ISASI Proceedings

VOLUME 11

Publisher
ISASI (Frank Del Gandio, President)

Editorial Advisor
Richard B. Stone

Editorial Staff
Susan Fager
Esperison Martinez

Design
William A. Ford

ISASI Proceedings (ISSN 1562-8914) is published annually by the International Society of Air Safety Investigators. Opinions expressed by authors are not necessarily endorsed or represent official ISASI position or policy.

Editorial Offices: 107 E. Holly Ave., Suite 11, Sterling, VA 20164-5405 USA. Telephone: (703) 430-9668. Fax: (703) 450-1745. E-mail address: isasi@erols.com. Internet website: http://www.isasi.org.

Notice: The *Proceedings* of the ISASI 38th annual international seminar held in Singapore, Republic of Singapore, features presentations on safety issues of interest to the aviation community. The papers are presented herein in the original editorial content supplied by the authors.

Publisher's Editorial Profile: *ISASI Proceedings* is printed in the United States and published for professional air safety investigators who are members of the International Society of Air Safety Investigators. Content emphasizes accident investigation findings, investigative techniques and experiences, and industry accident-prevention developments in concert with the seminar theme "International Cooperation: From Investigation Site to ICAO."

Subscriptions: Active members in good standing and corporate members may acquire, on a no-fee basis, a copy of these *Proceedings* by downloading the material from the appropriate section of the ISASI website at www.isasi.org. Further, active and corporate members may purchase the *Proceedings* on a CD-ROM for the nominal fee of $15, which covers postage and handling. Non-ISASI members may acquire the CD-ROM for a $75 fee. A limited number of paper copies of *Proceedings* 2006 is available at a cost of $150. Checks should accompany the request and be made payable to ISASI. Mail to ISASI, 107 E. Holly Ave., Suite 11, Sterling, VA 20164-5405 USA

ISSN 1562-8914

Air Safety Through Investigation

Proceedings of the 38th Annual International Seminar

'International Cooperation: From Investigation Site To ICAO'

Aug. 27–30, 2007
Singapore, Republic of Singapore

ISASI Information

OFFICERS

President, Frank Del Gandio (frank.delgandio@faa.gov)
Executive Advisor, Richard Stone (rbstone2@msn.com)
Vice-President, Ron Schleede (ronschleede@aol.com)
Secretary, Chris Baum (chris.baum@alpa.org)
Treasurer, Tom McCarthy (tomflyss@aol.com)

COUNCILLORS

Australian, Lindsay Naylor (lnaylor@spitfire.com.au)
Canadian, Barbara Dunn (avsafe@uniserve.com)
European, Anne Evans (aevans@aaib.gov.uk)
International, Caj Frostell (cfrostell@sympatico.ca)
New Zealand, Ron Chippindale (rc1@xtra.co.nz)
United States, Curt Lewis (curt@curt-lewis.com)

NATIONAL AND REGIONAL SOCIETY PRESIDENTS

Australian, Lindsay Naylor (lnaylor@spitfire.com.au)
Canadian, Barbara M. Dunn (avsafe@rogers.com)
European, David King (dking@aaib.gov.uk)
Latin American, Guillermo J. Palacia (Mexico)
New Zealand, Peter Williams (p.williams@taic.org.nz)
Russian, Vsvolod E. Overharov (orap@mak.ru)
*SESA-France Chap.,*Vincent Fave
(vincent.fave@aviation-experts.com)
United States, Curt Lewis (curt@curt-lewis.com)

UNITED STATES REGIONAL CHAPTER PRESIDENTS

Alaska, Craig Bledsoe
(craig_Bledsoe@ak-prepared.com)
Arizona, Bill Waldock (wwaldock@msn.com)
Dallas-Ft. Worth, Curt Lewis (lewis@curt-lewis.com)
Florida, Ben Coleman (ben.coleman@faa.gov)
Great Lakes, Matthew Kenner (mtkenner@esi-il.com)
*Los Angele*s, Inactive
Mid-Atlantic, Ron Schleede (ronschleede@aol.com)
Northeast, David W. Graham (dwg@shore.net)
Pacific Northwest, Kevin Darcy (kdarcy@safeserve.com)
Rocky Mountain, Gary R. Morphew
(gary.morphew@scsi-inc.com)
San Francisco, Peter Axelrod
(p_axelrod@compuserve.com)
Southeastern, Inactive

COMMITTEE CHAIRMEN

Audit, Dr. Michael K. Hynes
(hynesdrm@aviationonly.com)
Award, Gale E. Braden (galebraden@cox.net)
Ballot Certification, Tom McCarthy (tomflyss@aol.com)
*Board of Fellow*s, Ron Chippindale (rcl@xtra.co.nz)
Bylaws, Darren T. Gaines (dgaines@natca.org)
*Code of Ethic*s, John P. Combs (mandi2@charter.ne*t)*
Membership, Tom McCarthy (tomflyss@aol.com)
*Nominatin*g, Tom McCarthy (tomflyss@aol.com)
Reachout, James P. Stewart (sms@rogers.com)
Seminar, Barbara Dunn (avsafe@uniserve.com)

WORKING GROUP CHAIRMEN

Air Traffic Services, John A. Guselli (Chair)
(jguselli@bigpond.net.au)
Ladislav Mika (Co-Chair) (mika@mdcr.cz)
Cabin Safety, Joann E. Matley (jaymat02@aol.com)
Corporate Affairs, John W. Purvis (jpurvis@safeserv.com)
Flight Recorder, Michael R. Poole
(mike.poole@flightscape.com)
General Aviation, William (Buck) Welch
(wwelch@cessna.textron.com)
Government Air Safety, Willaim L. McNease
(billsing97@aol.com)
Human Factors, Richard Stone (rstone2@msn.com)
Investigators Training & Education,
Graham R. Braithwaite
(g.r.braithwaite@cranfield.ac.uk)
Positions, Ken Smart (ken.smart@ntlworld.com)

CORPORATE MEMBERS

AAIU Ministry of Transport Bulgaria
Accident Investigation Board, Finland
Accident Investigation Board/Norway
Accident Investigation & Prevention Bureau
Aeronautical & Maritime Research Laboratory
AeroVeritas Aviation Safety Consulting, Ltd.
Aerovias De Mexico, S.A.De C.V.
Air Accident Investigation Bureau of Singapore
Air Accident Investigation Unit—Ireland
Air Accidents Investigation Branch—U.K.
Air Canada Pilots Association
Air Line Pilots Association
Air New Zealand, Ltd.
Airbus S.A.S.
Airclaims Limited
Aircraft Accident Investigation Bureau—Switzerland
Aircraft Mechanics Fraternal Association
Aircraft & Railway Accident Investigation Commission
Airservices Australia
AirTran Airways
Alaska Airlines
Alitalia Airlines—Flight Safety Dept.
All Nippon Airways Company Limited
Allied Pilots Association
American Eagle Airlines
American Underwater Search & Survey, Ltd.
AmSafe Aviation
Aramco Associated Company
ASPA de Mexico
Association of Professional Flight Attendants
Atlantic Southeast Airlines—Delta Connection
Australian Transport Safety Bureau
Aviation Safety Council
Avions de Transport Regional (ATR)
BEA-Bureau D'Enquetes et D'Analyses
Board of Accident Investigation—Sweden
Boeing Commercial Airplanes
Bombardier Aerospace Regional Aircraft
Bundesstelle fur Flugunfalluntersuchung—BFU
Cathay Pacific Airways Limited
Cavok Group, Inc.
Centurion, Inc.
Charles Taylor Aviation, Singapore
China Airlines
Cirrus Design
Civil Aviation Safety Authority Australia
Colegio De Pilotos Aviadores De Mexico, A.C.
Comair, Inc.
Continental Airlines
Continental Express
COPAC/Colegio Oficial de Pilotos de la Aviacion
Comercial
Cranfield Safety & Accident Investigation Centre
DCI/Branch AIRCO
Defence Science and Technology Organisation (DSTO)
Delta Air Lines, Inc.
Directorate of Aircraft Accident Investigations—
Namibia
Directorate of Flight Safety (Canadian Forces)
Directorate of Flying Safety—ADF
Dutch Airline Pilots Association
Dutch Transport Safety Board
EL AL Israel Airlines
Embraer-Empresa Brasileira de Aeronautica S.A.
Embry-Riddle Aeronautical University
Emirates Airline
Era Aviation, Inc.
European Aviation Safety Agency
EVA Airways Corporation
Exponent, Inc.
Federal Aviation Administration
Finnair Oyj
Flight Attendant Training Institute at Melville College
Flight Safety Foundation
Flight Safety Foundation—Taiwan
Flightscape, Inc.
Galaxy Scientific Corporation
GE Transportation/Aircraft Engines
Global Aerospace, Inc.
Gulf Flight Safety Committee, Azaiba, Oman
Hall & Associates, LLC
Hellenic Air Accident Investigation
& Aviation Safety Board
Honeywell
Hong Kong Airline Pilots Association
Hong Kong Civil Aviation Department
IFALPA
Independent Pilots Association
Int'l Assoc. of Mach. & Aerospace Workers
Interstate Aviation Committee
Irish Air Corps
Irish Aviation Authority
Japan Airlines Domestic Co., LTD
Japanese Aviation Insurance Pool
Jeppesen
JetBlue Airways
Jones Day
KLM Royal Dutch Airlines
Korea Aviation & Railway Accident Investigation Board
Kreindler & Kreindler, LLP
L-3 Communications Aviation Recorders
Learjet, Inc.
Lockheed Martin Corporation
Lufthansa German Airlines
MyTravel Airways
National Air Traffic Controllers Assn.
National Business Aviation Association
National Transportation Safety Board
NAV Canada
Nigerian Ministry of Aviation and Accident
Investigation Bureau
Parker Aerospace
Phoenix International, Inc.
Pratt & Whitney
Qantas Airways Limited
Qwila Air (Pty), Ltd.
Raytheon Company
Republic of Singapore Air Force
Rolls-Royce, PLC
Royal Netherlands Air Force
Royal New Zealand Air Force
RTI Group, LLC
Sandia National Laboratories
SAS Braathens
Saudi Arabian Airlines
SICOFAA/SPS
Sikorsky Aircraft Corporation
Skyservice Airlines, Ltd.
Singapore Airlines, Ltd.
SNECMA Moteurs
South African Airways
South African Civil Aviation Authority
Southern California Safety Institute
Southwest Airlines Company
Southwest Airlines Pilots' Association
Star Navigation Systems Group, Ltd.
State of Israel
Transport Canada
Transportation Safety Board of Canada
U.K. Civil Aviation Authority
UND Aerospace
University of NSW Aviation
University of Southern California
Volvo Aero Corporation
WestJet ◆

Table of Contents

PREFACE

Welcome to Singapore!

By Frank Del Gandio, President

ISASI thanks our seminar hosts, Chan Wing Keong, director of the Air Accident Investigation Bureau of Singapore, and Barbara Dunn, who, as always, worked hard to ensure the success of this seminar. Also, our thanks to all the members of the seminar committee for their work and to everyone who helped to organize last week's tutorial programs at the Singapore Aviation Academy.

Five years ago, ISASI met in Taipei. That was the first time we had met in Asia, and I made the point then that Taipei was a powerful indication that the International Society of Air Safety Investigators was indeed an international organization. This week's meeting in Singapore introduces ISASI to South Asia. Much like Taipei, this is a powerful confirmation that ISASI is truly an international professional society.

Our theme is "International Cooperation: From Investigation Site to ICAO." The point of the theme is this: whatever we learn by investigating accidents will be of little practical use unless that learning is effectively shared with everyone in aviation.

The theme also suggests that all of us in this room today are really in the business of accident prevention as well as accident investigation. At a minimum, all the accident investigation authorities and civil aviation authorities represented here today seek to prevent accidents in their respective countries, but we also seek to prevent accidents elsewhere in the world. We do this for basic moral reasons, but we also do it because we understand that a major accident anywhere in the world reflects on all of us. We also do it because we understand that aviation was a truly global industry long before the term became popular, and we recognize that everyone's citizens fly in aircraft operated under foreign flags.

