voice index and assuming emergency situations (Kuroda, Fujiwara, Okamura, and Utsuki, 1976.). VSSR is as F0 increasing rate from that of uneventful situation.

Alpart and Schneider (1987) reported that reaction times tended to be faster and its standard deviation tended to be higher, and frequency and amplitude of the voice tended to be higher and its standard deviation tended to be lower in the high workload condition, as compared with the low workload condition. Brenner and Shipp (1987) examined the following eight voice indices as stress evaluation scales under the sponsorship of United States Air Force, based on the comprehensive literature review by Naval Air Test Center. Results showed that every voice index was less robust than that of heart rate index. Only three indices, as amplitude, fundamental frequency and speech rate, provided significant discrimination.

1. Fundamental frequency (pitch)

There may be an increase in fundamental frequency under stress. Fundamental frequency may reflect the physical tension of the vocal muscles.

2. Amplitude (loudness)

There may be an increase in amplitude under stress. Amplitude may reflect an increased air flow through the lungs.
3. Speech rate
There may be an increase in speech rate under stress. Speech rate may reflect a general speeding up of cognitive and motor processes.
4. Frequency jitter
There may be a decrease in jitter under stress.
5. Amplitude shimmer
There may be a decrease in shimmer under stress.
6. PSE scores (psychological stress evaluator)
There may be an increase in PSE scores under stress.
7. Energy distribution
There may be an increase in the proportion of speech energy between 500Hz and 1,000Hz.
8. Derived measure
There may be an increase in derived measure under stress. A derive measure combines other measures described above statistically.

Schneider and Alpert (1989) examined variation of a test pilot's voice during landing with cross window and turbulence on flight simulator, but it was impossible for them to identify the voice response profiles to the workload during flight. Mendoza and Carballo (1988) examined vocal characteristics under cognitive workload and stress, and results showed that fundamental frequency, frequency jitter, amplitude shimmer, and 1,600Hz to 4,500Hz band harmonics energy increased under stress. A part of these results contradicted the result reported by Brenner et al. (1987).

Teager (1980) invented a non-linear voice index (amplitude modulation component and frequency modulation component) by Teager Energy Operator (TEO). Then, Zhou, Hansen, and Kaiser (1999, 2001) reported TEO based voice index classified stress level accurately than fundamental frequency or Hidden Markov model (HMM).

During the progress of voice indices research, a workshop of "Speech Under Stress" took place in September 1995 by North Atlantic Treaty Organization (NATO), and discussed the stress model and their effects on voice. Then, Murray, Baber, and South (1996) proposed the necessity for another research, because their complexity of stress effects on voice and relationship between stress and voice was still unresolved. NATO has worked on a research project for speech under stress from 1995 to 2000. However, "*Changes in the characteristics of speech produced under workload stress remain unclear.*" due to the report of NATO (Hansen, Swail, South, Moore, Steeneken, Cupples, Anderson, Vloeberghs, Trancoso, and Verlinde, 2000). In addition, NASA (the National Aeronautics and Space Administration) reported that speech rate, fundamental frequency, and amplitude (loudness) have increased statistically under high workload situations, but their shift amount is rather small, as 4%, 2Hz and 1dB for each index. Yet, the relationship between fundamental frequency and emotional load is identified in researches (Johannes et al., 2000). Also, Johannes, Wittels, Enne, Eisinger, Castro, Thomas, Adler, and Gerzer (2007) reported fundamental frequency increased under mental workload, while there was no significant difference by physical workload, so a voice index of fundamental frequency is considered as excellent as a psychological stress index.

Gelfer and Fended (1995) compared voice measures of directly digitized samples with that of digitized from tape recordings. Results showed the high correlation coefficient for fundamental frequency (r=.989, p<.001, N=30), and for jitter (r=967, p<.001, N=30). On the other hand, results showed relatively low correlation coefficient for shimmer (r=.481, p<.01, N=30). Due to the fact that there exist the high correlation for fundamental frequency and jitter, it is reasonable to consider that fundamental frequency and jitter is more robust than shimmer, and it is a proper way to use the audio source of digitized from tape recordings for voice analysis, in case of only an analogue recording of air traffic control facility is available.

NASA's National Space Biomedical Research Institute (NASA/NSBRI) has developed Win SCAT (Spaceflight Cognitive Assessment Tool for Windows) as a cognitive performance evaluation tool for astronauts (Kane, Short, Sipes, and Flynn, 2005), voice analysis method as a index of stress and fatigue will be included as a cognitive monitoring method in near future (Fiedler, 2004). In aviation field, research for examining the relationship between fatigue and voice during a 36-hour mission using B-1B fighter bomber flight simulator took place (Whitmore and Fisher, 1996), but no voice index better than the physiological index has been found so far, for its sensitivity and identifiability. Besides, speech as a data source of voice index is available in natural operational environment, some amounts of data are indispensable for continuous evaluation. Nevertheless, research of voice index has been done without intermission, because researchers looked to voice for its unobtrusiveness, availability, and feasibility. Accompanied with the introduction of voice recognition system on modern aircraft system, research using Hidden Markov model with prior recognition training got into limelight to eliminate noise of fundamental frequency increase, formant frequency shift, higher spectrum component increase, and amplitude increase due to the Lombard effect, or consider an effect under stress of emergency situation, and improve the recognition rate of the system (Hansen and Bou-Ghazale, 1995).

Defense and jurisdiction authorities, as well as the space and aviation field, had great concerns about the advantage of voice index, especially in false detection. The Department of Defense Polygraph Institute began to examine voice stress analysis method. After CVSA (Computer Voice Stress Analyzer, National Institute for Truth Verification) appeared on the market, the United States government purchased the merchandise and trained some examiners, but the outcome failed to meet expectations. Nevertheless, the Department of Defense Polygraph Institute has been examining the software's reliability and validity, as well as the difference from traditional polygraph, because of spread of the software in jurisdiction authorities and great concerns of the United States government (Meyerhoff, Saviolakis, Koenig, and Yourick, 2000). Gamer, Rill, Vossel, and Godard (2006) investigated the validity of several traditional psychophysiological measures and vocal measures of TrusterPro (Trustech) in the detection of guilty knowledge. Results showed that electrodermal, respiratory, and cardiovascular measures achieved hit rates of more than 90%, but vocal measures of the TrusterPro were invalid for its validity and reliability, because its hit level was not above chance level. Moreover, Damphousse, Pointon, Upchurch, and Moore (2007) investigated the validity of VSA (Voice Stress Analysis) for LVA (Layered Voice Analysis, LVA Solutions) and CVSA (Computerized Voice Stress Analyzer, National Institute for Truth Verification). Their results also showed that both software were invalid for its validity and reliability, because its hit level was not above chance level.

After all these researches, no voice measures have been found so far that sensitivity and identifiability are beyond physiological

Figure 1. F-2 fighter aircraft.

measures. Nevertheless, the United States Department of Defense has been interested in voice measures as an important information sources, as EEG (electroencephalogram), eye movement, and thermography (Meyerhoff et al., 2000).

Another researcher examined voice measures for an estimation of intent or feeling of speaker. Maekawa and Kitagawa (1999) analyzed fundamental frequency, amplitude and duration of voice by Kruskal's multidimensional scaling method and multiple regression analysis; the results showed high correlation and predicted paralinguistic information (doubt, praise, dismay, indifference, neutral, and emphasis) precisely. Nwe, Foo, and Silvaet (2003) examined voice measure of log frequency power coefficients (LFPC), and the results showed that the proposed system yielded an average accuracy of 78% and the best accuracy of 96% in the classification of six emotions by using hidden Markov model (HMM).

Purpose

The purpose of this research is investigating the relationship between vocal indices and physiological indices of pilots under stressor during flight to find out the optimum voice indices to estimate psychological stress. The word "stress" in this paper deals with acute distress.

Method

During flight training of the JASDF (Japan Air Self Defense Force) fighter pilot training course, the voice and the physiological indices of the pilot was recorded and analyzed. The flight simulator scenario was derived from the JASDF fighter pilot training course syllabus.

1. Subjects

Thirteen pilots of the JASDF attended the experiments. Seven pilots were trainees, and six were instructor pilot.

2. Flight simulator

The flight simulator was F-2s, which precisely simulates flight characteristics and cockpit of F-2 fighter aircraft. The simulator has 210° horizontal field-of-view and 110° horizontal field-of-view visual display system; projection resolution is 8.5min/OLP(optical line pairs) for front area and 9.5min/OLP for peripheral area, and luminance is 2ft-L(6.85 cd/m^2). The F-2 is a multi-role, single engine, fighter aircraft based on the F-16C/D Block 40 and tailored to Japan's requirements (see Figure 1).

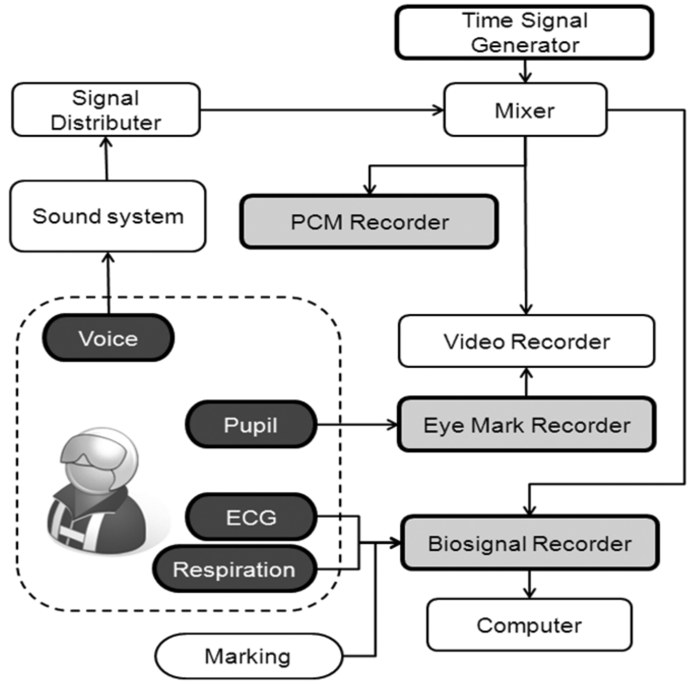


Figure 2. Schematic diagram of the measuring devices.

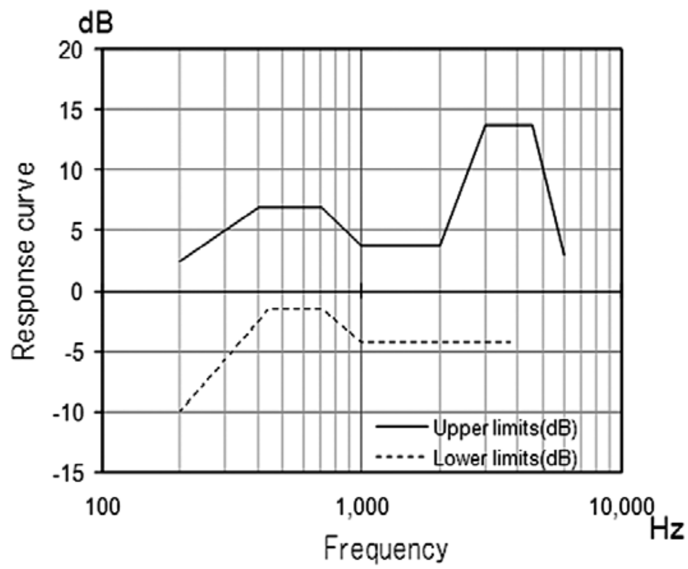


Figure 3. Frequency response chart of the microphone.

3. Measuring devices

The schematic diagram is as shown in Figure 2.

3.1. Digital audio recorder

Voice was recorded on PCM audio recorder (PCM-D1, SONY) (48 kHz, 16 bit) via built-in microphone of O_2 mask. Figure 3 indicates frequency response chart of the microphone.

3.2. Eye mark recorder

Pupil diameter was recorded on the eye mark recorder (EMR-8B with 62° visual angle lens, nac) by recording unit attached on helmet.

3.3. Biosignal Recorder

Electrocardiogram(ECG) and respiration was recorded on biosignal recorder (BIOPAC Type-MP30, BIOPAC System) at 250 Hz, by NASA lead using electrode leads(SS2L, BIOPAC System) attached to disposable electrode (Vitrode M, NIHON KOHDEN).

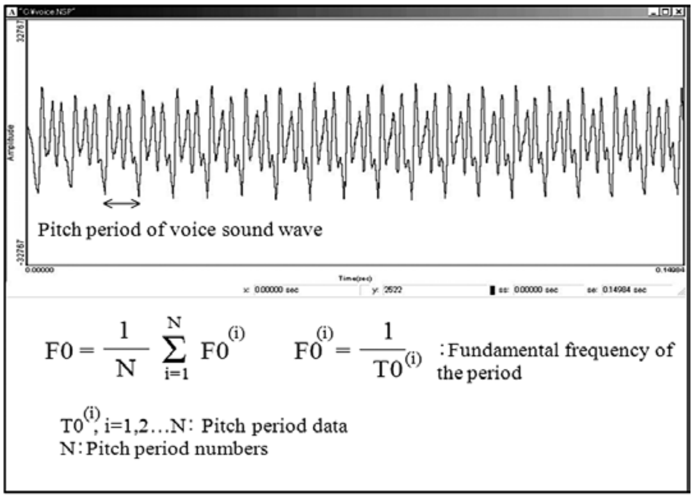


Figure 4. Fundamental frequency.