Today, the process of accident *prevention* employs a wide range of new tools or at least older tools that have been made much more capable by still relatively new data processing capacities, communication technology, data mining tools, etc. These new analytical tools hold real promise for the entire aviation safety community. One result is that, for the first time, we really have begun to analyze incidents and routine operations to identify new risks before they lead to accidents.

Yet, acquiring a fundamental understanding of accidents and serious incidents still begins at the accident site. In fact, the knowledge we have amassed from accident investigation has been the foundation for defining risk in the first generations of FOQA programs and voluntary reporting programs. What we learn in accident investigations will continue to be the first step in accident prevention and mitigation. Investigations often confirm well-understood issues, but they also produce new knowledge and new recommendations for corrective action.

However, to be useful, any understanding we achieve must be shared with the entire aviation community, based on detached, professional investigation of all accidents and serious incidents. It also requires that such investigations are not complicated by the still far-too-common practice of criminalizing accidents.

"From Investigation Site to ICAO" also requires that the ICAO member states make their data and investigative findings available to the rest of the world. The vehicle for that data sharing is ICAO. The aviation community has come impressively close to eliminating those accident scenarios that, not many years ago, explained most major accidents. The task now is to drive risk even lower. The only way we can do that is by sharing information in a manner that makes it useful to everyone in our community.

At a minimum, all the accident investigation authorities and civil aviation authorities represented here today seek to prevent accidents in their respective countries, but we also seek to prevent accidents elsewhere in the world.

Since we met last year, we have had nine major accidents, resulting in 857 fatalities.

This does not mean that aviation safety is on the verge of crisis; it is not. In fact, as IATA recently reported, 2006 was the safest year on record. By IATA's count, air carrier accidents decreased worldwide from 110 in 2005 to 77 in 2006, despite an increase in operations.

As all of us recognize, accidents can occur anywhere. That is why we seek new approaches and new tools for accident prevention in those countries where major accidents really are rare events. Yet, we also understand that many countries can still benefit greatly from more basic approaches. For either group of countries, sharing *and using* information from the accident site and from operational experience will make the system safer everywhere. ICAO remains the best vehicle by which sovereign countries can share data, safety knowledge, and good safety practice.

With that, I will close, but allow me to remind you that ISASI is proud to be in Singapore and we sincerely thank our hosts. ◆

OPENING ADDRESS
Importance of International Cooperation in Aircraft Accident Investigation

By Raymond Lim, Minister for Transport and Second Minister for Foreign Affairs

President of the International Society of Air Safety Investigators, Mr. Frank Del Gandio, distinguished guests, ladies and gentlemen—Let me first warmly welcome all of our overseas friends to Singapore.

Singapore is honored to be selected to host this 38th annual seminar of the International Society of Air Safety Investigators, the premier international event of its kind for air safety investigators to exchange views and experiences and discuss issues of common interest. I am heartened to see so many of you here, as it underscores the importance of inter-national cooperation in aircraft accident investigation and your endless pursuit in honing the skills required in this area.

With the growing affluence of individuals and the globalization of businesses, international air traffic is set for brisk growth ahead. In Asia, passenger volumes are expected to grow 7.9% annually over the next 5 years, according to the Airports Council International (ACI). Globally, with an average growth rate of 4% over the next 20 years, we will see a more than doubling of the current 4.2 billion passengers to some 9 billion passengers a year.

However, we must not allow ourselves to be lulled by the euphoria of a buoyant air travel industry and lose our focus on air safety. Infrastructure and air traffic management systems often lag behind the intense traffic growth in fast-growing aviation markets. This, coupled with the difficulty in maintaining the quality and experience level of pilots, air traffic controllers, and other safety-related manpower resources needed to cope with the rapid growth, would pose serious threats to safety standards.

Therefore, it is imperative that we strengthen our safety and accident investigation frameworks. With proper regulatory and enforcement actions in place, the valuable insights gained from accidents and near accidents could help prevent similar accidents from happening in the future. In addition, the willingness to openly and professionally share ideas, experiences, and lessons learned from accident investigations is an important element in upgrading the safety standards in the aviation industry, which is the core purpose of this important annual ISASI seminar.

Aviation-related accident investigations are by nature complex as the causes for accidents are seldom the result of a single factor. It is vital for governments and industry players to collaborate closely, in areas such as technical expertise, equipment, facilities, and training platforms, to achieve effective investigation. This will help to smoothen out problems that an individual country's investigation bodies may encounter, as a result of the complexity of aircraft and air transport systems. It is also worthwhile for those which lack resources of their own to tap into an international network of investigators and safety professionals who can support them in their investigations, as well as share and exchange views on experiences, techniques, best practices, and relevant issues.

E. MARTINEZ

Minister Raymond Lim addresses attendees at ISASI 2007.

On the part of Singapore, we are continually striving to contribute to such cooperation initiatives. For one, the Air Accident Investigation Bureau of Singapore, or AAIB for short, has recently set up a flight recorder readout facility to download and analyze data from the cockpit voice and flight data recorders.

Our AAIB is more than happy to offer to other organizations the use of its flight recorder readout facility as this is one of the most important areas of aircraft investigation procedure. In addition, AAIB has also assisted several regional countries in their aircraft investigations and in drafting accident investigation manuals.

Singapore is happy to do our part to contribute to air safety. More importantly, we hope that together with many other likeminded states, we can all do our part to cooperate and collaborate closely so that professional investigation resources are readily available when needed, contributing ultimately to making air travel safer for the traveling public.

On this note, I wish all of you a rewarding seminar, and an enjoyable stay in Singapore. ◆

KEYNOTE ADDRESS

Sharing Experience and Knowledge

By Mark V. Rosenker, Chairman, U.S. National Transportation Safety Board

Minister for Transport and Second Minister for Foreign Affairs, Raymond Lim, distinguished visitors, ladies and gentlemen, members of ISASI, and guests—on behalf of the organizers of ISASI 2007, Wing Keong Chong (who also goes by Chan Wing Keong) and the staff at the Singapore Air Accident Investigation Bureau, please allow me to welcome you to our venue here in Singapore and to the lovely Stamford hotel.

It is always a pleasure to return to Singapore; and since my first visit more than 20 years ago, each time I return, I am amazed at the continued growth and technical advancements that are taking place. Yesterday, I visited with corporate officials at Singapore Airlines to view some of that new technology. I was briefed on the challenges of integrating the A380 into the airline route structure. We are all aware of how big the airplane is, and it is equally interesting to observe the maintenance and crew training issues as they present themselves in the airline environment.

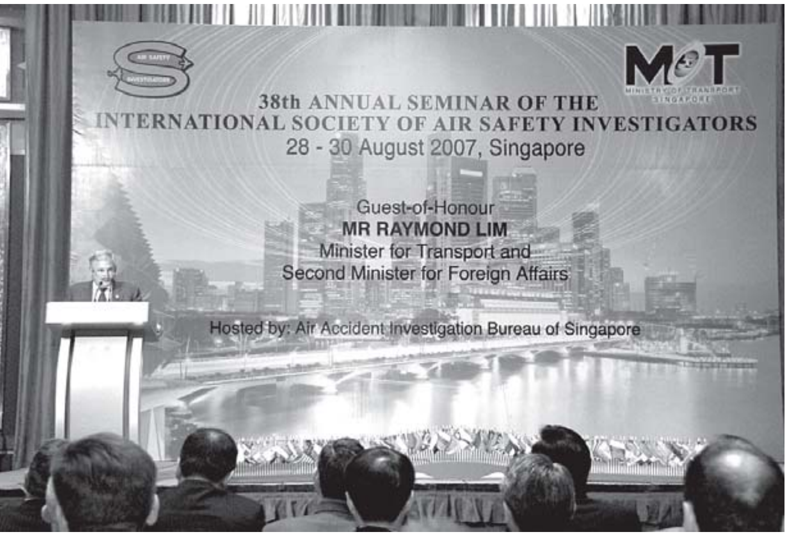
I'm also interested in viewing another transportation mode here in Singapore, the maritime sector. Of course, we are all interested in the surface movement of aircraft—and there is a similar challenge at the Singapore Port Facility. Singapore is No. 1 in the world for handling the movement of container ship traffic. The seaport traffic issues are very similar to those in aviation, where aviation is faced with ever-increasing air traffic volume and limited airport arrival and departure rates, with runway incursion and excursion risks; the marine sector has similar challenges with narrow ship channels and limited dock side berths. Singapore leads the industry with a tracking system equal to our aviation methods. In fact, it is already using technology similar to the automatic surveillance broadcast of the ship's GPS position for marine ship movement. So congratulations to you, Singapore, for showing such leadership in integrating a variety of new technology into our everyday lives.

Now it is time to talk about ISASI 2007. Let's start with the seminar title: "International Cooperation: From Investigation Site to ICAO." I believe we can take that title to mean working within the cooperative framework of international standards and recommended practices, and, further, to transfer vital information from an accident site anywhere in the world, with careful analysis along the way, to the offices and the staff of the International Civil Aviation Organization (ICAO) in Montreal. I've looked at the delegate list and note that we have representation from all continents of the globe. We know right away that our friends from South Asia and North Asia are well represented. And we see representation from all of Europe, the Mid East, and Russia. Looking further, Africa and Australia are here, and for the Americas, from Chile to Canada we have representation. This representation is truly the global approach desired by ICAO to permit the greatest exchange of ideas and international cooperation.

Now what do we do with these ideas? There are ample opportunities to apply multiple aviation safety initiatives through various avenues. There are local nation state opportunities, as well as action by regional organizations, and within the global framework. My agency, the U.S. NTSB, maintains an Internet website posting our "Most Wanted" list of safety recommendations. We try and keep the focus on those issues that offer the greatest potential for saving lives and avoiding a major disaster. As one example, we give the highest priority to reducing the risk of a runway collision. And we are certainly not alone. Just last month, the president of the ICAO Council, Roberto Kobeh Gonzalez, during an address to the Strategic Aviation Safety Summit in Bali, Indonesia, declared, "There is an urgent need to implement a concrete, realistic, and achievable plan of action." I fully endorse the words of President Kobeh. His personal attention to such issues will have lasting impact. And I believe we all can fully endorse ICAO's Global Aviation Safety Plan, and the industry developed the Global Aviation Safety Road Map to support the plan.

But I have to add something about the ICAO Road Map. As aviators, I believe you will be quick to recognize my point. When we discuss the roadmap, or any map, we know it will show you the direction to take—but it requires a commitment to reach your destination. In the case of the Global Aviation Safety Plan, we have to address the commitment of states and operators to reach the intended safety objectives. That is where the ICAO Universal Safety Oversight Audit Program (USOAP) plays a very important part. The ICAO USOAP audit results provide identification of a state's capabilities to provide adequate safety oversight. As the audit cycle becomes complete in 2008, and with the agreement among states to release ICAO audit information to the public in 2009, the states not meeting their safety oversight responsibilities, those requiring assistance to improve their infrastructure and technical competence, will be well known. Thereafter, we should be looking toward each and every state's high-level commitment to its long-term sustainable safety responsibilities … and to meet the milestones along the safety roadmap.

Let's take a moment to view the record of the aviation industry—and the ongoing safety efforts around the world. Consider for a moment the number of travelers—or the number of departures—that take place around the world every day. More than 2 billion passengers traveled by commercial air transportation in 2006. Certainly, we recognize the accidents that took place —and you will hear more about some of them during the seminar; however, we should also recognize that many of the safety



E. MARTINEZ

Chairman Rosenker addresses the assembly.

improvements that aviation safety professionals and groups such as ISASI have promoted over the years are now providing the benefits we predicted. I'm referring to the professional crew training and the elevated standards of SOPs, adherence to the stabilized approach criteria, improved reliability of aircraft powerplants, and the very specific enhancements such as satellite navigation systems, moving map airport displays, and Enhanced Ground Proximity Warning and Traffic Collision Avoidance Systems. What we have to do now,…today's challenge, is to maintain that momentum for an ever-increasing level of aviation safety.