4. Data reduction and analysis

4.1. Digital audio recorder

Voice data were analyzed by voice analysis software (Multi-Speech Model 3700 Ver.2.3 and Multi-Dimensional Voice Program Model 5105 Ver.2.3, Kay Elemetrics) to obtain fundamental frequency and frequency jitter. Proceeding to the analysis, fundamental frequency extraction errors that resulted from noise were eliminated by examining spectrogram and amplitude of the voice signal.

4.2. Eye mark recorder

Variations of pupil diameter were encoded to eye mark recorder codes and recorded on videotape recorder, and then the data were imported to personal computer via IEEE1394 port as DV stream and converted to avi files. The encoded data were decoded by eye mark recorder analysis software (EMR-dFactory Ver.1.2, nac Image Technology) to obtain variations of pupil diameter, and then the data were smoothed using moving average method (time span: 0.2 sec.).

EMR-8B eye mark recorder utilizes an image of binarization and obtains pupil diameter in the process of detecting the center coordinate. Spatial resolution of eye mark detecting unit is 0.02 mm.

4.3. Biosignal recorder

R-R interval, heartbeat rate, and respiration frequency were analyzed by biosignal data analysis software (Biopac Student Lab PRO Ver.3.6.7 BIOPAC Systems). R-R interval was detected by rate detector function of the software, using positive peak detection; the window was 0.33 for minimum and 1.5 for maximum (40 bpm-180 bpm). Noise reduction width was 5% (5% of peak to peak width), with "remove baseline ON," "Automatic threshold ON" to prevent miscounting of spike of noise.

Maximum entropy method (regression order=100, Number of estimated spectral values=8,193, Burg algorithm) was applied to examining spectrogram and confirmed validity of detected R-R interval. R-R interval was corrected by examining original electrocardiogram wave when respiration frequency was strongly observed or error of rate detector function of the software existed. In addition, heart rate variability was analyzed by HRV analysis software (HRV Analysis Software Ver.1.1, University of Kuopio), for 0 Hz-0.04 Hz as VLF band component, 0.04 Hz-0.15 Hz as LF band component, and 0.15Hz-0.40 Hz as HF band component.

The low frequency baseline trend component was removed using the smoothness priors method (g=300, equivalent for cutoff frequency at 0.043Hz). Spectrum estimation was analyzed by the Welch's Periodogram (1,024 points, hamming window 512, overlap 256) with interpolation rate of 4 Hz. Detrending method was that of Tarvainen (2002) recommended.

5. Measuring variables

Voice indices and physiological indices analysis range was 30 sec, which Roscoe (1992) recommended for HRV and heartbeat rate for relatively short time duration.

5.1. Voice index

The experiment was executed during flight simulator training, so there existed difficulty to control speech contents and microphone setting for amplitude analysis. Considering the experiment condition, fundamental frequency and frequency jitter related voice index was selected for voice index, though there are many voice indices such as speech duration, amplitude, frequency spectrum, formant pattern, and so forth.

5.1.1. Mode fundamental frequency

Fundamental frequency is the inverse of the pitch period length, or the lowest frequency in a harmonic series (see Figure 4).

Mode fundamental frequency is mode value, or the value that has the largest number of observations.

5.1.2. Average fundamental frequency

The average fundamental frequency is the average value of observations.

5.1.3. Fundamental frequency increasing rate

The fundamental frequency increasing rate is the value derived from average fundamental frequency divided by average fundamental frequency during aviation communication sentence reading task.

5.1.4. Stanine scale of fundamental frequency increasing rate

The stanine scale of fundamental frequency increasing rate is the value derived from the standardized point of fundamental frequency increasing rate as standard nine scale.

5.1.5. Fundamental frequency standard deviation

The fundamental frequency standard deviation is the value of standard deviation of fundamental frequency.

5.1.6. Absolute jitter

Absolute jitter is an evaluation of the period-to-period variability of the pitch period within the analyzed voice sample (see Figure 5). Absolute jitter has high sensitivity to the period-to-period variability, but susceptible to pitch extraction error.

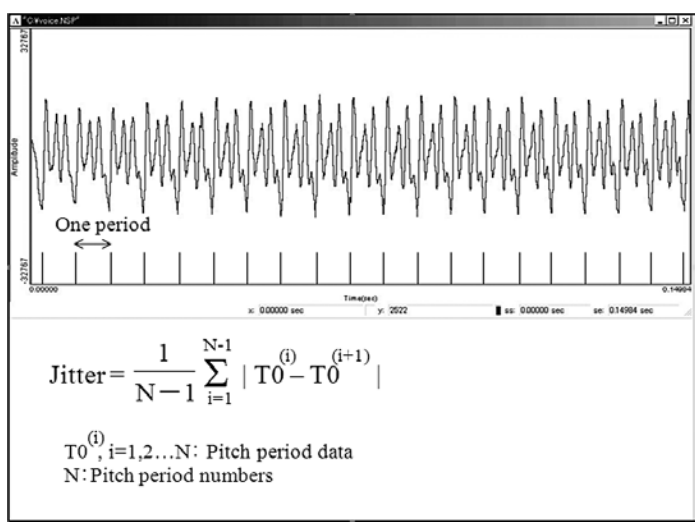
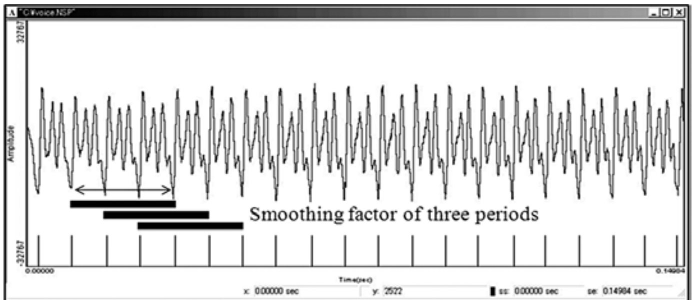


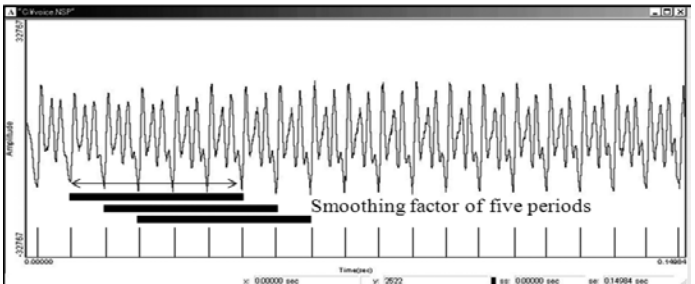
Figure 5. Absolute jitter.



$$RAP = \frac{\frac{1}{N-2}\sum_{i=2}^{N-1}\left|\frac{T0^{(i-1)}+T0^{(i)}+T0^{(i+1)}}{3}-T0^{(i)}\right|}{\frac{1}{N}\sum_{i=1}^{N}T0^{(i)}}$$

$T0^{(i)}$, i=1,2…N: Pitch period data
N: Pitch period numbers

Figure 6. Relative average perturbation.



$$PPQ = \frac{\frac{1}{N-4}\sum_{i=1}^{N-4}\left|\frac{1}{5}\sum_{r=0}^{4}T0^{(i+r)}-T0^{(i+2)}\right|}{\frac{1}{N}\sum_{i=1}^{N}T0^{(i)}}$$

$T0^{(i)}$, i=1,2…N: Pitch period data
N: Pitch period numbers

Figure 7. Pitch period perturbation quotient.

5.1.7. Relative average perturbation
The relative average perturbation (RAP) is relative evaluation of the period-to-period variability of the pitch within the analyzed voice sample with a smoothing factor of three periods. Relative average perturbation is less sensitive to both period-to-period variability and pitch extraction error, but is capable of indicating results of short period (three periods) in detail (see Figure 6).

5.1.8. Pitch period perturbation quotient
The pitch period perturbation quotient (PPQ) is the relative evaluation of the period-to-period variability of the pitch within the analyzed voice sample with a smoothing factor of five periods (see Figure 7).

5.1.9. Smoothed pitch period perturbation quotient
The smoothed pitch period perturbation quotient (sPPQ) is the relative evaluation of the period-to-period variability of the pitch within the analyzed voice sample with a smoothing factor, smoothing factor of 55 is adapted in this paper. The more the smoothing factor is high, the more detail results of long-term evaluation of the period-to-period variability of the pitch can derived from the data (see Figure 8).

5.2. Physiological index

5.2.1. Pupil diameter

$$sPPQ = \frac{\frac{1}{N-sf+1}\sum_{i=1}^{N-sf+1}\left|\frac{1}{sf}\sum_{r=0}^{sf-1}T0^{(i+r)}-T0^{(i+m)}\right|}{\frac{1}{N}\sum_{i=1}^{N}T0^{(i)}}$$

$T0^{(i)}$, i=1,2…N: Pitch period data
N: Pitch period numbers
Sf: Smoothing factor

Figure 8. Smoothed pitch period perturbation quotient.

The pupil diameter is the average value of observations.

5.2.2. Pupil diameter standard deviation
The pupil diameter standard deviation is the value of standard deviation of pupil diameter.

5.2.3. Average heartbeat rate
The average heartbeat rate is the average value of observations.

5.2.4. Incremental heartbeat rate
The incremental heartbeat rate is the difference between average heartbeat rate and average heartbeat rate during 2 minutes rest after flight simulator training.

5.2.5. Heartbeat rate increasing rate
The heartbeat rate increasing rate is the value derived from heartbeat rate divided by average heartbeat rate during 2 minutes rest after flight simulator training.

5.2.6. Heartbeat rate standard Deviation
The heartbeat rate standard deviation is the value of standard deviation of heartbeat rate.

5.2.7. Root mean square successive differences (RMSSD)
The RMSSD is the square root of the mean of the sum of the squares of differences between adjacent NN intervals.

5.2.8. Low frequency power (LF)
The LF is the relative power in low frequency range (0.04-0.15Hz) of heart rate variability.

5.2.9. High frequency power (HF)
The HF is the relative power in high frequency range (0.15-0.4Hz) of heart rate variability.

5.2.10. Ratio LF/HF (LF/HF)
The LF/HF is the value derived from LF absolute power divided by HF absolute power.

Results

1. Pearson Product-Moment Correlations between the voice index and the physiological index

Pearson product-moment correlations were calculated to examine the relationship between the voice index and the physiological index. The results are shown in Table 1.

The results showed that the correlation between the average fundamental frequency and the pupil diameter was significant (r=.411, p<.001), and between the mode fundamental frequency and the pupil diameter was significant (r=.306, p<.001). The correlation between the average fundamental frequency and the average heartbeat rate was significant (r=.236, p<.001). The correlation between the fundamental frequency increasing rate and the average heartbeat rate was significant (r=.251, p<.001), and between the fundamental frequency increasing rate and the pupil diameter standard deviation was significant (r=-.225, p<.001). The correlation between the stanine

	F0m	F0	F0 Rate	F0 Scale	F0 SD	JITTER	RAP	PPQ	sPPQ	PUPIL	PUPIL SD	HR M	ΔHR	HR Rate	HR SD	RMSSD	LPP	HPP	LF/HF
Mode Fundamental Frequency(F0m)		.803	.396	.365	.296	-.360	-.163	-.167	-.081	.306	.077	.171	.004	-.028	.048	.059	-.072	.077	-.069
Average Fundamental Frequency(F0)	926		.451	.405	.248	-.481	-.227	-.263	-.209	.411	.129	.236	-.001	-.047	-.039	-.022	-.116	.117	-.092
Fundamental Frequency Increasing Rate(F0 Rate)	926	926		.945	.495	-.149	-.047	-.020	.087	.143	-.225	.251	.122	.093	.124	.048	.004	-.009	.016
Stanine Scale of Fundamental Frequency Increasing Rate(F0 Scale)	926	926	926		.463	-.126	-.037	-.010	.079	.140	-.205	.250	.113	.083	.123	.043	-.004	-.002	.016
Fundamental Frequency Standard Deviation(F0 SD)	926	926	926	926		.140	.198	.300	.539	.052	-.055	.212	.272	.267	.280	.207	.014	-.013	.019
Absolute Jitter(JITTER)	926	926	926	926	926		.944	.941	.443	-.073	-.011	-.026	.113	.133	.134	.070	.061	-.069	.045
Relative Average Perturbation(RAP)	926	926	926	926	926	926		.962	.399	.027	.055	.021	.098	.107	.112	.040	.049	-.058	.047
Pitch Period Perturbation Quotient(PPQ)	926	926	926	926	926	926	926		.521	.037	.000	.059	.179	.193	.195	.119	.025	-.032	.017
Smoothed Pitch Period Perturbation Quotient(sPPQ)	926	926	926	926	926	926	926	926		.004	-.091	.081	.268	.291	.274	.198	.000	-.005	-.007
Pupil Diameter(PUPIL)	924	924	924	924	924	924	924	924	924		.121	.407	.149	.083	-.028	-.127	-.132	.125	-.113
Pupil Diameter Standard Deviation(PUPIL SD)	924	924	924	924	924	924	924	924	924	1163		-.169	-.103	-.081	-.132	-.087	.078	-.078	.067
Average Heartbeat Rate(HR M)	913	913	913	913	913	913	913	913	913	1144	1144		.585	.443	.004	-.413	-.084	.070	-.109
Incremental Heartbeat Rate(ΔHR)	913	913	913	913	913	913	913	913	913	1144	1144	1160		.980	.184	-.045	-.076	.064	-.105
Heartbeat Rate Increasing Rate(HR Rate)	913	913	913	913	913	913	913	913	913	1144	1144	1160	1160		.225	.047	-.077	.067	-.100
Heartbeat Rate Standard Deviation(HR SD)	913	913	913	913	913	913	913	913	913	1144	1144	1160	1160	1160		.718	.100	-.109	.066
Root Mean Square Successive Differences(RMSSD)	913	913	913	913	913	913	913	913	913	1144	1144	1160	1160	1160	1160		-.153	.165	-.094
Low Frequency Relative Power(LPP)	913	913	913	913	913	913	913	913	913	1144	1144	1160	1160	1160	1160	1160		-.994	.642
High Frequency Relative Power(HPP)	913	913	913	913	913	913	913	913	913	1144	1144	1160	1160	1160	1160	1160	1160		-.646
Ratio LF/HF(LF/HF)	913	913	913	913	913	913	913	913	913	1144	1144	1160	1160	1160	1160	1160	1160	1160	

Note: The upper right number indicates the correlation coefficients, the lower left number indicates the effective sample number. ***p<.001、** p<.01、* p<.05、† p<.10

Table 1. Pearson Product-Moment Correlations Between the Voice Index and the Physiological Index.

respectively.