As the industry moves to adopt the Safety Management Systems (SMS) approach, we have a unique opportunity to increase the level of safety—and to involve all the stakeholders in the solution. The industry has readily endorsed SMS objectives to find more efficient methods of safety data collection and to analyze that incident data in a proactive way to reduce the accident potential in our operations. With the SMS approach, the objective is to identify multiple risk factors and reduce or eliminate those risks, thereby providing intervention in the causal chain of events, with the end result to prevent major accidents before they occur.

However, we must be realistic—aviation is a human endeavor; unfortunately, air accidents and serious incidents will continue to occur. And related safety recommendations originating from those unfortunate events will be necessary. At every level of government and industry, we must be prepared for major accidents. We can see from the most recent occurrences that a major accident can quickly become a national crisis—with international consequences far beyond aviation interests.

So, we are gathered here today to share our experiences and knowledge in order to produce the best possible air safety investigations. We have a unique opportunity at ISASI 2007 to gain further insight into aviation safety initiatives from an outstanding group of presenters. And the topic list holds some very valuable subjects for each of us. We will hear about some recent investigations from a variety of locations, from Africa, from Indonesia, from Brazil, and from the oceanic area, to name a few. The airframes discussed will range from the general aviation Cessna and Cirrus to include the very light jets (VLJs) and extend to the most modern commercial transport airplanes—the complete spectrum of our industry.

As members of this unique professional Society, ISASI, I'm certain you are interested in the advancing investigative techniques. You won't be disappointed. Of course, flight recorders will be addressed, with views from several different perspectives. Also, there are several papers on the techniques and protocols of investigation with particular emphasis on the aspect of international cooperation. The cultural challenges of our variety of social systems that combine during an investigation are present in almost every investigation. National borders have become transparent in many ways—in the manufacture of the airframe and the various components, in the crew makeup and training of our personnel, in maintenance facilities, and with air traffic service providers. We are truly a multinational and fully global industry. Several speakers will discuss these cross-cultural challenges as they affect the workings of an air safety investigation.

Before closing, I'd like to make added mention of the importance of international cooperation and the need for harmonized best practices in investigation. This is especially true for those of us representing airplane-manufacturing states. Our industries desire to provide the most airworthy aircraft possible for the market place. To do this, we need to know how the aircraft perform in the market place, and when deficiencies do become apparent, to move swiftly to correct them—and avoid recurrence. As an effort to harmonize and promote efficiency in air safety investigation, in the fall of 2008, ICAO will convene an Accident Investigation and Prevention Divisional meeting (AIG 2008) for all ICAO state and interested organizations. The chief of the AIG Division, Marcus Costa, is with us for this seminar. He will make an address to us during the seminar. I would ask all attendees to pay particular attention to the message from Mr. Costa. AIG 2008 will be an opportunity for all of us to refine and modernize ICAO Annex 13 and our accident investigation process to be as efficient as possible.

And now, as delegates to ISASI 2007, I hope I have addressed some of your objectives in attending the seminar—and that I have addressed some of the safety challenges facing our aviation industry. I encourage everyone to take advantage of the multiple opportunities throughout the seminar to exchange and gather information, and equally important, to meet your colleagues in this productive environment.

I thank you for your attention, and I wish you the most stimulating and fruitful seminar. ◆

LEDERER AWARD RECIPIENT

'Independence and Integrity' Mark Tom McCarthy

By Esperison Martinez, Editor

The many ASIs who know or have worked with Tom McCarthy are familiar with his warm, bright smile and deportment, which signal the nature of the man: friendly, soft-spoken, patient, disciplined, deliberate, confident, and staunch integrity. Those who never heard of Tom before, but sat in the audience at the ISASI 2007 Awards Banquet when he accepted the ISASI 2007 Jerome F. Lederer Award, were able to quickly discern for themselves his nature, including his exuberance.

ISASI President Frank Del Gandio declared it an "honor and a privilege" to present the Lederer Award to the man who has served at ISASI's treasurer for the past 12 years. In truth, that is probably the lesser of his service to the Society. As President Del Gandio told it, Tom joined ISASI in 1981 and his achievements "are nothing short of phenomenal." He has chaired the Membership and Nominating Committees for more than two decades; serves with the Ballot Certification Committee; was the ISASI 2003 seminar technical chairman; and is "Mr. Ready" at the headquarters office, doing jobs such as plumber, window washer, box mover, maintenance man, etc. All because "It has to get done."

Add to all of this the acumen Tom has demonstrated in reducing by thousands of dollars the operational costs the Society incurs for office space and taxes and in his development of a highly effective financial and budget reporting system and a person can understand why President Del Gandio told the assembled audience, "I really can't exist in ISASI without him, and he knows I mean that from the bottom of my heart."

But the Lederer Award isn't about serving ISASI—the Award is conferred for outstanding lifetime contribution in the field of aircraft accident investigation and prevention. It was created by the Society to honor its namesake for his leadership role in the world of aviation safety since its infancy. Tom McCarthy also fills that requirement.

President Del Gandio tells why: "For the past 54 years, Tom has dedicated his talents, endless energy, in-depth technical expertise, and 'can do' spirit to improve aviation safety, through accident investigation and in support of investigator mentoring programs. He was a command fighter pilot in the U.S. Air Force who served for 22 years and retired as a lieutenant colonel. For more than a decade of that time, he was an aviation safety officer who performed in-depth accident investigations, which resulted in numerous safety regulations effecting technical refinements, operational policies, and procedures that are still current to this day in the Air Force.

"Following his retirement, he joined the National Transportation Safety Board, eventually moving to senior investigator in charge of major 'go team' investigations. During his NTSB tenure, he investigated approximately 100 aircraft accidents, resulting in numerous safety recommendations and noteworthy improvements to the National Airspace System, which caused procedural changes to flight operations, dispatch, air traffic, airport operations, CFR response, as well as highlighting issues concerning aircraft engineering, maintenance processes, and policies. Later, he joined NASA, becoming the director of the Aircraft Management Office. Again, analytical skills and lifelong experiences helped bring numerous changes to the operation and maintenance of the NASA fleet. Many of Tom's safety recommendations were adopted by the Interagency Committee for Aviation Policy and applied to all federally operated aircraft."

> **"…two things an investigator must have: independence and integrity. Independence to do the work without outside influence or pressure.… Integrity, without it true progress in accident investigation and prevention is not possible."**
> **—*Gerald "Tom" McCarthy***

President Del Gandio closed his talk this way: "Tom's actions have shown him to be deeply dedicated to aviation safety, to accident investigation, and to safety mentoring programs to help prevent aircraft accidents. His contributions to the National Airspace System and our Society are monumental and make him truly worthy of being selected as the recipient of the coveted 2007 Jerome F. Lederer Award presented annually by ISASI.

A thunderous applause filled the banquet hall as the Award presentation ceremony took center stage. Then Tom took his place at the lectern. Following is his acceptance address, abbreviated:

"Thank you very much! To say that I am honored would be an understatement. I am a bit overwhelmed. It is truly a

E. MARTINEZ

President Del Gandio (right) presents the Lederer Award to Tom McCarthy. With the formalities over, Tom exhibits the exuberant side of his nature.

privilege to be in the estimable company of past selectees such as John Purvis, Ron Schleede, Ron Chippindale, and Caj Frostell who are all present here tonight. "The very first Society of Air Safety Investigators (SASI) international seminar was held in November 1970 at the Sheraton-Park Hotel in Washington, D.C., with 159 delegates in attendance. Jerry Lederer, SASI's second president, opened the seminar. These are his words:

"I want to welcome you to the first international seminar on air accident investigation. It's an experiment, which we hope will go far. It is an idea that meetings such as this would have positive effect by getting people to know one another before accidents happen in foreign lands. You'll have an opportunity to meet with people and discuss mutual problem areas. In addition, we will be able to exchange ideas on new techniques as well as old proven techniques on aircraft accident investigations.

"Much of the progress in the development of aviation safety has come from lessons learned from accident investigation. There is reason to believe that this will continue and that new techniques will be developed to aid the investigator to determine probable causes in less time with greater accuracy than in the past in spite of the incredible growth and complexity of aviation. The use of recorders, X-ray, improved photography, improved search and rescue, better training, formalized safety engineering, and the system approach to investigation are some techniques developed in the past decade or two that are transforming accident investigation from an art to a science. But it still remains a considerable art. We are here to help each other uncover and disseminate new ideas on developments in both the art and science of aircraft accident investigation."

"As I sat at the opening of this 2007 seminar, I marveled at the intuition of Jerry Lederer and the growth of the seeds that he planted. Here we are, gathered in one of the premier cities of the world with hundreds of international delegates refining the art and science of aircraft accident investigation and prevention. The progress I've seen is astounding.

"Over the years' seminars, the demonstrated improvements in accident investigation and prevention are gratifying. I'm proud to be a part of all this. Let me give you a feel for Jerry Lederer. Did you know, for instance, that he inspected Lindbergh's aircraft before the history-making flight? That Jerry was a founder of the Flight Safety Foundation? That he became NASA's safety director as a result of the Apollo module fire and helped save the to-the-moon program? And that he was designated by the U.S. Congress as the Father of Aviation Safety?

"My own career in the business started in the early 1960s. I was stationed in Minot, N.D., flying a wonderful new fighter, the F-106 Delta Dart. We got a new squadron commander, Col. Jack Broughton. He observed for a short while, had a meeting, and laid out his plan for the squadron's future. I agreed with his ideas except for one that Capt. McCarthy was to be the flight safety officer. I approached him after the meeting and asked to be relieved of that job since I was about to become a flight commander. He looked me in the eye and said, 'You work for me, and I want you to be the FSO.' I answered, 'Yes sir,' and have been eternally grateful ever since. I joined a group of truly bright folks who are dedicated to saving lives.

"George van Epps, New York office, hired me at the NTSB. He was a great and humble man. He said, "This job is easy—all you have to do is work hard and tell the truth." I have never forgotten that. There are two things an investigator must have: independence and integrity. Independence to do the work without outside influence or pressure and the independence that comes when the investigator has the knowledge and wherewithal to accomplish the required task. Integrity speaks for itself. Without it, true progress in accident investigation and prevention is not possible.

"I want to thank Frank; my fellow Council members, past and present; Ann; and the Awards Committee for their help in making this possible.

"There is truly no way to express my feelings. I'm humbled, I'm honored, I'm extremely grateful. But most of all, I'm pleased that you are all here to share this wonderful moment with me. Thanks!" ◆

Royal Australian Navy Sea King Accident Investigation—Indonesia, April 2, 2005

By Nicholas Athiniotis and Domenico Lombardo, Defense Science and Technology Organization, Melbourne, Australia (CP0134)

__Nicholas Athiniotis__ graduated from RMIT in 1988, having obtained a degree in metallurgical engineering, with honors. In 1989 he commenced work for DSTO in the area of defect assessment and failure analysis, and has amassed extensive knowledge and experience in metallurgical investigations of aircraft structures and components, and research in the areas of fatigue and corrosion. Athiniotis is currently head of the aircraft forensic engineering and aircraft accident investigation area. His current duties include providing the ADF with direct support with scientific analysis of failures and defects in components and systems and assessing the significance to the structural integrity and economic operation of the aircraft and the fleet. He also provides scientific and technical support for investigations of accidents and incidents involving aircraft, including assistance on or off site, and identification and development of improved capability for investigation of aircraft accidents. Athiniotis has been involved in 17 accident investigations involving fixed- and rotary-wing aircraft. He also has participated in an Australian Transport Safety Bureau field exercise that simulated the crash of a small airliner.