The results demonstrated that eigenvalue λ^2 of canonical correlations using the average fundamental frequency, the fundamental frequency increasing rate, the fundamental frequency standard deviation and the smoothed pitch period perturbation quotient as voice variables was higher (λ^2=.238-.521) than that of canonical correlations using the average fundamental frequency, the fundamental frequency increasing rate only as voice variables (λ^2=.220-.510). The results suggest that the fundamental frequency standard deviation and the smoothed pitch period perturbation quotient should be included as voice variables, as well as the average fundamental frequency and the fundamental frequency increasing rate, when we estimate the autonomic nervous response effect.

scale of fundamental frequency increasing rate and the heartbeat rate was significant (r=.250, p<.001), and between the stanine scale of fundamental frequency increasing rate and the pupil diameter standard deviation was significant (r=-.205, p<.001). The correlation between the fundamental frequency standard deviation and the heartbeat rate was significant (r=.212, p<.001), and also the incremental heartbeat rate (r=.272, p<.001), the heartbeat rate increasing rate (r=.267, p<.001), the heartbeat rate standard deviation (r=.280, p<.001), Root mean square successive differences (r=.207, p<.001) was correlated significantly with the fundamental frequency standard deviation. The correlation between the smoothed pitch period perturbation quotient and the Incremental heartbeat rate was significant (r=.268, p<.001), and the heartbeat rate increasing rate (r=.291, p<.001), and the heartbeat rate standard deviation (r=.274, p<.001) were correlated significantly with the fundamental frequency standard deviation.

2. Multiple Regression Analysis of the physiological index to the voice index

The multiple regression analysis was run to examine the relationship between a single voice index as an index dependent variable and multiple physiological indices as criterion variables.

The stepwise method was selected (Criteria: probability of F to enter <=.05, Probability of F to remove >=.10), and the model that VIF (Variation Inflation Factor) was not greater than five was selected to avoiding multicollinearity problem during the analysis. As a criterion variable, the mode fundamental frequency, the average fundamental frequency, the stanine scale of fundamental frequency increasing rate, the fundamental frequency standard deviation, the absolute jitter, the relative average perturbation and the pitch period perturbation quotient were adopted. And as index dependent variables, physiological indices were adopted for all subjects, and for the instructor pilots and trainees group, respectively. R-square value which is an indicator of how well the model fits, the data were not good (R^2=.025-.282). The results of this analysis have identified the difficulty of using a single voice index as vocal indicator of stress during simulated flight.

3. Canonical correlations analysis

The canonical correlations analysis was run to examine the relationship between the voice indices and the physiological indices in consideration of the complexity of the autonomic response for all subjects, and for the instructor pilots and trainees group,

4. Discriminant analysis

The discriminant analysis was run to examine the discrimination ability of simulated emergency situation of the flight simulator training by the canonical variant of the voice index derived from the canonical analysis. The discriminant analysis adopted the canonical variant of the voice index as an index independent variable, and the situation whether emergency or not as dependent variables for all instructor pilots and trainees group respectively. The results demonstrated that the canonical correlations for all subjects was significant (λ=.283, p<.001), and also that for trainees group was significant (λ=.363, p<.001). The cross-checked error rate was 37% and 39%, respectively. Then the discriminant analysis for each subject was run, and the results demonstrated that the canonical correlations for five subjects was significant (λ=.331-.525,p<.001-p<.10). The cross-checked error rate was 25.5% to 41.7%. The results suggested that there were individual differences of the relationship between voice indices and autonomic responses, though the stressor level of the simulated emergency situation and direction from the instructor pilot during simulated flight was not enough to induce voice responses. So the possibility of repressors or sensitizers and alexithymia trait should be evaluated, as well as cardiovascular system response trait evaluation.

5. Covariances structure analysis (CSA)

Structural equation modeling (SEM) is used to test complex relationships between voice and autonomic responses. As a result, the structural model showed in the Figure 9 indicated the highest validity among structural models examined.

In Figure 9, we can visualize the structural model that shows the relations between the variables. The model adopted the average fundamental frequency and the absolute jitter as observed variables of the voice index, and the pupil diameter and the average heartbeat rate as observed variables of the physiological index.

SEM is used to test "complex" relationships between observed (measured) and unobserved (latent) variables and also relationships between two or more latent variables.

5.1. Assessing fit of the model

The measures of the assessing fit of the model showed very good value (χ^2=.535(df=1), p=.464, *n.s.*, CMIN/DF=.535, PRATIO=.100, NCP=0, LO90=0, RMSEA=0, PCLOSE=.845, CFI=1, AIC=26.535)

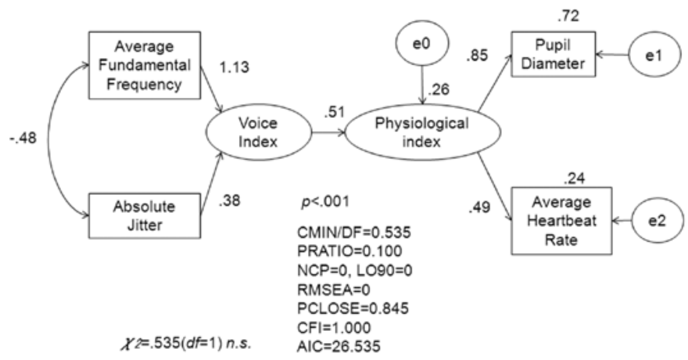


Figure 9. Covariances structure analysis result (standardized estimates).

5.2. Standardized regression coefficients of the model

The standardized regression coefficients of the path of the voice index to the physiological index was .51 (R^2=.26, p<.001).

Correlation between two observed variables of the voice index was significant (r=-.48,p<.001), the standardized regression coefficients of the path of the average fundamental frequency to the voice index was 1.13 (p<.001), and the standardized regression coefficients of the path of the absolute jitter to the voice index was .38 (p<.001).

The standardized regression coefficients of the path of the physiological index to the pupil diameter was .85 (R^2=.74, pp<.001), and the standardized regression coefficients of the path of the physiological index to the average heartbeat rate was .49 (R^2=.27, p<.001).

6. Application of new multiple voice index to real flight situation

To verify the efficacy of the new multiple voice index, the last model of SEM was applied to the voice index of real flight situations. Results show that the stanine scale of fundamental frequency increasing rate has faults to express the trend of psychological stress, comparing to the new multiple voice index. Besides, the new multiple voice index surpass the fundamental frequency increasing rate in interpreting the trend of psychological stress, and more sensitive to understand autonomic nervous responses.

Conclusions

To examine the relationship between voice and autonomic nervous responses more systematically, we should consider CNS activities, as EEG, cerebral metabolism, and blood flow, as well as internal secretion and immunity.

For efficient utilization of voice variables as stress index of the pilot in case of mishap investigation, I recommend that the safety investigation board construct a voice database of pilots during calm condition on ground in advance. And whenever interpreting the results of voice stress analysis, presume that there exists individual differences of autonomic nervous response characteristics, and the psychologist should interpret the results deliberately on a basis of psychological knowledge, as well as the pilot's personality and experiences.

Continued research including the basic study and application of the study results to field work in this area is required to provide reliable measures of stress during flight.

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Heathrow 777: Challenges in Understanding Unusual Properties in Aviation Fuel and Problems In Conducting Tests to Determine The Vulnerability of an Aircraft's Fuel System to the Accumulation and Release of Ice

By Brian McDermid, Senior inspector (Engineering), Air Accidents Investigation Branch

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Several days after the British Airways Boeing triple seven landed short at Heathrow airport I joined the investigation and was tasked with chairing the Fuel and Aircraft Fuel Systems Group. Up to that point, my main knowledge of the accident had been gleaned from the news media and there seemed to be a general consensus between the various commentators that as the aircraft was intact, and there was a considerable amount of recorded data available, it would only be a matter of days before the Air Accident Investigation Branch determined the cause of the accident. In reality, it was a further year before we felt that we had sufficient evidence to formally publish the most likely cause of the accident.

During the next 20 minutes, I will highlight some of the problems that we experienced during the investigation and give you some background on the decisions that were made and the evolution of the Boeing fuel test rig.

For my group, the initial priority was the testing of the fuel. And like many aspects of the investigation, the extent of the testing was agreed by telephone conferences involving representatives from the AAIB, the NTSB and specialists from Boeing, Rolls-Royce, and the fuels division at QinetiQ, who throughout this investigation acted as our independent fuels adviser. In excess of 66 fuel samples were taken from a variety of locations on the aircraft and engines. In addition, around three tonnes of fuel were removed from the aircraft fuel tanks and had to be kept in case it was required for further testing. The logistics of finding a sufficient number of suitable containers and the secure handling of such a large number of samples was an early indication that a complex investigation of a large aircraft brings large problems, which, to an extent, dictates the pace of the investigation.

Extensive testing could identify nothing unusual about the fuel samples taken from the aircraft, and as aviation turbine fuel contains thousands of different hydrocarbons we could not establish if there was a specific combination that made this batch of fuel more susceptible to icing. We compared the main hydrocarbon groups with the industry standards, and the fuel was found to be within the normal range. QinetiQ undertook a comparison of the fuel on the accident flight with more than 1,200 batches of fuel sampled during 2007. As you can see, in terms of the distillation range, the fuel from Mike Mike was more or less in the middle of the distribution.

In order for the runway to be returned to full operational use, a decision was made to move the aircraft from the accident site to a maintenance area adjacent to the threshold of Runway 27 Left. The proposed site seemed to be ideal. Close by there was a good size office, toilets, and storage facilities. Engineering support from British Airways was also readily at hand, and there was excellent IT and administrative support from our own staff. So what could possibly be wrong with such an ideal site? From the initial examination of the aircraft, analysis of the data on the flight recorders, and testing of the fuel samples, it quickly became apparent that the engine control system had functioned correctly and there was nothing apparently wrong with the fuel remaining on the aircraft. With no obvious cause for the double engine roll back, it was decided to conduct a more detailed inspection and test of the aircraft fuel delivery system prior to any part of the fuel system being disturbed. This would require us to carry out pressure and vacuum tests during which we would have to listen for and trace leaks in a fuel delivery system containing more than 110 feet of fuel pipes. Unfortunately the hold for Runway 27 Left was adjacent to the area in which we were working on the aircraft, and it was impossible to detect any leaks over the noise from the engines of aircraft waiting to line up on the runway. The constant exposure to the noise was also very tiring, and communication, and any type of fault finding, was difficult when this runway was used for aircraft taking off. Whilst noise-abatement procedures are a sensitive issue at Heathrow, the investigator in charge negotiated with the airport authorities for a 48- hour period during which Runway 27 Left would only be used for landings. However, it still took more than 24 hours for the operational changes to be instigated.

The large aircraft syndrome came into play again during the inspection and testing of the aircraft fuel system. The fuel delivery pipes still contained fuel that could not be drained out. This meant that it was not possible to use the videoscopes that are normally used in the aviation industry, as they are not safe to use in an explosive environment. We tried to blow the fuel out of the pipelines with nitrogen, but this was unsuccessful, and consequently there was a further delay as we tried to find an explosive proof videoscope with a probe at least 30 feet long. A suitable videoscope was eventually hired from a company in Hamburg. Later in the investigation, we discovered that the water industry use explosive proof videoscopes to inspect sewers and one was used during an inspection of another Boeing triple seven aircraft to determine where ice and water might accumulate in the fuel tanks. Nevertheless, the issue of cameras plagued us throughout this investigation and none of the parties in the investigation could identify a suitable camera that we were happy to use in the explosive environment of a wet fuel system. Instead we relied on still photographs taken from the videoscope.

On the positive side, we were very thankful for an early decision to accept the offer from Boeing for one of their videoscope operators to be flown over from Seattle. He was not only familiar with inspecting the inside of the fuel delivery system, but he also had a great ability to tease the probe around the many contours and corners in the long pipe runs.

The extensive testing and examination of the aircraft fuel system could not identify a fault that would have caused the engines to roll back. Therefore, many of the fuel system components were removed and in most cases sent to the original equipment manufacturer for further inspection and testing under the supervision of one of our inspectors. We also made the decision to assemble the left side of the engine and aircraft fuel delivery system removed from the accident aircraft in one of our hangars at Farnborough. This reconstruction proved to be invaluable and was the first time that most people involved in the investigation had actually seen a large aircraft fuel system laid out. The reconstruction was also useful in identifying potential scenarios and subsequently helped us in defining the boundaries and factors that we wished to be included in the Boeing fuel test rig. It was also necessary during the investigation to construct a fluid dynamic model of the fuel feed system, and again the reconstruction proved to be very useful as pipe dimensions and gradients could be taken directly from the reconstruction.

Whilst the work on the aircraft was still ongoing, representatives from all the parties in the investigation met in Seattle to develop possible scenarios and provide technical support for the fieldwork. As various causes were eliminated, the possibility that ice in the fuel might have caused the accident gradually took greater precedence and Boeing identified two of their test facilities where they could carryout some fuel system icing tests.

Small-scale fuel tests were carried out in a climatic chamber at the Boeing Kent facility to allow us to understand how ice forms in cold fuel. At the same time, Boeing assembled a large-scale fuel test rig at their North Boeing Field facility. Whilst it was not intended to replicate the fuel system on the aircraft, it did use 2-inch diameter fuel pipes and components fitted to the Boeing triple seven aircraft and the Trent 800 engine. Over time a number of changes were made to the rig such that it became more complex and components such as the engine driven low pressure fuel pump were fitted and hot oil was fed to the fuel oil heat exchanger.

The tests carried out on the rig consistently proved that it was possible to restrict the fuel flow through a hot fuel oil heat exchanger with a relatively small quantity of water, providing the water was introduced at a high enough concentration.

However, we had less success in generating ice in other parts of the fuel system, and even with identical conditions we experienced poor repeatability and the term "the randomness of ice" regularly cropped up in test reports and briefings. Consequently we began to question if the variations between the aircraft and fuel test rig, and the technical innovations used to try and maintain the water concentration in cold fuel, might mask other subtle causal factors with the risk that we might inadvertently engineer a restriction that could not occur in flight.

It is worth stating that there was tremendous support from within the aviation industry, and whilst Boeing was running the tests on their fuel rig we explored the problems of ice forming in aircraft fuel systems with other aircraft manufacturers, universities, and research organizations. Information was also freely exchanged between Airbus and Boeing, which both use the Trent engine on their aircraft. As investigators, we go to great lengths to protect proprietary information, and therefore it was a new experience to be in

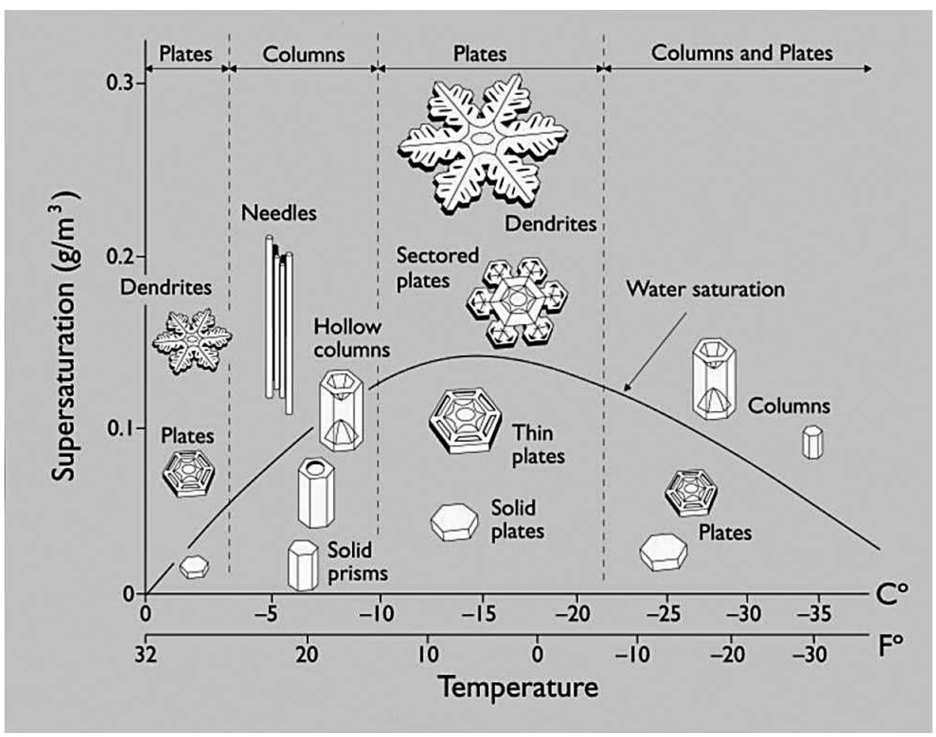

Figure 1. The crystal structure of water ice at different temperatures.

the same room with two of the major aircraft manufacturers as they described how their fuel systems were designed and discussed how they may or may not be susceptible to icing. We were also present at a similar meeting that Boeing arranged with Rolls-Royce, GE, and Pratt and Whitney.

Documentation searches were also carried out, and we discovered that fuel icing was a known problem on civil aircraft in the 1940s and 1950s and that some research had been carried out to address problems such as blocked inlet screens and fuel filters. Whilst these early papers frequently recommended that further research was required to understand the root cause of fuel icing, the recommendations did not appear to have been taken forward. Instead measures such as fuel heaters and filter bypasses were introduced, which addressed the symptom rather than the root cause.

During the 1950s the United States Air Force suspected that a number of accidents involving B-52 aircraft were caused by ice in the fuel system, but given the perishable nature of ice they could not find any evidence. That was until 1958 when on a cold day, all eight engines on a B-52 lost power during the approach and the aircraft crashed in South Dakota where the ambient temperature was below freezing. Despite the aircraft catching fire, ice was found throughout the fuel system and in the engine fuel filters. As a result of this finding, the United States Air Force initiated an extensive research programme that resulted in the development and introduction of a fuel system icing inhibitor. However, it is extremely difficult to establish what research military organisations have carried out, and it is even more difficult to obtain copies of their test reports. This is a particular problem with foreign military organisations. But we also had difficulty in obtaining test reports for the spar valve fitted to the Boeing triple seven as the testing had been carried out to meet a military requirement. Despite this difficulty, some test reports and supporting documentation was eventually released to the investigation.

Figure 1 shows the crystal structure of water ice at different temperatures, and I think most of you can look at some of these structures and hazard a guess at the properties of the ice. Would you be surprised if I told you that this was taken from a snow boarding website on the Internet, and no one in the aviation, or fuel industry, could provide us with anything like this for ice that forms in aviation fuel?

The more we delved into the early research papers on fuel system icing, the more we began to understand how complex it is. The size, and perhaps the type, of the ice crystals is dependent on the size of the water droplets, the rate of cooling, amount of agitation, and the number and type of nuclei. Large water droplets settle quickly; larger ice crystals cannot negotiate corners as easily as smaller crystals. I could spend the rest of the day talking to you about the formation of ice, but instead I just want to leave you with the message that as an industry we appear to know relatively little about ice in fuel. This lack of knowledge was a concern to us during the investigation as we could not be totally sure that the type of ice that we generated on the fuel test rig was representative of the ice that is generated in flight.

The data mining group activity identified the low temperatures experienced on the accident flight as being a possible significant factor, and there were suggestions from certain quarters outside the Air Accident Investigation Branch that as an interim measure the Boeing triple seven should not be used on routes where extreme low temperatures were likely to be encountered. However from our documentation review we knew that that it was difficult for ice to adhere to components when the fuel temperature was extremely

low and that ice was most likely to accumulate when the fuel temperature was between -8 and -20 degrees Celsius. The slide above summarises some of the facts we know about water ice in aviation fuel, though I should caveat this information by warning you that these temperature bands are not well defined and several papers appear to contradict each other. Whilst we had some knowledge of the sticky range of ice, we could not say with any great confidence that the very low fuel temperature experienced on the accident flight was a coincidence, rather than a causal factor, until we analysed the data from the roll back that occurred on one of the engines on a Delta aircraft in November 2008.

With our increasing concern that the Boeing fuel test rig might mask some subtle factor, a number of options were explored to try and more accurately replicate the aircraft installation and the environment during the accident flight. These options included flight testing; full scale testing of an aircraft in a climatic chamber, and testing of the fuel system in an environmental test rig.

Flight testing initially appeared to be the most obvious choice and was something that Boeing and Rolls-Royce were prepared to support. The main advantage is that you test the actual aircraft systems in its normal operating environment. There were, however, a number of disadvantages that swayed us from going down this path. Firstly we needed a suitable aircraft that might need to be modified with sensors and recorders; we would have been unable to control the external environment; we weren't sure what we were looking for and as a fuel flow restriction caused by a blockage of ice was such a rare event there was a real possibility that it might not occur during any of the test flights. There was also the difficulty in establishing when ice was forming as the roll-back experienced on the accident flight would require around 97% of the cross sectional area of the pipe to be blocked by ice. A lesser amount of ice would have little effect on the fuel pressure and temperature, so pressure and temperature instrumentation would have been of little help. We also could not use cameras to detect the accumulation of ice as cold fuel containing suspended water, and ice, is very cloudy.

The McKinley climatic chamber at Eglin Air Force Base in Florida was identified as a suitable facility in which to conduct full scale testing of a Boeing triple seven aircraft. The downside was that the facility is heavily utilised and there was only a 3-week window available, which would have given us around 10 days of testing. The facility would have allowed us to expose the aircraft to the total air temperature experienced during the accident flight for an unlimited period. We could have used the aircraft boost pumps to pump fuel from the main tanks to the engine where the fuel would be tapped of to a collector tank. Alternatively, we could have run one of the engines at cruise power for one hour at the fuel flow experienced during the accident flight. Unfortunately, like the flight testing option, we would still have the problems of aircraft availability, matching all the environmental factors, and the detection of the formation of ice.

Testing the fuel system in an environmental fuel rig appeared to be the only viable option remaining, and we discussed our desired requirement for a single pass test of sections of the aircraft fuel system with a number of agencies. Single pass testing is where fresh conditioned fuel is pumped from a supply tank through the test section and into a collector tank. For a large aircraft system this requires a considerable quantity of fresh fuel that needs to be stored and cooled down to the required temperature. By recirculating the fuel, it is possible to use a smaller quantity of fuel and therefore smaller storage tanks. However, a disadvantage of a recirculating test rig is that it effectively dries the fuel out, and we were concerned that introducing additional water to maintain the required concentration might give us unrepresentative results. Unfortunately, there are few facilities that could carry out single pass testing on the scale required.

In the end we had to accept the limitations of a recirculating test rig in order to achieve the desired long endurance runs, which were necessary to establish if ice would accumulate along the inside of the fuel delivery pipes. We were fortunate in that Boeing had a suitable fuel tank available in which we could mount the fuel delivery pipes removed from the right main fuel tank of Mike Mike. These fuel pipes were fed from a supply tank that had been cooled and conditioned with water to represent the condition of the fuel during the accident flight.

The results from the environmental testing were very consistent, and the final test proved the theory that ice can build up in the pipes and then release in a sufficient quantity to restrict the fuel flow through the fuel oil heat exchanger.

This has been a very quick overview of the fuel systems aspect of the Mike Mike investigation. However, I hope that you do not fall into the trap of believing that it was a fault in either the fuel oil heat exchanger or the aircraft fuel system that was the cause of the accident to the British Airways Boeing triple seven. Modification of the FOHE will make the system more tolerant of ice, but it will not prevent ice accretion and release within the fuel feed system. The problem of fuel system icing was identified in the 1940s and 1950s and recommendations were made on a number of occasions that further research was required to fully understand the extent of the problem. However research to establish the root cause of fuel system icing does not appear to have been carried out, and instead a number of measures such as the introduction of fuel heaters and bypasses were introduced to fix specific problems. But as we have seen, these measures only store up problems for the future, and we do not know what combination of aircraft, engine, and environmental factors will result in the next fuel icing accident. It is for this reason that the we believe that it is important that the regulative authorities instigate a number of coherent research programmes into fuel system icing in order to underpin the future design and certification requirements for commercial aircraft.

That concludes this presentation. Hopefully I have given you a feel for the problems we encountered and the close cooperation among ourselves, Boeing, and Rolls-Royce. And of course not forgetting the support we were given by a large number of organisations and individuals within our industry. ◆

Undersea Search Operations: Lessons and Recommendations From Flight 447

By Alain Bouillard, Head of Safety Investigations, and Olivier Ferrante, Head of Recovery Group, BEA, France

Alain Bouillard *Photo and bio not available*

Olivier Ferrante*, topic presenter, joined the BEA in 2000 as the head of the Safety Analysis Division. He was seconded to the FAA in 2006 and 2007 to work on data sharing and risk modelling under a BEA-FAA cooperation agreement. He also worked with the Commercial Aviation Safety Team (CAST). Olivier holds a master's degree in aviation engineering from the French National Civil Aviation School (ENAC). He is also a pilot and a certified diver.*

Abstract

On June 1, 2009, Air France Flight AF447, an Airbus A330-200 registered F-GZCP, disappeared over the ocean while en route between Rio de Janeiro (Brazil) and Paris-Charles de Gaulle (France). Several underwater sea search campaigns were undertaken to locate the wreckage over a vast area of the Atlantic Ocean.