__Domenico Lombardo__ is a senior research engineer in the helicopter structural integrity area of DSTO. His current duties are to assist the ADF to understand and resolve structural integrity issues that affect the airworthiness of ADF helicopters. He joined DSTO in December 1986 after graduating from the Royal Melbourne Institute of Technology (RMIT) with a bachelor of engineering (aeronautical) degree (with distinction). In 1997, he received a master of applied science (information technology) degree, majoring in artificial intelligence techniques, from RMIT. From 1987 to mid-1990, Lombardo worked in support of F/A-18 and F-111 structural fatigue investigations. In mid-1990, he helped develop a new helicopter structures group, and as part of this development, from October 1991 to November 1992 was assigned to the U.S. Army Vehicle Structures Directorate, NASA Langley Research Center, Va., U.S., where he worked with both U.S. Army and NASA engineers on helicopter structural integrity issues. Since returning from the U.S. in 1992, he has conducted research and provided advice on structural integrity issues for all ADF helicopter types. Most of his work has involved understanding the fatigue loads on, and lifting procedures for, dynamic components on helicopters. Lombardo has been involved in eight aircraft accident investigations (five on helicopters and three on fixed-wing aircraft). He also has participated in an Australian Transport Safety Bureau field exercise that simulated the crash of a small airliner.

Abstract

At approximately 4 p.m. local time on April 2, 2005, RAN helicopter N16-100 (call sign "Shark 02"), deployed to Indonesia as part of the Australian humanitarian support operation "Sumatra Assist II" and crashed on approach to the village of Tuindrao, on the Indonesian island of Nias. The investigation team from the Australian Defense Force and the Defense Science and Technology Organization found that the cause of the crash was due to a linkage separating in one of the flight control systems, which led to an uncontrollable nose-down motion, impact, and subsequent fire. Nine of the eleven persons on board died. The investigation was the largest ever carried out by the Australian Defense Force, and drew upon expertise from various specialist fields, including metallurgy, cockpit sound frequency analysis, and aircraft flight modeling. The crash-site investigators received exceptional support and collaboration from several military agencies including the Tentara Nasional Indonesia (TNI—Indonesian Armed Forces), the Singaporean Air Force, and the United States Navy, together with the support from the Russian UN Mi8. Without this support, the on-site investigation process would have taken much longer and the entire investigation severely delayed. This paper presents the investigation into the crash of Sea King "Shark 02," the difficulties encountered during the investigation process, and the welcome support and collaboration provided by the various international agencies.

Introduction

On April 2, 2005, at approximately 1605 hours local, Royal Australian Navy (RAN) Sea King Helicopter N16-100[1] crashed on a soccer field near the village of Tuindrao, in the region of Amandraya, on the island of Nias, Indonesia (Figure 1). As a result of the accident, a Directorate of Defense Aviation and Air Force Safety Aircraft Accident Investigation Team (AAIT) and two Defense Science and Technology Organization (DSTO) officers left Canberra on April 3 and traveled by RAAF C-130J to Indonesia to commence the on-site investigation. Personnel from the Defense Section, Australian Embassy, Jakarta, were also sent to join the team. Later, the AAIT was supported by a detachment of the RAAF 381 Expeditionary Combat Support Squadron (ECSS), which built and maintained a camp at the accident site to support the AAIT. This team was also augmented by seven members of the RAN's Clearance Diving Team 4 (CDT4).

Subsequent to the on-site investigation, the aircraft wreckage was recovered and transported to Australia for further investigation at DSTO Melbourne.

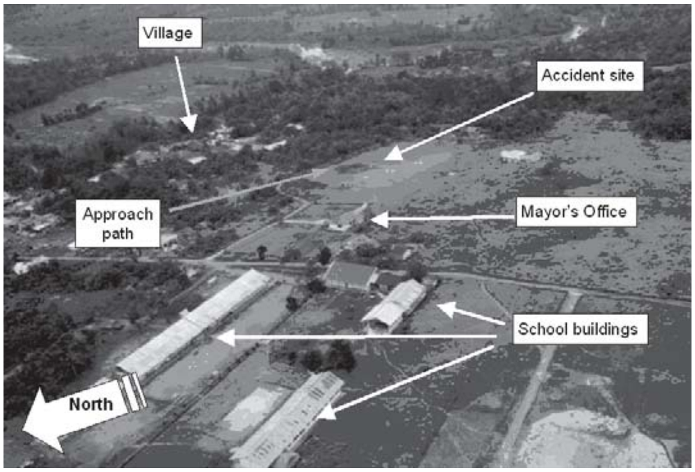


Figure 1. Location of the Sea King crash site.

Figure 2. Aerial photo of the crash scene, 90 minutes after the accident.

Figure 3. Ground photo of the crash scene. Crash data recorder visible in foreground.

Background

Australian Defense Force (ADF) personnel assisted the Indonesian government authorities as part of the Australian government program of humanitarian relief following the 2004 Boxing Day tsunami. The Australian relief assistance, known as Operation Sumatra Assist, was part of a cooperative effort involving the ADF, the AusAid section of the Department of Foreign Affairs and Trade (DFAT), and Emergency Management Australia. Water, tents, medical supplies, blankets and other emergency provisions, and logistical support were provided, with the aid of the Royal Australian Navy's ship HMAS *Kanimbla*, with two Sea King helicopters on board.

On March 28, 2005, the island of Nias, located off the west coast of northern Sumatra, Indonesia, was hit by a devastating earthquake. Approximately 1,300 people were killed by the earthquake, mostly on the island of Nias. HMAS Kanimbla, which had already departed Indonesia and was temporarily at anchor in Singapore, enroute to Australia, was immediately recalled to sail for the earthquake-affected island. On March 30, 2005, HMAS *Kanimbla* sailed for Nias and commenced Operation Sumatra Assist II.

RAN Sea King N16-100, with a crew of four, a team of seven aeromedical evacuation (AME) personnel, and their supplies, was one of the two Sea Kings from HMAS *Kanimbla* designated to assist earthquake victims on the island of Nias, Indonesia. On the day of the accident, the aircraft took off from HMAS *Kanimbla* to conduct a Medevac (medical evacuation) of personnel from Tuindrao. The plan for the sortie task involved the AME team being inserted at Tuindrao to assess casualties and for "Shark 02" to continue on to Teluk Dalam, a town on the southern tip of Nias. The crew of "Shark 02" was then to offload approximately 200 pounds of medical supplies and return to HMAS *Kanimbla* with any casualties and await notification by the AME team when they required extraction from Tuindrao.

When "Shark 02" arrived at Tuindrao, the local soccer field, located at the nearby school, was chosen to land the aircraft. As the aircraft entered the boundary of the soccer field, from the north, immediately to the eastern side of a set of soccer goal posts, it pitched nose down and fell, the main rotor blades striking the ground, resulting in a violent impact with the ground. The aircraft came to rest on its port side and sustained extensive damage as a result of the subsequent intense fire (Figure 2 and Figure 3) that continued for more than 90 minutes[2]. Of the eleven people aboard the helicopter, only two survived. Eyewitnesses indicated there were some small explosions and smoke shortly after the aircraft impacted the ground, and several assisted in the extraction of the two survivors from the wreckage before several larger explosions and fire prevented any further rescue attempts.

The second Sea King from HMAS *Kanimbla*, N16-239, "Shark 21," landed twice at the site, once to pick up the two survivors and once to search for more survivors. A Republic of Singapore Air Force Chinook helicopter also hovered over the accident site at some stage.

International collaboration

Following confirmation of the Sea King accident on April 2, an AAIT was immediately established late that night and deployed from Australia to Indonesia by C130J Hercules aircraft early on the morning of April 3, arriving in Jakarta that evening for a few hours' stay, where personnel from the Defense Section of the Australian Embassy joined the team. The team of 14 was then transported on the C130J to Sibolga[3], arriving at approximately 0715 hours local time (April 4).

The Indonesian National Defense Force (TNI) conducted a memorial ceremony to honor the lives lost in the accident in Nias, and the AAIT was requested to form part of the honor guard lining the runway as the caskets containing the remains of the nine victims were loaded onto the C130J for transport to Australia. Immediately following the ceremony, a Republic of Singapore Air Force (RSAF) Chinook, laden with humanitarian supplies, flew the AAIT to the crash site. Due to the extent of supplies on board, there were not enough seats for all the team and "combat loading" was used (i.e., a number of seats had to be improvised from boxes). Limited time was available at the crash site, as the Chinook was low on fuel, but this brief stop allowed the crash data recorder (CDR), which was ejected from the aircraft during the accident, to be collected and subsequently transported back to Australia for download of data.

The RSAF Chinook transported the AAIT to Gunung Sitoli, the capital of Nias (Figure 4) where a RSAF headquarters and field hospital had been established near a "Stadium"[4] and associated school complex. Four members of the AAIT were transferred to HMAS *Kanimbla* via boat to begin the process of interviewing personnel. An overnight camp in the school yard was established with the assistance of the RSAF. As the AAIT had only limited supplies, the RSAF provided some additional food and access to electricity for recharging batteries and powering equipment. That evening, the officer-in-charge (OIC) of the AAIT attended a UN meeting with the RSAF detachment commander, which allowed discussions for planning for further RSAF support. Sleep for the AAIT, exhausted and sleep deprived, was difficult with wailing throughout the night coming from a number of ceremonies being held following the deaths caused by the devastating earthquake, not to mention the rather noisy local livestock.

A local truck driver transported some members of the AAIT to the nearby wharf, collecting a small amount of supplies from HMAS *Kanimbla* and, importantly, meeting up with the Australian embassy staff linguist, who played a crucial part in communications and logistics, and assisted in interviewing eyewitnesses to the accident. An Indonesian SAR helicopter transported two of the AAIT to the crash site, while the remaining members arrived by RSAF Chinook.

Delays in receiving supplies and technical problems and subsequent delay with a TNI-AU Super Puma added extra stress to personnel on the mission, which resulted in heat distress and collapse of one member of the AAIT. Immediately after arriving at the crash site, this member suffered severe heat stress and stopped breathing on two occasions. Communications were difficult on the island; however, an Iridium satellite phone link was established with HMAS *Kanimbla* with a request for Medivac. The second Sea King on HMAS *Kanimbla* was deployed to the crash site with a medical team. On departure, with the AAIT member on board, the aircraft was signaled to return due to a loose panel being noticed on the tail boom. This panel turned out to be a non-structural fairing for the rear of the tail pylon and the aircrew was authorized to remove the panel, then return to the ship. During the delay caused by this problem, the AAIT member had recovered sufficiently to be offloaded to remain with the team.

A TNI-AU VIP Super Puma and one additional passing helicopter (police) arrived and evacuated all nine personnel to Sibolga. The AAIT, through the linguist, arranged bus transport to the city; however, there were no accommodations available. Negotiations by the linguist and locals established that a small resort island (Sibolga Marine Resort—the equivalent of a three-star backpackers hotel with air conditioning and a restaurant) could accommodate the AAIT, and a ferry was arranged to transport the AAIT to the resort. The resort became the operations center for the AAIT, and established a safe, efficient, and effective place for the conduct of the investigation—since the crash site had no electricity, and food supplies were at a minimum. It would be another 5 days before the RAAF's 381 Expeditionary Combat Support Squadron (ECSS) would arrive at the crash site and establish a functional camp site to permit the AAIT to move the operations center to the crash site.

Figure 4. Republic of Singapore Air Force Chinook with members of the AAIT at Gunung Sitoli.

Figure 5. Members of the AAIT waiting to board the UN Russian Mi8.