These searches faced several difficulties such as the remoteness of the zone, the absence of any trace of the accident in the first days, the absence of an emergency distress message, and the lack of radar data. The environment was also very unfavourable since the search zones were above the Atlantic ridge close to the equator. This implied that the underwater terrain was rough, with great variations in depth over short distances. The proximity to the equator also affected the modelling of the currents in the estimated accident zone.

This paper aims to share the wealth of experience that has been gained from preparing and managing the sea search campaigns. The search teams analyzed several types of data coming from a wide range of means: underwater hydrophones, side scan sonars (autonomous and towed), submarines (deepwater and nuclear), remotely operated vehicles, AWACS, satellites (military and civilian), etc. No efforts were spared in this challenging endeavour. A wide range of specialists from all over the world are closely supporting the BEA with the same objective of finding the wreckage and the flight recorders so as to better understand the circumstances and determine the causes of this accident.

Introduction

On Sunday May 31, 2009, the Airbus A330-203 registered F-GZCP operated by Air France was scheduled to undertake Flight AF447 between Rio de Janeiro Galeão and Paris Charles de Gaulle. Twelve crewmembers and 216 passengers were on board. The airplane took off at 22 h 29. The crew contacted, successively

- RIO DE JANEIRO approach control,
- the CURITIBA ATC centre, which cleared it to climb to FL350 at 22 h 45,
- the BRASILIA ATC centre at 22 h 55,
- the RECIFE ATC centre at 23 h 19, the airplane being stable at FL350, and
- the ATLANTICO ATC centre on HF at 1 h 33.

At 1 h 35, the crew informed the ATLANTICO controller that they had passed the INTOL point then announced the following estimated times: SALPU at 1 h 48 min then ORARO at 2 h 00. They also transmitted their SELCAL code and a test was performed. The controller asked them to maintain FL350 and to give their estimated time at the TASIL point. The crew did not answer. Afterwards, the controller asked the crew three times for its estimated time at the TASIL point. There was no further contact with the crew.

The airplane was configured to send position messages every 10 minutes via the ACARS system. The last position message (operational type message) was transmitted on June 1 at 2 h 10. The last coordinates received were latitude +2.98° (north) and longitude -030.59° (west). This point is also called the last known position

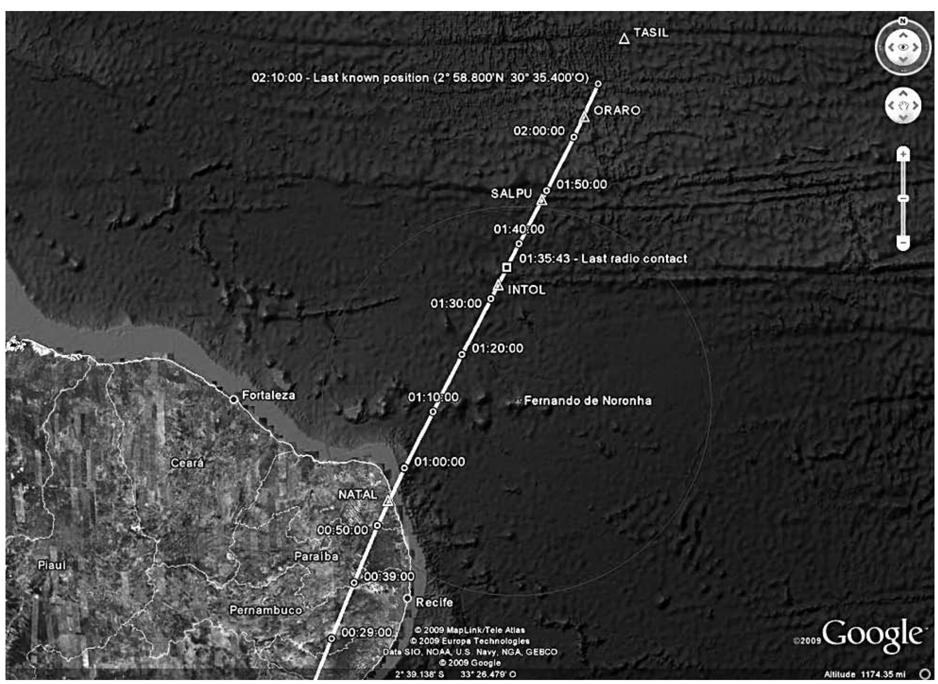

Figure 1. AF447 trajectory.

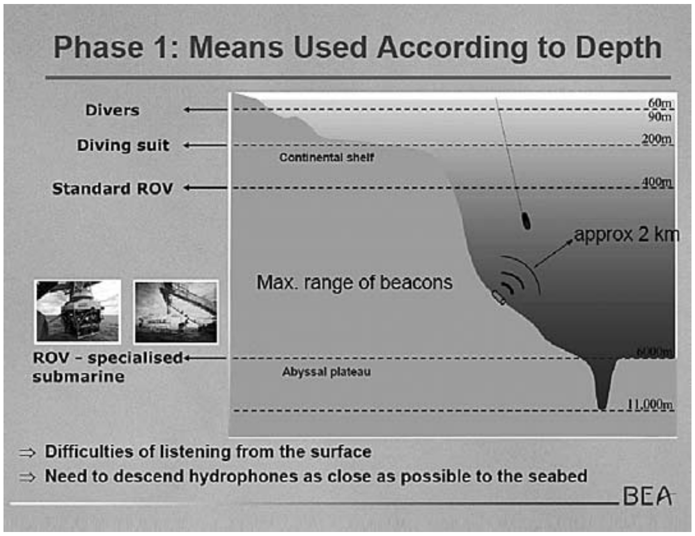

Figure 2. Adapting the search means to the depth.

(LKP). In addition to this operational message, 24 maintenance messages were received on June 1 between 2 h 10 and 2 h 15. Their analysis suggests that the airplane probably did not fly for more than another 5 minutes. This means a likely maximum distance of less than 40 nm. The accident site is thus probably located within a circle with a radius of 40 nm centred on the last known position.

Surface search

A massive international search and recovery effort was undertaken after the disappearance of Flight AF447. The Brazilian and French armed forces mobilized search and rescue vessels and aircraft. The United States also participated and several merchant vessels joined the search, which was coordinated by the Recife MRCC, the airplane having disappeared in its zone of SAR responsibility.

The surface searches focused on possible transmissions from ELT beacons[1] and the localisation of floating debris. This led to the recovery of bodies and parts of the airplane from June 6, 2009, onward.

Difficulty of the searches

The first difficulty is the remoteness of the zone, which requires transits of the order of 2 to 4 days from ports such as Praia (Cape Verde), Natal (Brazil), or Dakar (Senegal). The absence of any trace of the accident in the first days and the absence of an emergency distress message or radar data complicated the searches. The environment is also very unfavourable since the search zones are above the Atlantic ridge close to the equator. This implies that the underwater terrain is rough, with great variations in depth over short distances.

The proximity to the equator affects the modelling of the currents in the estimated accident zone. The lack of available on-the-spot data and the complex oceanic dynamic (notably due to the seasonal start of the north-equatorial counter-current during the month of June) also made it difficult to model the marine currents. These factors contributed to making the reverse-drift calculations imprecise, added to which it was necessary to make them over a period of 5 to 6 days, which accentuated the gaps.

From Searching with hydrophones to using side scan sonars

Searching with towed hydrophones

As the aircraft's recorders were each equipped with an underwater locator beacon, it was decided to prioritise an acoustic search initially, though taking into account the limited range of the beacon transmitters, which is about 2 km at most. The propagation of acoustic waves in a liquid medium, which depends on many interdependent parameters such as the salinity and the temperature of the water, must also be taken into account. When an acoustic wave is propagated in the sea, it can be subjected to refractions and this generates multiple trajectories. The acoustic waves may also be deflected in such a way that there is a "shadow" region that is never reached by these waves.

Acoustic searches using beacons that transmit at 37.5 KHz (± 1 KHz) are in general more effective than searches using sonar, magnetometers, and video cameras. Nevertheless, the duration of the beacon transmission is limited, being certified for a minimum transmission duration of 30 days from immersion. This short timeframe implied a race against time to select, contract and send search assets to the middle of the Atlantic. The BEA contacted the manufacturer of the beacons, which stated that the duration of transmission was of the order of 40 days. This is why the search using hydrophones ended on July 10, 2010 (later called phase 1).

Taking into account the range of the beacon transmissions, the hydrophones had to be brought closer to the source of any transmission, by towing specialized equipment near the seabed.

In relation to towed acoustic devices, the BEA approached the U.S. Navy. The latter has two towed pinger locator (TPL) hydrophones and uses them regularly to search for civil or military aircraft crashed at sea. The U.S. Navy TPLs can operate at up to a depth of 6,000 m. They operate on a waveband between 5 and 60 KHz, which includes the frequency transmitted by the underwater locator beacons. To optimize the use of this equipment, the BEA chartered two available ships from the Dutch subsidiary of Louis-Dreyfus Armateurs. These two tugs were the *Fairmount Expedition* and the *Fairmount Glacier.*

Deploying side scan sonars

At the end of 31 days of acoustic searches in phase 1, no signals had been detected from the flight recorders' ULBs, and no parts of the wreckage of F-GZCP could be located after underwater observations of the seabed. Side scan sonars represented the best-adapted search means in the absence of any beacon transmissions.

Operating principle

A side scan sonar is designed to produce detailed acoustic images of the seabed. A narrow acoustic beam is transmitted at a low angle (see Figure 3). It illuminates the seabed over a narrow strip. Within

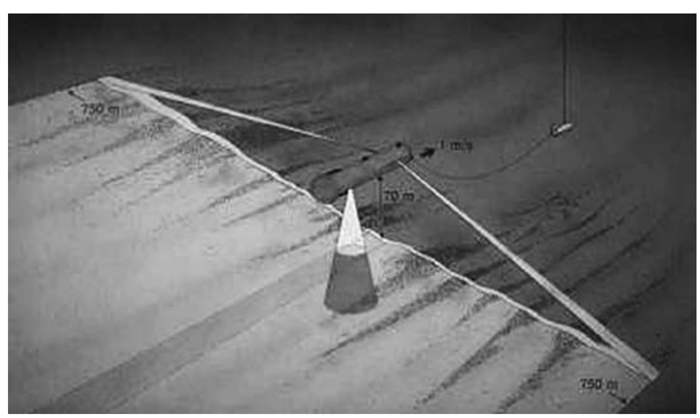

Figure 3. Towed side scan sonar towed at 70 m above the seabed and having a swath of 1,500 m.

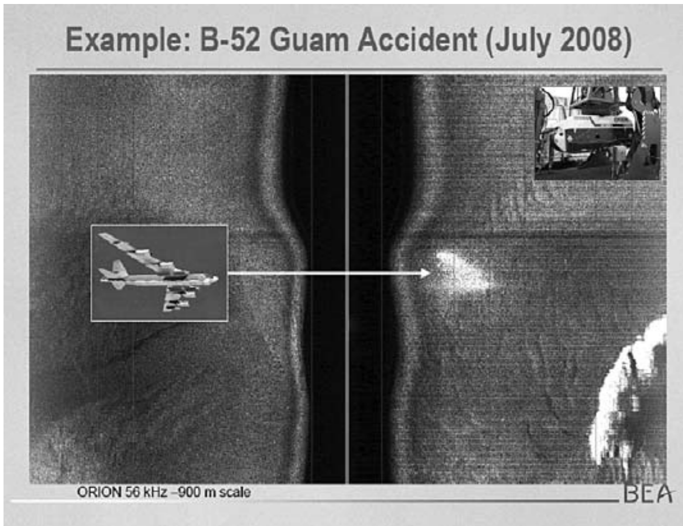

Figure 4. Underwater sonar image.

its range, the transmitted signal delineates an "acoustic area" that sweeps on both sides of this whole zone, called a swath. Thus, the sonar represents a backscattered image of the seabed along its swath. This backscattered data enables visualisation of the presence of anomalies or small obstacles, which are detected by this signal, through its high resolution capacity. This signal is laterally recorded as the sonar moves forward. This is how, line after line, an "acoustic image" of the seabed is built up.

Backscattered images

Backscattering depends on the composition of the seabed. Rocks or hard sediments will reflect (backscatter) more than soft sediments. The formation of "shadows" on the seabed also has an interesting effect. An obstacle with enough elevation will intercept a portion of the transmitted beams, and therefore prevent some seabed backscattering at some times and at given angles. This will mean that the image will contain some shadows with a shape associated with that of the object. Careful analysis will enable to assess its size and shape. This specificity is very useful in the search for objects on the seabed such as wreckage. The following image (see Figure 4) shows an acoustic image of the seabed (depth of approx 3,600 m) with the presence of the wreckage of a crashed airplane. It represents a B-52 that crashed off Guam in July 2008 and that was localized with the ORION towed side scan sonar. The size of the Airbus A330 is comparable to that of a B-52. The wreckage of the disappeared Airbus could resemble this image with similar underwater terrain. Using sonar (mounted on towed or autonomous vehicles), analysts have been searching for man-made objects that appear as anomalies on backscattered images.

For phase 2, the IFREMER towed sonar array was installed on the *Pourquoi Pas?* ship in Dakar during its port call. For this exploratory mission to deep undersea sites, the *Pourquoi Pas?* was equipped with its multibeam echosounder, the towed sonar array, the Victor 6000 ROV and the Nautile submarine.

During this mission, a detachment of the French Navy Hydrographical and Oceanographic Service (SHOM) completed data on the topography of the area and carried out a complete bathymetric survey of the zone within a circle of 40 nm centred on the last known position (see Figure 5). The *Pourquoi Pas?* also acquired 12 kHz and 24 kHz acoustic images of the seabed thanks to its hull-mounted multibeam echosounder. The IFREMER team on board the *Pourquoi Pas?* developed a methodology based on the analysis of the various acoustic images. The geologists in the search team were a very valuable asset during the sonar search.

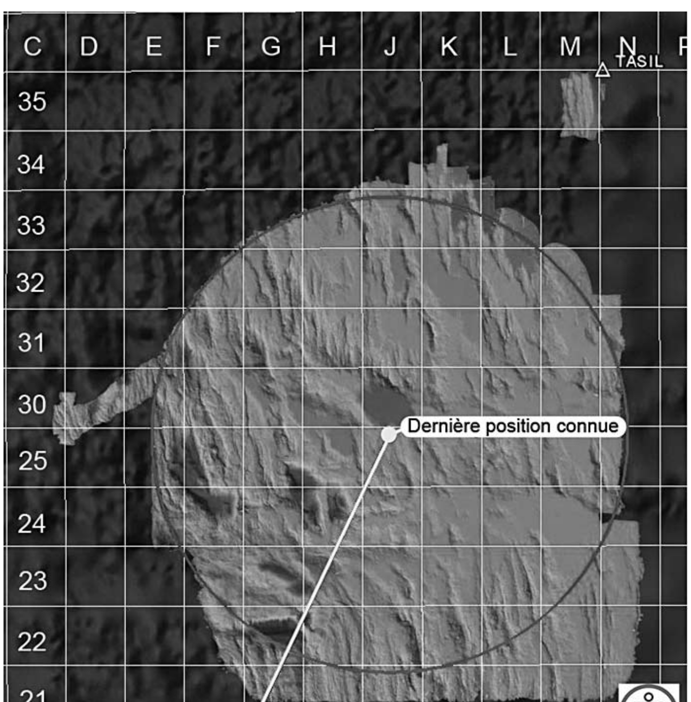

Figure 5. Bathymetry of the search area.

Summary of the various search phases

The various search phases involved several specialized organizations from all over the world. The contractual and the financial aspects involved numerous complex operations.

Phase 1: June 10–July 10, 2009 (on site)

The first phase involved the search for the flight recorders via the signals transmitted by the underwater locator beacons (ULB), each recorder being equipped with a beacon designed to transmit a signal for a notional period of at least thirty days when immersed. In the first few days after the accident, a search zone of the order of 17,000 km was defined within a circle with a radius of about 40 nm (around 72 km).

The French Navy deployed two ships, *BPC Mistral* and the frigate *Ventôse,* and the *Emeraude* nuclear submarine. The United States made available a team of specialists and technical equipment.

The BEA chartered three ships (the *Pourquoi Pas?* from IFREMER and the two tugs from Fairmount Marine). This operation required establishing an appropriate formal legal framework immediately after the accident to ensure mobilisation of

- equipment from IFREMER in the context of a procurement contract signed by the BEA within the context of article 35-II of the public works contract regulations, taking into account the overriding urgency of this commitment.
- ships to tow the U.S. Navy's acoustic systems. These were chartered as early as June 5 by the BEA under the terms of a contract established under Dutch law that was signed with the Dutch company Fairmount Marine.

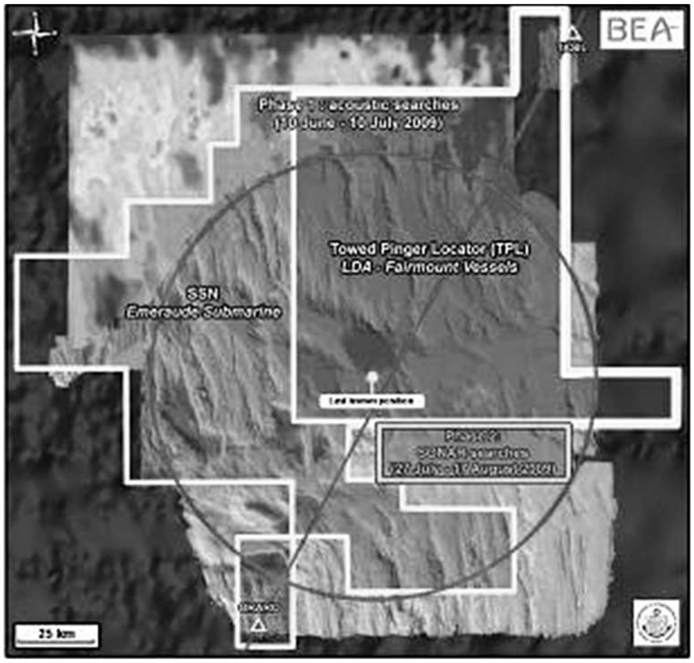

Figure 6. Zones covered during phases 1 and 2.

Phase 2: July 27–Aug. 17, 2009 (on site)
The objective of the second phase was to search for the airplane wreckage with the aid of towed sonar and Victor 6000 and Nautile underwater vehicles. This phase was concentrated on the squaring line (J-M 24), which had not been explored because of a lack of time. The bathymetry of the zone, consisting of a plain and slight slopes, was compatible with the use of the IFREMER towed sonar. An area of 1,230 km was covered during phase 2, completed by reconnaissance dives. None of the detections corresponded to airplane debris.

The first two phases cost the BEA an estimated 10 million Euros. This does not include the millions spent by the Brazilian and French armies in the immediate aftermath of the accident.

Preparation of phase 3: September 2009–January 2010
During phase 1, scientists were brought together in the context of a "Drift Committee" working group. The objective was to estimate a search zone based on calculations of the drift of the bodies and airplane parts that had been recovered. To prepare phase 3 of the sea searches, the BEA enlarged this working group with international partners, in order to identify the possibility of improving the reverse drift calculations. The group was made up of representatives from the following scientific organisations: CNRS/Brest, University of Massachusetts/Dartmouth, INMRAS/Moscow, Mercator Océan/Toulouse, CLS/Toulouse, WHOI/Woods Hole, IMT/Toulouse, SHOM/Brest, NOC/Southampton, IFREMER/Brest and Météo-France/Toulouse.

During the preparatory work, analysis of the data from the previous phases and modelling of the structures of the sea currents made it possible to estimate the drift of the airplane debris between the date of the accident on June 1, and the time of recovery from June 6 onward. This work led to a significant reduction in the area of the zone, which was thus reduced from almost 17,000 km to around 2,000 km (see initial zone on Figure 7).

In January 2010, an international call for tenders made it possible to select candidates and offers from international operators. This required a complex legal framework that included

- a charter contract under U.S. law between the BEA and the two companies selected, Seabed AS and Phoenix International Inc., in accordance with maritime practices.
- two service contracts, respectively under Norwegian and U.S. law, with these two companies.
- an amendment to an intergovernmental agreement in order to be able to pay for services provided through the U.S. Navy.

The above services were financed thanks to a fund set up with Airbus and Air France, who each provided $6.5 M.

In February 2010, the BEA chartered two ships with the most high-technology equipment on board that could operate down to depths of 6,000 m:

- The American ship *Anne Candies* from Phoenix International equipped with an ORION deep towed sonar and a CURV 21 remotely operated vehicle (ROV) belonging to the U.S. Navy.
- the Norwegian ship *Seabed Worker* from the Seabed AS company equipped with one Triton XLX 4000 remotely operated vehicle (ROV) and three REMUS 6000 autonomous underwater vehicles (AUV) operated by the American Woods Hole Oceanographic Institution (WHOI), of which two belonged to the Waitts Institute for Discovery (WID) and one to GEOMAR, the German oceanographic institute.

Phase 3: April 2–May 24, 2010
1st period: from April 2-25, 2010 (on site)
The ships left the port of Recife (Brazil) on March 29and the sea searches took place from April 2-25, 2010, which was when the ships left the search zone. They arrived in the port of Recife on April 28, 2010, for a port call. At the end of this first period, an area of around 4,500 km had been explored.

2nd period: from May 3-24, 2010 (on site)
In order to take advantage of the means already mobilized for this operation, it was decided to extend the searches. Since the U.S. Navy ROV and sonar, installed on board the *Anne Candies*, were no

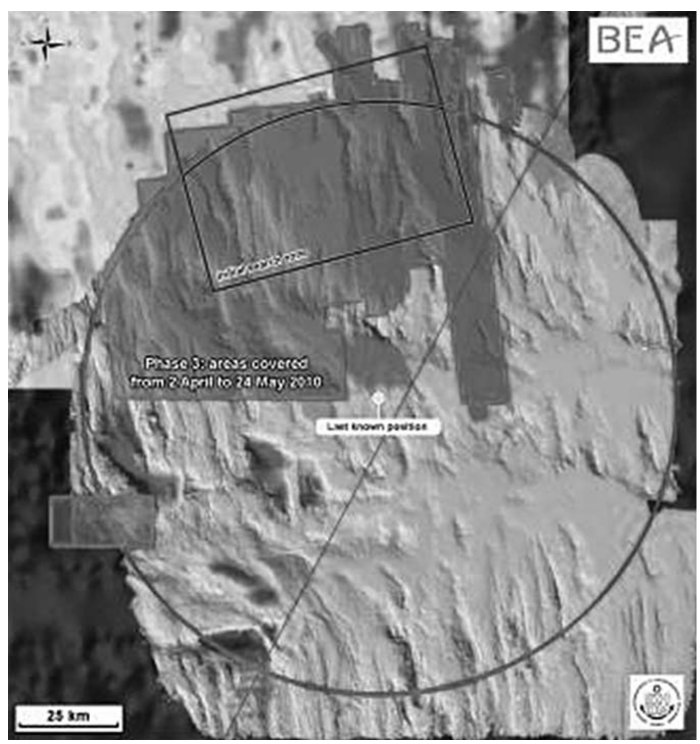

Figure 7. Areas covered during phase 3.

longer available as a result of an American military operation, and the GEOMAR Remus had to participate in a scientific operation, the sea search operations continued with the *Seabed Worker* and the two Remus operated by WHOI.

On May 6, the French Ministry of Defence provided information on the results of analytical work carried out on the data recorded on June 30 and July 1, 2009, by the *Emeraude* nuclear submarine, during the first phase of the searches. The BEA thus decided to extend its searches: a zone was defined based on the French Navy's identification of acoustic signatures similar to those transmitted by an underwater locator beacon (ULB) during post analysis of the data.

The *Seabed Worker* then sailed to an area located south-west of the last known airplane position. This was explored from May 7-12, 2010, without any success in localising the airplane wreckage. After ensuring optimal coverage of the whole of the zone, the BEA decided to return to the original search area. The *Seabed Worker* continued its searches in zones from May 13-24, which was when the ship left the search area to sail to the port of Praia (Cabo Verde). During this second period, an area of almost 1,800 km was explored, including the zone of around 300 km^2 defined on the basis of the data provided by the French Navy.

In total, an area of nearly 6,300 km was thus explored between April 2 and May 24, 2010, but without having been able to find the airplane wreckage.

Conclusions

These search efforts to find the wreckage and solve the enigma of the Rio-Paris flight have required wide-ranging international cooperation (Brazil, France, the USA, Norway, and others). From a race against time to operate the TPLs while the beacons were still transmitting, it became a very complex operation for the preparation of the subsequent phases when time was less of a factor. The BEA has been fortunate to benefit from the assistance of the international group in order to ensure that it selected the best means available.

The negative search results triggered some lessons learned (which are presented in Interim Report n°2) in order to facilitate the localisation of the wreckage:

• The dropping of drift-measurement buoys by the first aircraft to arrive over the zone would have made it possible to understand the drift better from the earliest hours.

• The utilisation of ULB beacons capable of transmitting for 90 days would have made it possible to prolong the search for the ULB beacons in this vast zone.

• The 37.5 kHz ULB beacons have a limited range, which means that specific equipment, not very widely available, must be used for depths greater than 1,500 m, above all when the wreckage is far from the coast. The utilisation of beacons transmitting at lower frequencies (for example between 8.5 and 9.5 kHz) would have made it much easier to detect the wreckage. The French and foreign military equipment is designed to detect these low-frequency signals, which carry further, more quickly from the surface.

Some of this feedback and other BEA safety recommendations have been taken on board by ICAO so that future accidents at sea should be easier to investigate.