Transportation

Helicopters were the only way to reach the site from Sumatra in reasonable time. Roads between the Nias towns of Gunung Sitoli and Teluk Dalam were unsuitable for re-supply or in case of an urgent casualty evacuation. The roads were narrow, earthquake damaged, and most bridge repairs were unsound. The TNI provided good support and had arranged to supply a Super Puma to airlift the AAIT to and from the crash site the following day, and for the remaining days leading up to permanent transfer to the crash site. Unfortunately, the TNI-AU helicopter became unserviceable later in the day at Medan and was unable to provide airlift from the crash site. However, it so happened that the UN Russian-built Mil Mi8 heavy-lift helicopters and crews, supporting the relief effort, were staying at the Sibolga Marine Resort as well. Negotiations between the OIC-AAIT and Mi8 crews paved the way for some members of the AAIT to be transported to and from the crash site, approximately 1 hour away, each day (Figure 5). Passenger restrictions meant that four personnel had to stay behind at

Figure 6. USN MH-60S helicopter delivering supplies to the campsite adjacent to the crash site.

Figure 7. U.S. Naval hospital ship, USNS Mercy.

Figure 8. Members of the AAIT with full PPE in preparation for applying the floor wax solution over the burned carbon fiber.

the resort each day, undertaking administration duties. The team traveling to the crash site was also required at times to assist with the ongoing humanitarian support provided by the UN Mi8.

This became the routine for the AAIT until 381 ECSS arrived to establish a camp at Tuindrao. Once the camp was deemed to be suitable, the engineering part of the AAIT relocated to Tuindrao to continue the crash site investigation. The non-engineering parts of the team returned to Australia.

The camp supplies were based upon an establishment of 25 personnel. The camp initially provided the bare essentials, relying on ration packs that were used by the camp site chef to produce hot meals. On April 17, additional supplies (fresh food and water, and other equipment required for the investigation) were transported to the site by several USN MH-60S helicopters (Figure 6) via sling loading, from Sibolga and the USS *Tippecanoe*. The Mi8 helicopter was also tasked to conduct heavy-lift supply of equipment for the recovery phase. About 100 locals assisted with clearing the supplies from the drop sites.

On April 15, a USN helicopter was to redeploy the AAIT to Sibolga to meet the representatives of the New South Wales state coroner, who was conducting a separate inquiry into the crash. However, thunderstorms at Sibolga prevented the helicopter from landing and so it diverted to the U.S. naval hospital ship, USNS *Mercy* (after refueling on USS *San Jose*), and the AAIT was welcomed onboard and given accommodation for the night including medical check and treatment for minor skin irritations (Figure 7). The USN helicopter then transferred the AAIT to the crash site the following morning.

Accident site

The accident site was a level soccer field (as was shown in Figure 1) in the Indonesian village of Tuindrao. Tuindrao is situated at an elevation of approximately 45 meters above sea level in coastal rainforest on the western side of a small ridge, one kilometer inland from the Indian Ocean, on the southwestern side of the island of Nias.

From the eastern side of the soccer field, the terrain slopes down to a river several hundred meters away. The main village of Tuindrao was located along this river and comprised a collection of dwellings of concrete with thatched roofs. From the western side of the soccer field, the terrain rises gently to a ridge approximately 150 meters away. Two buildings are located near the western boundary of the soccer field: a police station on the southern end, and the local government building (the mayor's office) on the northern end. Sited in front of these buildings are flagpoles, and behind the local government building is a radio mast. The school at Tuindrao is located approximately 100 meters further along the slope to the north and is a substantial complex of single-story buildings and open areas.

The impact of the earthquake meant that there were no supplies of fresh food, clean water, or electricity. The majority of school buildings had varying earthquake damage, and earth tremors were frequent. The local school, adjacent to the crash site, was temporarily suspended, which allowed the AAIT to use some of the schoolrooms to store technical equipment and to use as offices. School recommenced during the investigation so the AAIT had to move its equipment. Minor tremors were still occurring daily. A larger tremor occurred on the evening of April 10, registering 6.8 on the Richter scale (epicenter Siberut Island, southwest coast of Sumatra).

Once the 381 ECSS established a functional camp site adjacent to the crash site, the AAIT was able to relocate from Sibolga, allowing more investigation time per day at the site. Due to the extreme weather conditions, and the fact that the AAIT was wearing personal protective equipment (PPE)—initially full PPE to apply the floor wax solution over the burnt carbon fiber (Figure 8), then PPE with P2 masks for the wreckage examination—three shifts of 10-40 minutes *per day*, depending on the intensity of the sunlight, was all that could be achieved to prevent heat stress and exhaustion. In general, it took about a week for personnel to acclimatize, after which they became progressively more comfortable and effective.

Communications between the site and others supporting the investigation were initially difficult. There was no mobile phone coverage at the site. Portable Iridium satellite telephones were fairly reliable when communicating with land lines, but not mobile telephones. The NERA Saturn-B satellite telephone provided good communications, but succumbed to the humidity after 2 days.

Investigation

Where possible, all wreckage was identified, photographed, and labeled during either the mapping stages or subsequent detailed wreckage examination. The intense fire had destroyed a significant proportion of fuselage making identification difficult. In addition, the monsoonal conditions of extreme heat, humidity, and occasional night rain, together with the heat damage from the fire, caused significant deterioration of the aircraft wreckage during the course of the investigation (Figure 9).

Wreckage distribution

The main fuselage wreckage was contained in an area of approximately 80 square meters, northeast of the center of the soccer field. The aircraft was lying such that it was facing the direction from which it had approached the field (Figure 10). The majority of the wreckage, forward of station 493, had been engulfed and substantially consumed by the post-impact fire. The two engines were located on top of each other, with the port (left) engine below the starboard (right) engine, as shown in Figure 11. Extensive post-impact fire damage was associated with the main rotor gearbox area; however, the direction of the wind from the southwest prevented major fire damage to the main rotor hub, as shown in Figure 12. Part of the rear fuselage (tail cone), connecting pylon, tail undercarriage, tail rotor intermediate gearbox, and tail rotor gearbox were damaged to a lesser extent by the post-impact fire. Ground impact had caused the tail cone to separate from the forward fuselage at approximately fuselage station 493.

Between the first set of main rotor blade strike marks and the main fuselage wreckage were a number of key areas of ground impact marks and wreckage that helped to form a picture of events from the time the aircraft departed normal flight to when it reached its final position.

Post-impact fire

The post-impact fire was very intense, fuelled by onboard material (a mixture of aviation fuel, oils, medical oxygen cylinders, and magnesium/aluminum structure). Photographic evidence, which was taken at least 90 minutes after the estimated time of the accident, and upon nightfall, revealed that the fire was still intense.

The fire was initiated when residual fuel from the engine or oil came into contact with hot engine components, which rapidly spread through the aircraft and resulted in a series of explosions (butane cans inappropriately carried in the aircraft would have also contributed to the fire). The fire damage was contained to the fuselage region, and a burnt grass area adjacent to and east of the wreckage consistent with a fuel burn.

Figure 9. Photograph of the wreckage showing the extent of damage caused by the fire. The monsoonal conditions caused significant deterioration to the wreckage.

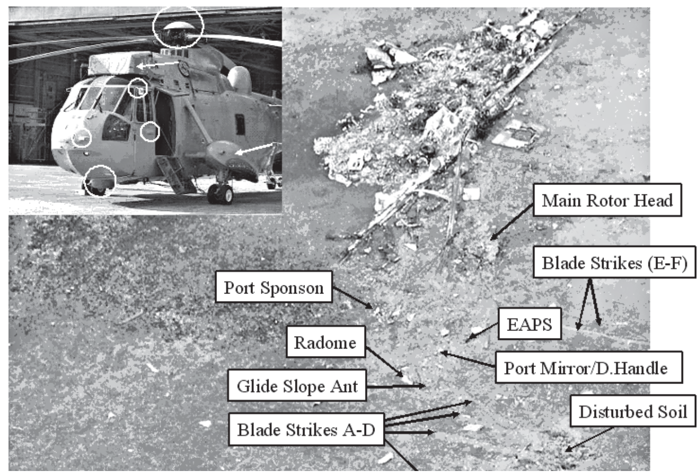


Figure 10. Aerial photograph of the aircraft wreckage. Its final position was on its port (left) side, facing the direction from which it had approached the field.

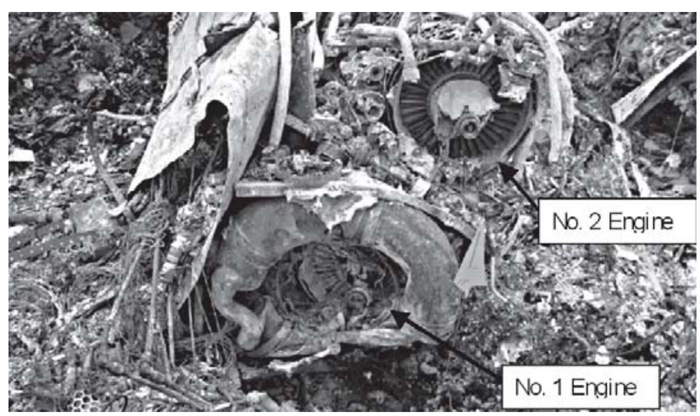


Figure 11. Photograph of the port (No. 1) and starboard engines.

Wreckage mapping

The wreckage was plotted using a GPS mapping unit (Figure 13). Normally, DSTO conducts mapping using a differential GPS signal to provide accuracy of the mapped points to within centimeters[5]. The differential GPS signal is obtained from a communications (Optus) satellite, however in this case, the island of Nias was outside the coverage of the Optus satellite, and it was not pos-

Figure 12. Although the fire was so intense that it consumed the magnesium gearbox casing, the main rotor hub was less affected by fire due to the wind direction.

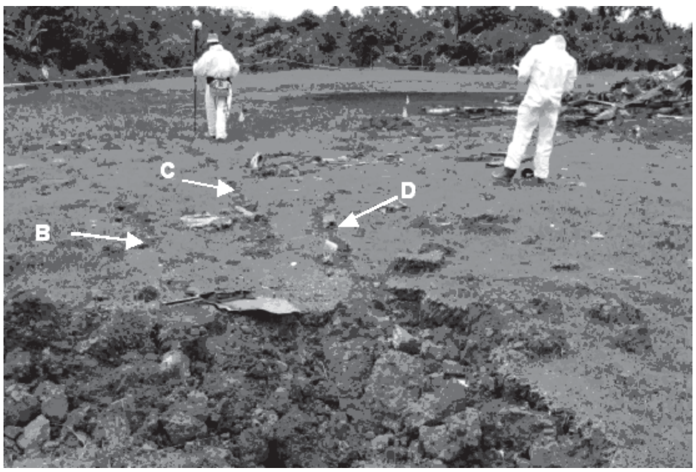


Figure 13. Photograph showing the GPS wreckage mapping of the main rotor ground strike marks.

sible to modify the unit in the time available to access an alternative satellite. Hence, the wreckage was mapped using standard GPS. There are two problems with using standard GPS for wreckage mapping. First, the error is much greater than that of differential GPS (potentially an order of magnitude greater) and, second, the error is not constant so that the apparent location of a fixed point will change over time and may appear to move several meters. In light of this, steps were taken to provide a partial error correction capability.

Flight control systems

Damage to the flight control systems was extensive due to the intense heat of the post-impact fire. The majority of aluminum and copper alloy components had melted. The control runs from the cockpit to the auxiliary servo equipment (ASE) pack and back to the primary servos were significantly damaged due to impact and subsequent fire. The aluminum alloy control rods had melted, leaving the steel control rod eye ends visibly attached to their associated steel bolts, heat affected but unmelted.

The ASE pack provides servo assistance through four separate channels, fore/aft (pitch), lateral (roll), collective (altitude), and directional (yaw) to the control linkage of the primary servo jack units and tail rotor. The unit, which is located within the auto-

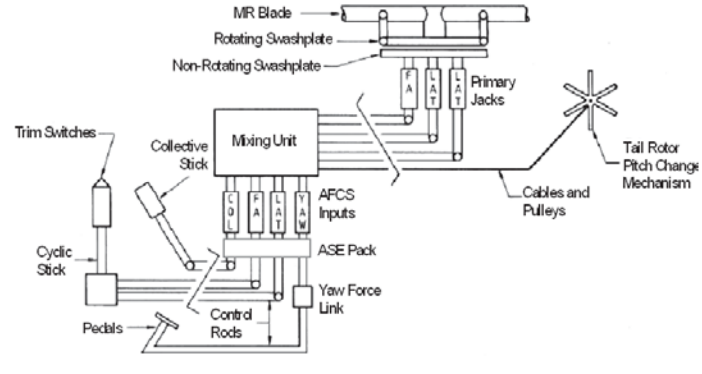


Figure 14. Schematic of the flight control system. Note: To simplify the schematic, the inputs to the mixing unit (i.e., collective, fore/aft, lateral, and yaw) are not shown in the correct order.

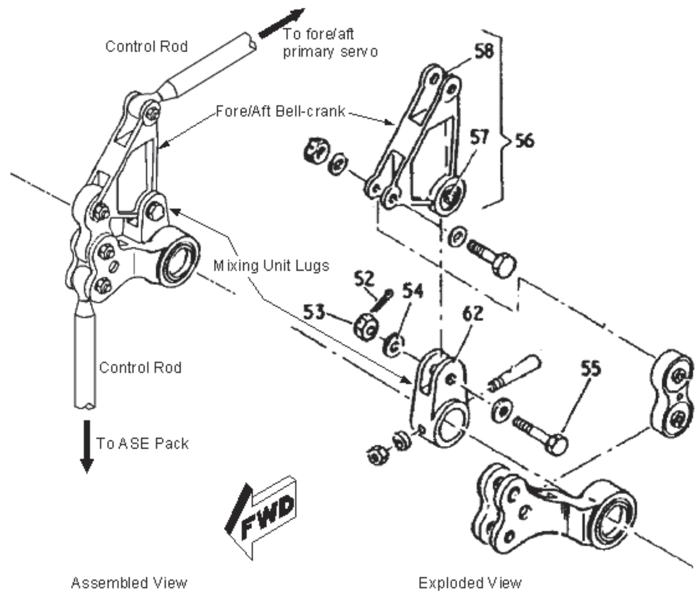


Figure 15. Diagrams showing the mixing unit and fore/aft bellcrank assembled together (left) and an exploded view of the significant items (right). The numbers shown in the exploded view correspond to item numbers from the Sea King illustrated parts breakdown manual. The split pin, washers, nut and bolt, items 52, 53, and 55, respectively, connect the fore/aft bellcrank to the mixing unit.

matic flight control system (AFCS) compartment (known as the "broom closet") behind the first pilot's seat, is connected mechanically to the control linkages by push pull rods, hydraulically to the auxiliary hydraulic system and electrically to the AFCS and beeper trim system.

The ASE pack had experienced damage to the auxiliary servos and electrical system, and the heat of the post-impact fire had resulted in melting and fusion of the aluminum components. The aluminum control rods connected to the push-pull rods of the ASE pack had melted away leaving their steel rod ends connected to the push-pull rods.

On April 9, the high strength steel mixing unit shaft was found in the main fuselage wreckage. The mixing unit couples and directs pilot control inputs to the main and tail rotor systems of the helicopter. A detailed view of the mixing unit and fore/aft bellcrank assembly is shown in Figure 14 and Figure 15. The mixing unit

Figure 16. Location of the mixing unit, showing the lugs for the attachment of the fore/aft bellcrank.

Figure 17. Location of the fore/aft bellcrank near the mixing unit.

Figure 18. Area of location of the fore/aft bellcrank attachment bolt, discovered under debris.

also allows the same control rods to be used for both cyclic and collective pitch changes. This is achieved by fitting freely mounted levers on a central shaft that can operate individually when cyclic selections are made, but rotate as a whole when a collective selection rotates the central shaft. The unit was lying in a horizontal position, approximately in the region (relative to the wreckage) where it is located in the aircraft and orientated as per its position in the aircraft (Figure 16). Although fire had consumed the aluminum alloy lateral, collective, and yaw bellcranks, and associated aluminum alloy assemblies, their respective high strength steel taper pins and nuts were still attached to the mixing unit main shaft. In each case, any aluminum washers present had melted. It was evident, however, that there was no attachment of the high strength steel fore/aft bellcrank to the mating lugs of the mixing unit main shaft. The fore/aft bellcrank was located near by (Figure 17) forward of the mixing unit. The bolt and castellated nut and split pin were not immediately locatable.

On-site examination of the high strength steel lugs of the mixing unit (for the attachment of the fore/aft bellcrank) with a 10X magnifying glass revealed no evidence of damage or deformation to the internal and external surfaces of both lugs. The lack of any damage or deformation strongly suggested that the bolt for the attachment to the mating bellcrank had not been forced out of the lugs as a result of the accident. While the adjacent aluminum alloy bellcranks and attachment fittings had melted,[6] the temperature of the fire in the region of the mixing unit did not exceed the melting temperature of the high strength steel fore/aft bellcrank, or of the steel bolt and nut that attached the fore/aft bellcrank to the steel mixing unit lugs[7].

The separation of the fore/aft bellcrank from the mixing unit might have occurred as a result of loss of the securing bolt by

a. a bolt failure before or during the impact, or

b. failure of both the castellated nut and the associated stainless steel split pin, or

c. separation of the castellated nut (Part Number AN320-6) from the bolt, i.e., the nut had spun off, allowing the bolt to withdraw, which could only occur if there had been a loss of the security provided by the stainless steel split pin.

Hence, finding the bolt and nut became an important part of the investigation.

The bolt that connects the fore/aft bellcrank to the lugs on the mixing unit in the Sea King helicopter is unique in that no other bolt (in the Australian Defense Force inventory) of the same material, head size, and shank diameter has the same length. On April 15, a bolt of similar description to the missing item was found in the area adjacent to the mixing unit (Figure 18). The bolt was not attached to any part of the aircraft structure or mating nut, washer, or split pin. The bolt was complete with no visible damage. A castellated nut was discovered in the grid area comprising the mixing unit on April 17. The nut was fused to a melted piece of aircraft wreckage (Figure 19), which was not normally associated with this piece in the aircraft. The nut was complete and had no damage to the internal threads. Unlike the bolt, the castellated nut for the attachment of the fore/aft bellcrank to the mixing unit is not a unique item. Further examination of wreckage surrounding the mixing unit failed to find the associated split pin. It was apparent that meticulous sifting of the aircraft wreckage debris would be required at the DSTO Laboratory in Melbourne.

While the search for the bolt and nut was being conducted by some members of the AAIT, other members were examining the rest of the aircraft to determine if there were any other unusual features or failures in the wreckage. This search determined that all observed features of the wreckage were consistent with damage from the impact with the ground and the post-impact fire. This on-site conclusion was confirmed by the laboratory examination of the wreckage at DSTO Melbourne.

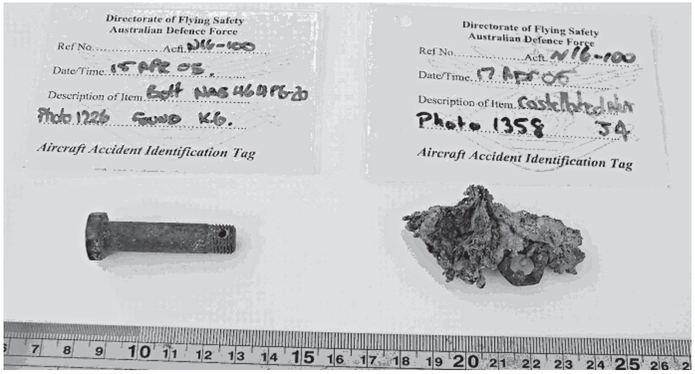


Figure 19. On-site photograph of the located bolt and nut (fused to aluminum).

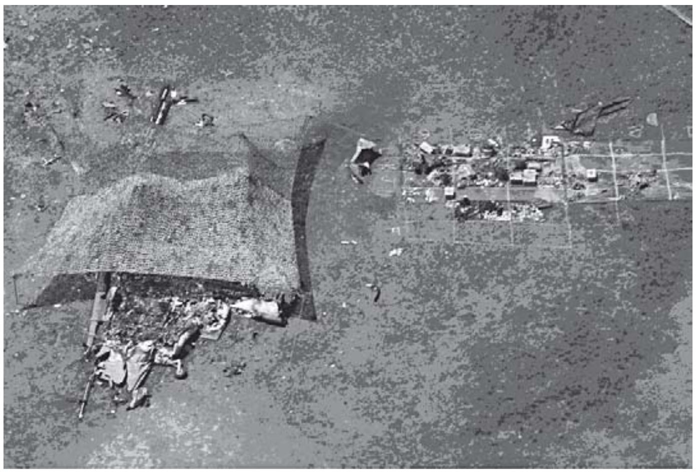


Figure 20. Aerial photograph showing the adjacent grid, which correlated to the grid developed for the wreckage to enable identification of the location of the wreckage.

Figure 21. DSTO investigators sieving the wreckage at DSTO Melbourne.

Wreckage recovery from the crash site, Nias, Indonesia

To facilitate controlled recovery of the wreckage back to Australia, the investigators developed a grid referencing system over the wreckage and duplicated this on the field adjacent to the wreckage (Figure 20). The grid was designed such that wreckage could be identified as coming from a one meter square area.

Figure 22. DSTO investigators carefully sifting through the sieved wreckage at DSTO Melbourne.

The entire wreckage was removed from the crash site and packaged into ADF "G"-sized containers (2x2x1 meter) for return flight to Australia. Australian quarantine requirements meant that the containers were sent direct to the AQIS facility in Darwin, Northern Territory, to be cleaned of any soil or organic matter, or for subsequent sterilization at a recognized facility, to make the contents benign. Smaller, more fragile items contained in boxes in nine containers were subsequently transferred to Steritech Pty. Ltd. for treatment with gamma radiation and ethylene oxide gas.

DSTO laboratory examination

Wreckage sieving and sifting

A high priority was placed on sorting through material removed from the site in the area of the mixing unit, looking for the existence of a split pin. Due to the scale of this process, it was necessary to hire an industrial sieve with a 6 millimeter and 1 millimeter coarse mesh size (Figure 21). Material that had been captured by the 1 mm mesh (material 1 millimeter to 6 millimeter size range) was then passed to investigators who sifted carefully through the material using smaller kitchen-type sieves, brushes, and tweezers (Figure 22).

Wreckage melting

The fire had led to the formation of many lumps of melted aluminum alloy. Although the sieving/sifting process was designed to identify small components, there was a possibility that small parts, like split pins, could have been trapped within a lump of aluminum. An industrial furnace was hired to melt the lumps of aluminum and capture any steel components that may have been trapped in the molten aluminum.

Mixing unit, nut, and bolt

The laboratory examination confirmed the on-site examination results—the surfaces of the lugs and lug bores were undamaged, and there was no evidence of thread marks on the bore walls of the lugs. The pivot bolt found in the wreckage was the only bolt of that type recovered and, therefore, was most probably fitted to the fore/aft bellcrank; the slight damage to the threads was consistent with it extracting from the bearing as a result of normal flight vibrations, and not through a sudden and dynamic separation as a result of the accident sequence. The castellated nut was also the only loose nut of the correct type to be recovered from the wreckage. All other nuts of the same type were accounted for (they were still attached to their respective components).

Split pins

Split pinning provides redundancy in connection security. Numerous used and un-used split pins were recovered from the wreckage, together with cut tails (trimmings during installation). Of the split pins recovered, none exhibited any evidence that they had failed. There are no forces acting on a correctly installed split pin to cause it to fail. No split pin of the type (3/32 inch) that should have been fitted to the pivot bolt and nut connection of the fore/aft bellcrank in the mixing unit was found in the wreckage. Other secured connections associated with the mixing unit contained undersized split pins. Although providing security in this case, the installation of undersized split pins was not in accordance with maintenance documentation.