The BEA has been reviewing all the data gathered since the accident as well as the results of the unsuccessful search efforts. These efforts included air, satellite, and surface searches for floating debris as well as the results of phase 1 (pinger search) and phase 2 and 3 (wreckage search). The performance of each sensor is also being assessed. The objective here is to produce a probability map of the areas to be searched. This will be helpful in making appropriate decisions about the fourth campaign of sea searches. ◆

Endnotes

1 The airplane was equipped with three emergency locator transmitters (one automatic activation ELT and two manual activation ELTs). One manual activation ELT was recovered. Its switch was found to be in the OFF position.

Colgan Air Flight 3407: Achieving The Delicate Balance Between Timely And Thorough While Staying True To the Investigative Process

By Lorenda Ward, Senior Investigator-In-Charge, United States National Transportation Safety Board

***Lorenda Ward** has worked for the National Transportation Safety Board (NTSB) since 1998. In addition to the Colgan Air investigation, she was the investigator-in-charge for the Edelweiss uncontained engine failure in Miami, Fla.; the Era S76A++ helicopter crash in the Gulf of Mexico; the Executive Airlines ATR 72 crash in San Juan, Puerto Rico; the Air Midwest Flight 5481 crash in Charlotte, N.C.; the Pinnacle Airlines CL-600 2B-19 accident in Jefferson City, Mo.; the Cirrus SR20 accident in Manhattan, N.Y.; and the ABX Air B-767 ground fire in San Francisco, Calif. She has acted as an accredited representative to numerous foreign accident and incident investigations. She worked six major water recovery accidents, along with numerous mid-air collisions and inflight breakups. She supported the Federal Bureau of Investigation at both the Pentagon and the World Trade Center after the terrorists' attacks. Before coming to the NTSB she worked for the U.S. Navy as an aerospace engineer on the EA-6B and F-14 programs. She received her bachelor degree and master of aerospace engineering degree from Auburn University.*

Abstract

In keeping with the International Society of Air Safety Investigators theme for this year's conference, "Investigating ASIA in Mind—Accurate, Speedy, Independent, and Authentic," this paper will convey the author's ASIA experience on the Colgan Air accident investigation. The investigation identified numerous safety issues, which resulted in 25 safety recommendations to the Federal Aviation Administration (FAA) that focused on operations and human performance. This paper discusses the challenges and decision-making process followed in order to complete the Colgan Air investigation within one year without compromising thoroughness and quality.

On Feb. 12, 2009, about 10:17 p.m. Eastern Standard Time,[1] a Colgan Air, Bombardier DHC-8-400, N200WQ, operating as Continental Connection Flight 3407, experienced a loss of control on an instrument approach to the Buffalo-Niagara International Airport, Buffalo, N.Y., and crashed into a residence in Clarence Center, N.Y., about 5 nautical miles northeast of the airport.

The 2 pilots, 2 flight attendants, and 45 passengers aboard the airplane were killed, one person on the ground was killed, and the airplane was destroyed by impact forces and a post-crash fire. The flight was operating under the provisions of 14 Code of Federal Regulations Part 121 as a scheduled passenger flight from Liberty International Airport, Newark, N.J., to Buffalo. Night visual meteorological conditions prevailed at the time of the accident.

The flight crew was scheduled to report for duty at 1:30 p.m. on the day of the accident. The crew's first two flights of the day were cancelled because of high winds at the airport. The planned departure time for Flight 3407 was 7:45 p.m. with a planned arrival time of 10:21 p.m.

The captain was the pilot flying, and the intended cruise altitude was 16,000 feet. During the ascent to 16,000 feet, all de-ice systems were selected on, including the icing reference speed switch, and stayed on throughout the flight. About 40 minutes into the flight, the crew began the descent portion of the flight.

About 9:54 p.m. the first officer briefed the airspeeds for landing with flaps at 15 degrees as 118 knots (reference landing speed) and 114 knots (go-around speed). The first officer had obtained the landing airspeeds for non-icing conditions. She did not enter the keywords that would indicate the flight was in icing conditions; therefore, the landing speed of 118 knots that was set by the flight crew was 13 knots below the actual stick shaker activation speed of 131 knots, which was applicable with the reference speed switch activated.

About 10:10 p.m. the flight crew discussed the build-up of ice on the windshield. A few minutes later, the flight was cleared to 2,300 feet. About 10:14 p.m., the airplane reached 2,300 feet and maintained this altitude for about 2 minutes before the stick shaker activated.

During this time, power was reduced to near flight idle, the altitude hold mode was active, airspeed slowed down from about 180 to about 130 knots, and pitch increased from 3 to 10 degrees. About 10:16 p.m. the crew lowered the landing gear. About 20 seconds later, per the captain's request, the first officer moved the flaps from 5 to 10 degrees.

When the airplane reached 131 knots, the stick shaker activated and the autopilot disengaged. A review of performance data indicated that the airplane was not close to an actual stall because the airplane had minimum ice accretion, but the flight crew was unaware of that fact. The captain reacted to the stick shaker by pulling back on the control column and applying less than the fully rated power. The captain's aggressive pulling back on the control column increased the angle-of-attack, pitch, and load factor, causing the airplane to enter an accelerated stall.

This action was accompanied by a pitch-up motion, and a left roll, followed by a right roll, during which the stick pusher activated and the flaps retracted. The airspeed decreased, and, after further pitch and roll excursions, the airplane pitched down, entering a steep descent from which it did not recover.

During the stall sequence, the stick pusher fired three times to decrease the angle-of-attack. However, after each activation, the captain continued to pull back on the control column, which exacerbated the airplane's stalled condition and prevented a potential recovery.

At the time of the accident, the weather observed at Buffalo indicated winds from 250 degrees at 14 knots, visibility 3 miles in light snow and mist, a few clouds at 1,100 feet, ceiling overcast at 2,100 feet, and temperature of 1 degree Celsius.

Throughout the day there had been pilot reports (PIREPS) of light rime icing in the Buffalo area. The last PIREP before the accident was at 6:15 p.m., when an Airbus 319 pilot reported light to moderate rime icing at 5,000 feet, 10 miles southeast of Buffalo. The temperature was minus 7 degrees C.

The National Transportation Safety Board (NTSB) was notified of the accident about 10:30 p.m. on Feb. 12, 2009. A go-team consisting of a Board member and 17 NTSB staff members was launched early the next morning. The cockpit voice recorder (CVR) and flight data recorder (FDR) were recovered the first day on scene and sent back to NTSB headquarters in Washington, D.C. The CVR had 2 hours of data, and the FDR had 250 parameters.

The team was on scene for 8 days documenting the wreckage, conducting interviews, and collecting records related to the accident flight, airplane, and crew. On the eight day, the wreckage was transported to a storage facility in Delaware.

During March and April, the team conducted more than 30 interviews and completed documentation in preparation for the enbanc[2] public hearing that was held May 12-14, 2009. During the hearing, 20 witnesses from Bombardier, the National Aeronautics and Space Administration (NASA), Colgan Air, the Air Line Pilots Association (ALPA), and the Federal Aviation Administration (FAA) were sworn in to discuss the following:

- airplane performance,
- cold weather operations,
- sterile cockpit,
- flight crew training and performance, and
- fatigue management.

The technical panel was comprised of investigators from the NTSB and the Transportation Safety Board (TSB) of Canada, along with the NTSB's director of aviation safety and the director of research and engineering. Parties to the public hearing were the FAA, Colgan Air, ALPA, and Bombardier.

After the public hearing, both the U.S. Senate and U.S. House of Representatives held hearings on issues stemming from the Colgan Air investigation. Then-Chairman Mark V. Rosenker provided testimony to the Senate and House in mid-June. Testimony was also given by the FAA administrator, members of the aviation industry, and a spokesman for the families of the passengers. Shortly after the June hearings, the FAA administrator issued a "Call to Action" to address ways to improve pilot hiring, training, and testing at all airlines.

On July 29, 2009, HR3371: Airline Safety and Pilot Training Improvement Act of 2009 was introduced to Congress. This bill increases pilot training requirements, addresses pilot fatigue, makes pilot records easier to obtain, and strengthens the FAA's safety programs.

The flight crew's experience and training was examined by the NTSB's operations and human performance experts. The captain had received his type rating in the Dash 8 in November 2008, only a few months before the crash. He had a total flight time of 3,379 hours, with 1,030 as pilot-in-command and 110.7 in the Dash 8. In the 90 days preceding the accident, he had flown 116 hours, including 56 hours in the last 30 days and 16 hours in the last 7 days.

The first officer received second-in-command privileges on the Dash 8 in March 2008. She reported 2,244 hours total pilot time with 774 hours in the Dash 8. In the 90 days preceding the accident, she had flown 163 hours, including 57 hours in the last 30 days and 15 hours in the last 7 days.

During the investigation, the NTSB discovered that the accident captain had four FAA certificate disapprovals, and the accident first officer had one. During public hearing testimony, the principal operator inspector (POI) for Colgan Air was not able to verify if Colgan Air had complied with the FAA's 2006 Safety Alert for Operators (SAFO) 06015, the purpose of which was to promote voluntary implementation of remedial training programs for pilots with persistent performance deficiencies. In fact, at the time of the accident, Colgan Air did not have a remedial training program in place as recommended in the SAFO 06015.

The investigation explored how commuting may have affected the pilots' performance. Both pilots were based in Newark but lived outside of the Newark vicinity. The captain had commuted from the Tampa, Florida area a few days before the accident, and the first officer had commuted from the Seattle, Wash., area on an overnight flight before the accident. She did not arrive into Newark until 6:23 a.m. the day of the accident flight.

Of the 137 Colgan Air pilots based at Newark in April 2009, 93 identified themselves as commuters. Forty-nine pilots had a commute greater than 400 miles, with 29 of those pilots living more than 1,000 miles away.

Colgan Air's commuting policy was outlined in its Flight Crewmember Policy Handbook. The Handbook stated that "a commuting pilot is expected to report for duty in a timely manner." A previous edition of the Handbook stated that flightcrew members should not attempt to commute to their base on the same day they are scheduled to work. This statement was not in the Handbook at the time of the accident.

The investigation examined how violating the sterile cockpit rule impacted the pilots' situational awareness of the decreasing airspeed. The CVR transcript documents non-essential conversation between the accident flightcrew members when sterile cockpit procedures should have been in effect. For example, there was a 3-minute conversation regarding the crew's experience in icing conditions and training that occurred just a few minutes before the stick shaker activated and while the crew was executing the approach checklist. (The investigation did reveal that ice accumulation was likely present on the airplane prior to the initial upset event, but its effect on aircraft performance was minor and the airplane continued to respond as expected to flight control inputs throughout the accident flight.)

A controversial issue was how fatigue may have affected the flight crew's performance. The investigation revealed that, on the day of the accident, the captain logged into Colgan Air's crew scheduling computer system at 3:00 a.m. and at 7:30 a.m. In addition, the first officer commuted to Newark on an overnight flight and was sending and receiving text messages throughout the day of the accident.

At the time of the accident, Colgan Air had a fatigue policy in place that was covered in the basic indoctrination ground school. Colgan Air did not provide specific guidance to its pilots on fatigue management.

On April 29, 2009, Colgan Air issued an operations bulletin on crewmember fatigue that reiterated the company's fatigue policy and provided information to crewmembers on what causes fatigue, how to recognize the signs of fatigue, how fatigue affects performance, and how to combat fatigue by properly utilizing periods of rest.

The investigation was completed in just under one year. On Feb. 2, 2010, the NTSB determined that the probable cause of this accident was the captain's inappropriate response to the activation of the stick shaker, which led to an aerodynamic stall from which the airplane did not recover. Contributing to the accident were (1) the flight crew's failure to monitor airspeed in relation to the rising position of the low-speed cue, (2) the flight crew's failure to adhere to sterile cockpit procedures, (3) the captain's failure to effectively manage the flight, and (4) Colgan Air's inadequate procedures for airspeed selection and management during approaches in icing conditions.

The safety issues discussed in the report focused on strategies to prevent flight crew monitoring failures, pilot professionalism, fatigue, remedial training, pilot training records, airspeed selection procedures, stall training, FAA oversight, flight operational quality assurance programs, use of personal portable electronic devices on the flight deck, the FAA's use of SAFOs to transmit safety-critical information, and weather information provided to pilots. Safety recommendations concerning these issues were addressed to the FAA.

The NTSB had issued past recommendations on stall training, stick pusher training, pilot records, remedial training for pilots, sterile cockpit environment, situational awareness, pilot monitoring skills, low airspeed alerting systems, pilot professionalism, and fatigue. Although these issues were not new, this accident investigation still resulted in a flurry of activity in the aviation community, in Congress, and with the family members of the passengers.

Up until now, this paper has focused on the information gathered to support the accident report. The rest of the paper will focus on a behind-the scenes look at how the Colgan Air accident investigation came together. This paper is written from my perspective as the investigator-in-charge (IIC) and is my opinion of how certain events evolved.

As mentioned earlier, the NTSB was notified of the accident about 10:30 p.m. on Feb. 12, 2009, and a go-team launched early the next morning from the FAA hangar in Washington, D.C. Accompanying the team to Buffalo was former Board member Steven Chealander, who gave a quick press briefing at the hangar before the team left for Buffalo. The team traveled by FAA airplane and commercial flights.