Engine examination

Examination of the engine by DSTO and Rolls-Royce confirmed the CDR frequency analysis that the engines were providing power at the time of the accident.

Mechanical component examination

All mechanical components associated with the main rotor gearbox, tail rotor gearbox, tail rotor, hydraulic pumps, and servo hydraulics were examined. No mechanical failures were found, confirming the CDR frequency analysis.

CDR frequency analysis

The crash data recorder (CDR), which is contained within the beacon airfoil unit (BAU), had ejected during the aircraft impact with the ground and was located south of the main wreckage, undamaged.

The CDR is a four-channel unit, capturing sound from the pilot microphone, the copilot microphone, cockpit area microphone (CAM) as well as recording main rotor speed (referred to as the rotor speed encoder, RSE, channel). A copy of the CDR download was provided to DSTO to perform a frequency analysis of the background sounds, as the frequencies obtained could be related to the various frequencies generated by the rotating propulsion system components of the aircraft.

The CDR analysis of the microphone channels confirmed that the main rotor gearbox and engines were working correctly and did not show any evidence to indicate a failure in the rest of the aircraft rotating propulsion system components. This supported the accident site and laboratory assessment and analysis. The analysis of the CDR crew vocalizations supported the view that there were no unusual problems with the aircraft prior to the sudden departure from controlled flight during the landing approach.

The main rotor speed over the entire mission (from the time rotors are up to speed to the end of the CDR data) is shown in Figure 23. The main rotor was engaged at EOR-59:57 and take-off occurred at EOR-49:10. The aircraft climbed at EOR-10:30 and, at EOR-05:00, the crew performed a power check. The first indication that the crew was aware of any problem with the aircraft occurred at approximately EOR-2.5; at this point there was a vocal response from the crew accompanied by a brief increase

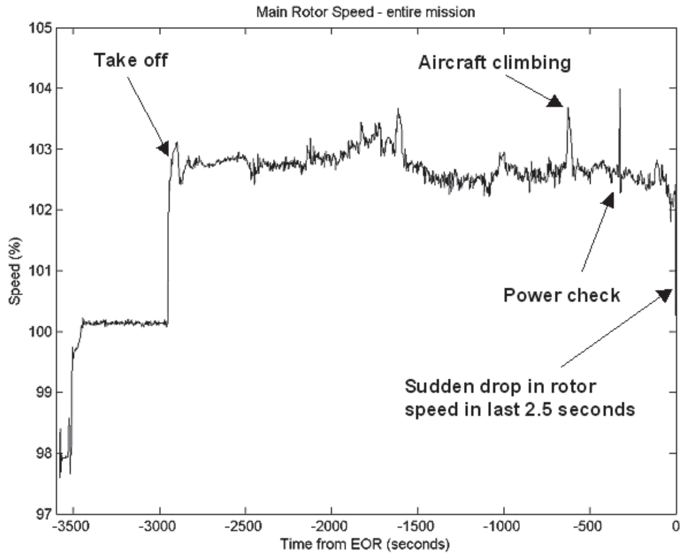


Figure 23. Graph of the main rotor speed for the entire mission.

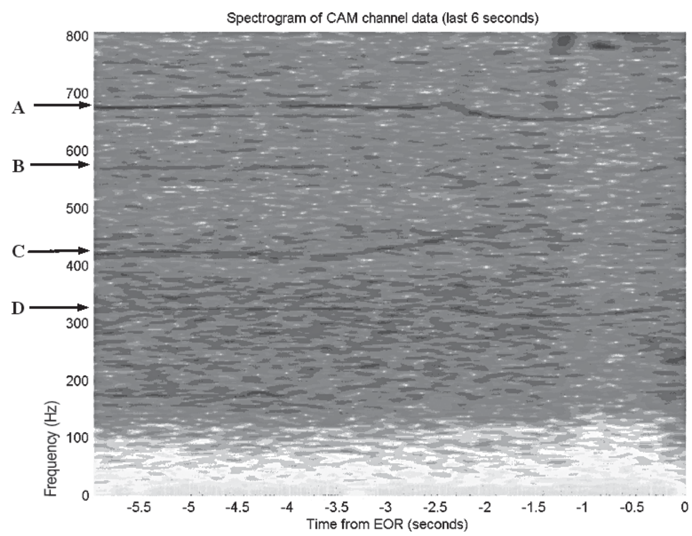


Figure 24. Spectrogram of CAM channel (final 6 seconds). Frequency components are (A) epicyclic gear mesh, (B) auxiliary pumps, (C) engine gas generator once per rev, and (D) engine power turbine and MRGB high-speed input shaft once per rev.

in rotor speed followed by a large drop in rotor speed.

Figure 24 shows a spectrogram of the CAM channel data over the final 6 seconds before EOR, for the frequency region below 800 Hz. Noise from the epicyclic tooth meshing (A), auxiliary pumps (B), engine gas generator (C), and power turbine/MRGB high speed input shaft (D) are all identifiable (as marked) in this Figure.

The following observations were made in relation to the marked frequency components in Figure 24:

A: **Epicyclic gear mesh**. The noise from the epicyclic gearbox varies with main rotor speed as expected and continues until the EOR.

B: **Auxiliary pumps**. This frequency is at nine times the auxiliary drive speed and is related to one or more of the auxiliary pumps. These are the auxiliary hydraulic pump, utility hydraulic pump, and secondary lubrication pump, all of which are nine-piston pumps driving at the same speed (i.e., they all produce sound at the same frequency). The noise from these pumps appears to stop at EOR-3.7. The fact that the noise from these pumps stop does not indicate that there was any failure as these are constant-pressure, variable-flow piston pumps that operate on demand. Examination of the noise from these pumps in early portions of the flight indicated that it comes and goes and was present more or less constantly (with fluctuating levels) for about 90 seconds before it stopped at EOR-3.7.

C: **Engine gas generator**. The frequency of the once-per-revolution noise from the engine gas generator begins to increase at EOR-3.7, coinciding with noise ceasing from the auxiliary pumps. The frequency continues to increase until approximately EOR-1.8, when it becomes difficult to distinguish from the background noise. At this point, the rotor speed has already dropped significantly, there were vocalizations indicating that the crew was aware of a problem, and there was an increase in general background noise. The fact that the gas generator once-per-rev frequency was still noticeable and increasing after the sudden drop in rotor speed indicates that an engine failure is unlikely to have been the cause of the accident.

D: **Engine power turbine/MRGB high-speed input**. This frequency is the once per rev of the engine power turbine shaft, which is connected to the high-speed input of the main rotor gearbox (MRGB). This varies in speed with the main rotor speed which is to be expected as they are mechanically linked. Although the high speed input shaft frequency and power turbine speed cannot be separately identified, there are freewheel units on the input intermediate shafts of the MRGB that would allow a failed engine to run down in speed with the other engine still driving the gearbox. No evidence of this happening is observed, making it unlikely that there was a loss of drive from either engine. In the event of failure of the input from an engine to the gearbox (such as shaft, coupling, gear, or freewheel unit failure), the sudden release of load on the power turbine would cause it to overspeed and the overspeed trip governor would shut down the engine. Again, there is no evidence of this occurring.

The DSTO frequency analysis revealed the following:

1. There were no indications of mechanical failure of the rotating propulsion system components.
2. There was power to the engines when the aircraft suddenly pitched nose down.
3. The crew vocalizations indicated that they became aware of problems approximately 2.5 seconds before the CDR ceased working on the pilot/copilot/CAM and RSE channels.
4. A rapid reduction in main rotor RPM (approximately 4%), and an increase in engine gas generator RPM in the 1.5 seconds before the CDR ceased working are indicative of an increased torque requirement, e.g., such as occurs with a rapid collective input.

Simulation

Two simulations were performed during the investigation, a ground simulation on a Sea King and a mathematical simulation.

Ground simulation

The first was a simulation on a Sea King at HMAS Albatross, Nowra, NSW. This simulation involved a step-by-step process of assessing the effect on a Sea King control system of removing the pivot bolt from the fore/aft bell crank in the mixing unit.

Due to the critical likely effects of this simulation, it could not be performed in flight, but this was not a problem as the Sea King hydraulics system is set up to isolate the control system from all aerodynamic loads generated by the main rotor. A Sea King control system only experiences the loads generated when the pilot moves the cyclic, collective, or pedals. Hence, a ground-based simulation, with rotors stopped and hydraulics on, was a suitable simulation.

The outcomes of this simulation were that (i) the pivot bolt is loose enough in the bellcrank to fall out under normal flight vibrations if it is not restrained by the nut and split pin, (ii) the control system moves to a position corresponding to a full forward cyclic position (i.e., full nose down), and (iii) no possible combination of pilot inputs would be effective in restoring control.

Mathematical simulation

The DSTO staff that attended the flight control systems tests at HMAS Albatross, used this information together with a number of initial conditions and assumptions, including information made available from the AAIT, to develop a Sea King mathematical flight model of the events leading to loss of aircraft control. The flight model also took into account the loss of the fore/aft bellcrank bolt by disconnecting the pilot longitudinal cyclic control to have no effect on the rotor longitudinal cyclic pitch angle.

The flight model closely simulated the events that led to the accident, based on the evidence of the initial main rotor blade ground scars at the crash site. The flight model indicated that the aircraft would have exhibited a rapid change in pitch rate and a pitch forward 0.5 seconds after the bellcrank had detached from the mixing unit lugs. The pilot's instinctive reaction would have been to pull aft cyclic, which now had no connection to the flight control system. The aircraft, however, would have continued to pitch forward rapidly. According to the simulation, 2.3 seconds after detachment of the bellcrank, the main rotor tip would have hit the ground with an aircraft pitch attitude of 55 degrees nose down.

DSTO investigation summary

The assessment and analysis of the wreckage at the crash site suggested that a number of lines of potential causes of the accident were able to be discounted. These views were supported by examination of components at DSTO Melbourne and HMAS Albatross. The following failure scenarios were therefore discounted as probable hypotheses:

1. *Engine failure (single or double)*—the on-site assessment, the engine disassembly at HMAS Albatross, and the DSTO assessment of melted blades and stators from the engines, showed no evidence of an inflight engine failure. All indications are that both engines were working normally at the time of the accident. The significant damage to the No. 1 engine was due to a very intense, magnesium-fuelled fire, post impact.
2. *Fuel system failure*—analysis of the CDR indicated that the aircraft was under power at the time the aircraft nose-dived. Analysis of the fuel showed that its condition was acceptable. There is a high level of confidence that a fuel system failure did not occur.
3. *Fuel starvation*—evidence of a fuel-rich fire discounted lack of fuel as a factor.
4. *Transmission failure*—no evidence was found of main rotor, intermediate gearbox, or tail rotor gearbox transmission failure.
5. *Main rotor head failure*—the assessment made at the crash site

and at DSTO indicated that there was no evidence of structural failures that may have contributed to the accident.
6. Main rotor blade failure—there was no evidence of inflight blade or blade-root failure. All damage was consistent with ground impact and the post-impact fire. All blade roots were found securely fastened to the main rotor hub.
7. Tail rotor hub failure—the assessment made at the crash site and at DSTO indicated that there was no evidence of structural failures that may have contributed to the accident.
8. Tail rotor blade failure—there was no evidence of blade failure in flight. All six tail rotor blades were located. Two blades had overload failures at their roots, indicative of impact with the ground and/or fuselage. The remaining four blades had compressive buckling damage, indicative of low rotational speed and impact with the ground or fuselage.
9. Tail rotor drive shaft failure—there was no evidence of drive shaft failure. The drive shaft was complete along the entire run. The drive shaft coupling to the intermediate gearbox had disconnected when the tail cone had broken open during ground impact. The drive shaft coupling splines were undamaged. The drive shaft bearings were complete, showing no evidence of failure other than from the post-impact fire.
10. Hydraulic failure (single or double)—the extent of the post-impact fire damage prevented a thorough assessment of all hydraulic systems. Of those systems examined, no evidence was found to suggest that a hydraulic failure had contributed to the accident.
11. Structural failure—examination of the wreckage remaining after the post-impact fire showed no evidence of structural failures that may have contributed to the accident.