Once we arrived on scene, we checked in with the incident commander for status of the rescue, recovery, and overall firefighting efforts. We were informed that there was a broken natural gas line at the accident location that was feeding the fire. The natural gas company shut off the flow of gas to the houses on either side of the accident site but was unable to stop the flow at the accident site because the shut-off valve was located directly in the fire area.

The natural gas company developed a plan to do a sectional shutdown that would have required cutting off gas service to about 50 homes in 32 degrees F weather. This would have led to the evacuation of 50 residences in the early morning hours along with the assumption of responsibility for the evacuated homes. The incident commander deemed this solution unacceptable. Other options were explored; and by mid-morning, the natural gas company secured the gas flow at the accident site, putting out the natural gas fire.

The structures group chairman retrieved the FDR and CVR and sent them back to Washington, D.C., on one of the FAA airplanes. While waiting for the natural gas fire to be extinguished, member Chealander participated in a press briefing with other local, state, and federal officials. We also visited the three other command posts that were set up by different agencies.

That night we began the press and family briefings and also held our organizational meeting, which normally takes a few hours. At this meeting we identified the teams to be formed and the parties to the accident investigation. The following investigative teams were formed: operations and human performance, structures, systems, powerplants, air traffic control, meteorology, aircraft performance, maintenance records, and pipeline. In addition, specialists were assigned to conduct the readout of the FDR and transcribe the CVR at the NTSB's laboratory in Washington, D.C.

Parties to the investigation were the FAA, Colgan Air, ALPA, the National Air Traffic Controllers Association (NATCA), and the United Steelworkers Union (flight attendants). In accordance with the provisions of Annex 13 to the International Civil Aviation Organization, the TSB of Canada participated in the investigation as the representative of the State of Design and Manufacture (Airframe and Engines), and the Air Accidents Investigation Branch of the United Kingdom (AAIB) participated in the investigation as the representative of the State of Design and Manufacture (Propellers). Transport Canada, Bombardier, and Pratt & Whitney Canada participated in the investigation as technical advisors to the TSB, and Dowty Propellers participated in the investigation as a technical advisor to the AAIB.

The overall schedule for the briefings was to inform the families first, have the news media interviews, and then hold the team progress meeting. Since the family and news media briefings were held ahead of the progress meetings, I had to touch base with the group chairman mid-afternoon to get an update on how things were going. This information, along with "bullets" from headquarters, was the framework for the briefings.

The concern with multiple briefings was maintaining consistency of the information. The family members and the news media are able to ask questions at their respective briefings. If additional information was provided in an answer to a question in a meeting for one group, another group might feel slighted that it did not receive that information. To prevent this from happening, we stuck to the talking points and provided follow-up at the next briefing.

The challenges on scene were the natural gas line break, the outside air temperature, the approaching snowstorm, and the long hours. The natural gas fire created a hot, concentrated fire that left molten metal and ash in its wake, making the examination of flight control continuity and some parts identification very difficult. Fortunately we had good FDR data that allowed us to conclude that the accident flight had flight control continuity and no "fault" discretes were identified as to a failed part or system.

One of the repercussions from trying to put the natural gas fire out was that the wreckage site was saturated with fire suppressant material. Every morning the team used portable heaters to thaw out the frozen wreckage site, creating a mud zone by the afternoon. This ultimately slowed down the recovery effort.

To help speed things up, personnel from the Federal Bureau of Investigation's (FBI) Evidence Recovery Team and local medical students assisted with the recovery of the airplane and passengers from the house. The house was excavated down to its foundation. We also had help from the local volunteer fire department.

The FBI gave our team access to its mobile command post, and the local volunteer fire station opened its doors so the team could get out of the cold and work on field notes. Local volunteers provided hot meals and warm conversation. In addition, the FBI interviewed all of the witnesses and provided detailed reports to us.

Anyone familiar with accident investigation is no stranger to long hours. This accident investigation started with a prelude to long hours since the accident occurred during the night and the notification and coordination continued throughout the night and early morning. The first few days were really long just getting the investigation up and running. To combat the eventual fatigue associated with long, stressful days, a few days in we started holding our progress meetings at an earlier time so that our teams had a better opportunity for sleep.

While we diligently worked through the challenges on scene, we had no idea what was in store for us over the next year. The news media attention was constant. This was the third major domestic aviation accident in 3 months. The first was the Continental Flight 1404 runway excursion accident in Denver, Colo., and the second was the US Airways Flight 1549 ditching on the Hudson River. Fortunately, neither of those accidents involved fatalities. Prior to these cases, the last major domestic fatal air carrier accident in the United States had occurred almost 2.5 years earlier in Lexington, Ky.

Early in an investigation, the foundation needs to be set for a timely investigation. It starts with the accident notification and flows through to the presentation of the Board report. The NTSB group chairmen and management, the parties, accredited representatives, and even the Board members must have a clear understanding of what the vision is and then commit the resources to fulfill that vision. That is in a perfect world, and I do not usually work in a perfect world.

On scene, we started from scratch, building teams from a group of individuals who can have competing interests and agendas. To neutralize the playing field, I set clear expectations from the very first meeting. The organizational meeting was so important because it set the tone for the rest of the investigation. Unfortunately, not all of the participants had arrived on scene when we held the organizational meeting, so those individuals were briefed in by their party coordinator and/or group chairman.

Progress meetings were held daily until the day before we left the accident scene. These meetings continued telephonically after the on-scene portion of the investigation concluded. The frequency of the call-ins varied. The month before the public hearing, they were held weekly. As the investigation progressed, they were held bi-monthly to monthly. Recognize that once we left the accident site, a lot of the participants went back to their regular jobs, either flying the line or a desk. The use of an electronic calendar and email helped maximize participation in the progress meetings.

New challenges awaited us when we returned from the scene of the accident. The natural course of an investigation is complete the on-scene activities, return and decide if a public hearing is warranted, hold such a hearing and open a public docket, continue with the investigation, hold a technical review, and burrow into the report writing while waiting for party submissions. That process works well if the team members do not have other work waiting for them when they return.

I and others on the team had accident reports that were in the pipeline and were scheduled to go before the Board in 2009. For example, in April and June, I brought two major accident investigations to the Board, and sandwiched in between was the Colgan Air public hearing in which I had the additional role as hearing officer. I was fortunate to have an experienced team, which is essential in conducting a timely investigation. An experienced team can require less oversight, produce better written reports, and have a better understanding of overall agency mission.

To put the workload issue in perspective, the Office of Aviation Safety presented five draft reports to the Board, a recommendation package on helicopter emergency medical services, and three public hearings during the course of the Colgan Air investigation. Those numbers do not take into consideration the work associated with supporting the other two major air carrier accidents that occurred immediately before the Colgan Air accident.

Despite the additional challenges associated with competing resources, we were still able to hold a public hearing within 3 months of the accident and present the draft report to the Board in just under a year. The final report was 285 pages, with 46 conclusions and 25 new recommendations to the FAA. The public docket held 4,462 pages and 152 documents.

Producing a detailed report in a short timeframe can be challenging. The support documents (public docket material) have to be collected or generated. Once the docket is open, it is available to the public. In trying to be expeditious, we had to be cautious not to sacrifice accurate or factual detail to meet a deadline. To ensure accuracy, we have an internal policy of having at least three sets of eyes review a document before it is released.

One of the hurdles we faced in this investigation was the delay associated with receiving documents late, with incomplete information, or with stamps indicating "for investigative use only." These delays had the potential to slow down the progress of the team and increased the frustration level of the group chairmen. It took some refining, but better communication helped to minimize the document issues.

The accident report writing process itself can be challenging with many different people reviewing the report for different details. When one person changes a sentence, it can potentially change the intended meaning, and we have to carefully review every version so that an error does not creep into the report. The problem with multiple reviews and short turn-around times is that when one section is nailed down, the reviewers skip to the more troublesome sections. This leads to the potential for misinformation to promulgate to the final report. We had to make the time to do a complete reread of the report to ensure accuracy.

During the report writing phase, we quickly identified two areas that would take more time than we had to develop for the report. The team tried to peel back the layers on professionalism and code-sharing, but the more we dug into these issues, the more complex they became. We knew both areas had to be addressed, and a compromise was offered. Professionalism and code-sharing would be explored in more detail, separate from the report. On May 18-20, 2010, the NTSB held a forum on professionalism titled, "*Professionalism in Aviation: Ensuring Excellence in Pilot and Air Traffic Controller Performance.*" On Oct. 26-27, 2010, the NTSB will hold a symposium on code-sharing titled, "*Airline Code-Sharing Arrangements and Their Role in Aviation Safety.*"

This report was my first experience that involved the need to continually update a report with new information from the FAA and the U.S. Congress. It was challenging to keep current with all the changes that were occurring in such a short timeframe. A disadvantage was not being kept in the loop by the FAA on some issues and only becoming aware of these details when the FAA administrator delivered testimony to Congress. We relied on the NTSB government affairs office to keep the team informed of scheduled testimony, and we regularly checked the FAA and congressional websites for updates.

Another first was the family members of the passengers on Flight 3407 became safety advocates and even after the NTSB report was published they continued to fight for changes in the aviation industry. Family members and close friends of the victims went to Buffalo immediately after the accident to learn more about what happened to the accident flight. In the weeks following the accident, a bond was formed amongst the family members and they formed an alliance to promote positive change in the aviation industry. Their goal is to bring awareness to outstanding safety issues yet to be addressed by the FAA and major airlines and to improve overall safety of passengers in the skies.

An authentic investigation depends on facts. Board reports are structured so that any analytical statement is supported by factual documentation. The NTSB recently adopted a new procedure that requires all group chairmen reports to be vetted by the parties to the investigation before these reports go into our public docket. Normally, these reports would go through the group members and then be finalized and put into the docket. The legacy process involved the conduct of a technical review meeting only after the public docket was opened and all of the factual reports were completed. At this technical review, all parties would preview the reports and provide technical comments for consideration by the NTSB. We still have the technical review, but now party coordinators are asked to review and comment on the factual reports earlier in the investigation, before the docket is opened and released to the public.

In summary, the NTSB has the luxury of being an independent agency. We conduct our investigations with an unbiased approach, where our main objective is to determine probable cause and issue safety recommendations. Speed is measured by the eye of the beholder. The fastest turtle is still beaten by the slowest hare. We will never be as fast as the news media or political pundits. Our reports will never be quick enough to answer the families' questions.

Remember that NTSB safety recommendations can be issued at any time, independent of an accident report. Our public docket is now available on the Internet, and anyone can access all the factual documentation before the Board report is released with just the click of a mouse. All of our Board meetings and public hearings are open to the public and can be remotely viewed from the internet.

For more details on the accident, please download a copy of the report titled *Loss of Control on Approach, Colgan Air, Inc., Operating as Continental Connection Flight 3407, Bombardier DHC-8-400, N200WQ, Clarence Center, New York, February 12, 2009,* Aircraft Accident Report NTSB/AAR-10/01, (Washington, DC: National Transportation Safety Board, 2010) at the following link: http://www.ntsb.gov/publictn/2010/AAR1001.pdf. ◆

Endnotes

1 All times are Eastern Standard Time unless noted otherwise.

2 In an enbanc hearing, all of the Board members participate as part of the Board of Inquiry for the public hearing.

ISASI 2010 Pictorial Review

Photos by Esperison Martinez


Improved Environmental Performance
Lower emissions
20% lower carbon dioxide emissions
Well below regulated limits on hydrocarbons, smoke, NOX, CO
Quieter
Community noise contained within airport boundaries
Ramp noise well below ICAO regulations
Cabin noise optimized
Life cycle improvements
ISO 14001 factory, working on suppliers
Lean manufacturing, reducing our environmental footprint
Composite recycling
Careful choices, clever design create cleaner airplane


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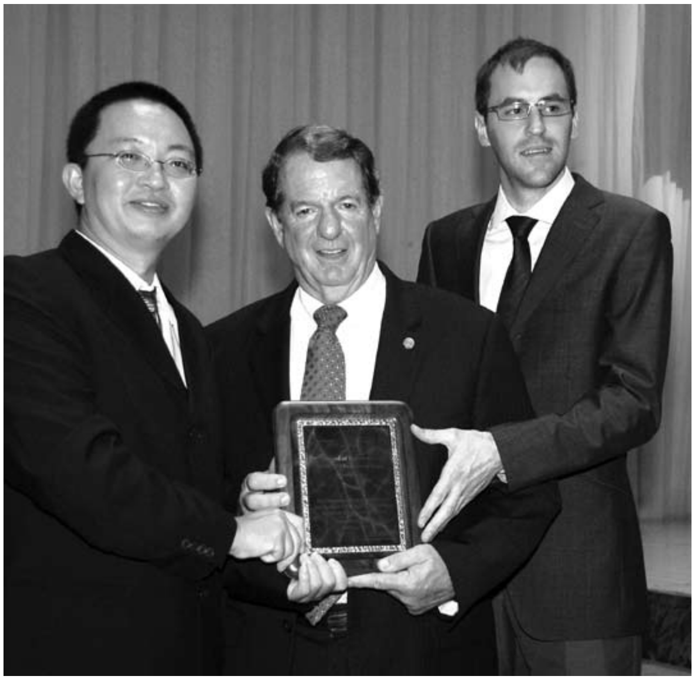


ISASI


INVESTIGATORS