The most significant evidence found suggested a flight control system failure, due to disconnection of the fore/aft bellcrank from the mixing unit. The physical evidence indicated that an unsecured castellated nut detached from the end of a bolt holding the fore/aft bellcrank onto the mixing unit lugs. The bolt then slid out of the lugs, permitting the bellcrank to separate from the mixing unit. The unwinding of the nut suggested failure to correctly torque, a finding that was accepted by the Board.

The Sea King flight modeling developed at DSTO indicated that the forward motion of the bellcrank and its detachment from its contact with the fore/aft lugs of the mixing unit would, in less than a second, cause the aircraft to pitch forward rapidly, leading to a nose-dive toward the ground. Any fore/aft inputs made by the pilot with the cyclic stick would have been ineffective because the disconnection of the fore/aft bellcrank from the mixing unit prevented fore/aft cyclic stick motions from being transmitted to the swashplate. There was no chance to recover the aircraft. The simulation indicated that approximately 2.3 seconds after detachment of the bellcrank, the main rotor tip would have hit the ground with an fuselage pitch attitude of 55° nose down. The unrecoverable nose-dive and ground impact caused significant fuselage damage, and the intense, post-impact fire, fuelled by aviation fuel, magnesium, and oxygen cylinders, consumed most of the aircraft.

Aircraft maintenance

The last known maintenance activity on the fore/aft bellcrank occurred on HMAS *Kanimbla,* 40 flight hours before the accident, by Sea King detachment personnel on Feb. 4, 2005. The fore/aft bellcrank was removed due to suspected lateral play in the pivot point of the mixing unit.

While there was no spare bellcrank to replace the item, it was decided to re-install the item, and carry forward the unserviceability. No specific authorized maintenance procedure exists in the Aircraft Servicing Manual (300) for the removal and reinstallation of the fore/aft bellcrank.

Due to the difficulty of reinstalling the item, the maintenance activity carried out by the early watch handed over the task to the late watch with the fore/aft bellcrank loosely secured at the pivot point, with the castellated nut not torqued and with no split pin fitted. While those undertaking the maintenance were aware of the activity, no aircraft maintenance documentation existed that recorded the removal, serviceability assessment, reinstallation, or final inspections of the fore/aft bellcrank. This meant that there was no documented record of a critical maintenance operation maintenance task to act as a prompt for the necessary associated maintenance and inspections. It is this lack of documentation and, therefore, prompt to inspect the critical item to notice the missing split pin that ultimately led to the unwinding of the castellated nut, extraction of the bolt, and separation of the fore/aft bellcrank from the mixing unit pivot point.

Board of Inquiry

The maritime commander of Australia, the appointing authority, established the Sea King accident Board with a president (naval officer of commodore rank), three senior military officers providing specialist aviation operator, engineering and human factors expertise, and a civilian with experience in commercial aviation.

The Board of Inquiry (BOI) commenced on Sept. 5, 2005, and concluded, almost 1 year later, on Sept. 6, 2006. The BOI sat for 111 days, heard 161 witnesses, and tendered 566 exhibits. At the conclusion of the Inquiry, just more than 9.5 thousand pages of transcript had been produced and made available on the Navy website (and in excess of 1.5 million pages of A4 paper had been copied and generated in the course of these proceedings).

The Board of Inquiry report was released to the Public on June, 21, 2007. It is approximately 1,700 pages long and consists of 759 findings and 256 recommendations for improving aviation safety.

The Board determined that "the primary cause of the accident was a failure of the flight control system caused by separation of the fore/aft bellcrank from the pitch control linkages in the aircraft's mixing unit. This separation was the result of a series of errors and non-compliances with the maintenance regulations, which ultimately led to the deficient fitment of the split pin and nut that secured the pivot bolt of the fore/aft bellcrank to the mixing unit assembly. This maintenance activity occurred some 57 days before the accident."

The post-accident fire "was initiated when residual fuel from the engine or oil from a fractured reservoir came in contact with hot engine components. After about 5 minutes, the fire spread rapidly through the aircraft as a result of the explosion of either another engine oil tank or butane cylinders that were inappropriately carried in the aircraft. The subsequent ignition of leaking fuel, internal cargo and stores, and flammable aircraft linings led to the rapid consumption of the aircraft by fire."

Summary

DSTO support for the investigation of the crash of RAN N16-100 began with the on-site investigation support with specialist materials and structural assessments of the wreckage, and wreckage mapping, followed by analysis by a larger DSTO team with assistance from a number of DSTO specialists.

The crash-site investigation analysis suggested that initial contact with the ground was by the main rotor blades. Four blades had contacted the ground before there was evidence of first impact of the aircraft fuselage with the ground. The distance between the blade marks indicated that the aircraft had some forward velocity and was in a steep nose-down, pitch attitude.

Following the initial blade strikes, the first fuselage ground impact occurred to the lower-front port side, damaging the cockpit area. The fourth blade strike then scooped out a large section of ground, indicating that the fuselage was probably near to, or over, vertical. This strike would have rotated the aircraft further around the impacted nose.

The main rotor head struck the ground further forward from this initial impact. The next two main rotor blade strikes indicated that the pitch control rods had failed in overload allowing the two blades to rotate freely.

At this stage, the aft fuselage and, therefore, the tail rotor blades, had not made contact with the ground. The last two blade strikes pushed the fuselage away from the ground for a brief period before it hit the ground again, coming to a stop with the nose of the aircraft facing the direction in which it had approached the field.

The intense post-impact fire destroyed most of the aircraft.

The CDR analysis of the microphone channels confirmed that the main rotor gearbox and engines were working correctly and did not show any evidence to indicate a failure in the rest of the aircraft rotating propulsion system components. This supported the accident site and laboratory assessment and analysis. The analysis of the CDR crew vocalizations supported the view that there were no unusual problems with the aircraft prior to the sudden departure from controlled flight during the landing approach.

The most significant evidence found suggested that a flight control system failure occurred due to disconnection of the fore/aft bellcrank from the mixing unit. The physical evidence indicated that an unsecured castellated nut detached from the end of a bolt holding the fore/aft bellcrank onto the mixing unit lugs. The bolt then slid out of the lugs, permitting the bellcrank to separate from the mixing unit.

The Sea King flight modeling developed at DSTO indicated that the forward motion of the bellcrank and its detachment from its contact with the fore/aft lugs of the mixing unit would, in less than a second, cause the aircraft to pitch forward rapidly, leading to a nose-dive toward the ground. Any fore/aft inputs made by the pilot with the cyclic stick would have been ineffective because the disconnection of the fore/aft bellcrank from the mixing unit prevented fore/aft cyclic stick motions from being transmitted to the swashplate. There was no chance to recover the aircraft.

The simulation indicated that approximately 2.3 seconds after detachment of the bellcrank the main rotor tip would have hit the ground with a fuselage pitch attitude of 55° nose down. The unrecoverable nose-dive and ground impact caused significant fuselage damage, and the intense post-impact fire, fuelled by aviation fuel, magnesium, and oxygen cylinders, consumed most of the aircraft. ◆

Acknowledgements

Indispensable support was provided to the AAIT by members of the RAAF 381 Expeditionary Combat Support Squadron. Without the members of the 381 ECSS, the AAIT could not stay on site and the investigation process would have been delayed significantly.

Significant, essential, and very welcomed support was provided to the AAIT by Indonesian, Singaporean, American, and United Nations personnel. Without that support, the investigation would have been severely hampered in its ability to conduct the investigation in a timely and efficient manner.

In memoriam

In memory of the nine young brave Australian men and women who tragically died on April 2, 2005, serving their country.

Endnotes

1 The aircraft is also known by its RAN side number, 902, and also as "Shark 02."

2 News footage of the scene taken at night shows the fire still burning.

3 Sibolga is the major town on the island of Sumatra nearest to Nias. It was the assembly point for mission personnel and supplies.

4 The stadium was a large soccer field situated near a school complex and was being used as a helicopter landing zone for the earthquake relief effort to the island.

5 The accuracy being referred to in this case is the accuracy of the position of each point relative to the positions of all the other points. The absolute accuracy of each mapped point in terms of its position on the earth is a different matter, and one that is not relevant here.

6 Melting temperature of AA 2024-T4/7079-T6 ~ 640°C, *Aircraft Structural Metals Handbook, Vol. 3, 1992.*

7 Melting temperature of 4140/4340 ~ 1500°C, *Aircraft Structural Metals Handbook, Vol. 1, 1992.*

Russia/France: Safety and Cultural Challenges in International Investigations

By Alexey Morozov, IAC (Interstate Aviation Committee) and Sylvain Ladiesse, BEA (Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation civile)

Alexey N. Morozov, *36, graduated from Moscow Aviation University as a specialist in flight dynamics, aircraft control systems, and flight tests. He joined the Interstate Aviation Committee (IAC) in 1994. In 1997 he became the head of the FDR Research Division, and in 1998 the vice-chairman of the IAC Air Accidents Investigation Scientific and Technical Support Commission. In 2005 Alexey became the chairman of the Air Accident Investigation Commission and from 2006, keeping the previous position, he was promoted to be IAC vice-chairman, responsible for all IAC activities in the field of accident investigation. Since that time, he has managed the investigations of several major accidents including the A320 and A310 accidents that occurred in 2006 in Sotchi and Irkutsk.*

Sylvain Ladiesse*, 31, received a master's degree in aerospace engineering and aviation operations from the French National Civil Aviation School (ENAC). He joined the BEA in 1999 and acted as investigator-in-charge, accredited representative, or group leader on many investigations. As of September 2007, he is resident twinning advisor in Ukraine in the framework of a European project aimed at implementing the JARs. Sylvain holds a commercial pilot's license.*

1. Introduction

Globalization has created many challenges to society in terms of transfer of knowledge and know-how. It has highlighted the need for humans to adapt themselves to systems and activities outside of their usual orbit, and to understand cultural differences in order to further international cooperation.

Aviation accident investigations require close international cooperation between states, whether they are Involved in design, manufacture, operations, registration, or through the passengers on board.

Language barriers and cultural differences are the main obstacles to a correct understanding of the approach taken, and consequently, to a common agreement on working methods. These impediments can be overcome by investigators applying basic human values such as adaptability and the capacity for dialogue.

2. Background

Annex 13 to the Chicago Convention sets out the international standards for technical investigations, and thus provides a framework for bilateral or multilateral cooperation in case of an accident. However, this framework leaves wide scope for interpretation as to the concrete outcome of this cooperation. In practice, there are plenty of cases where the various participants work in isolation without any interaction. Equally, at times, reports arrive at the destination with no warning, or comments issued by an investigative body are not taken into account. Such cases compromise the mutual confidence necessary between investigative bodies and fail to meet our goal of improving safety.

During 2006, the Commonwealth of Independent States (CIS) suffered three major accidents[1], of which two involved Airbus airplanes. The first occurred in May near Sochi and the second in July at Irkutsk. The Interstate Aviation Committee (IAC) conducted the investigations, and the French BEA (Bureau d'Enquêtes and d'Analyses pour la sécurité de l'aviation civile) participated as state of design.

The two states had signed a memorandum of understanding in 1993, which was renewed in 2005. They had had the opportunity to work together in the context of the investigation into the accident to an A310 that occurred in 1994. This collaboration brought to light different working methods. Nevertheless, the two events that occurred in 2006 allowed the IAC and the BEA to get to know each other better, to develop a climate of confidence, and to overcome cultural differences. The progress of the investigation into the Irkutsk accident reflected this positive state of mind and showed a strong desire to work together for the benefit of safety.

3. The Events

3.1 Sochi

On May 2, 2006, at 22 h 13 min UTC, an A320 registered EK-

32009, operated by Armavia Airlines, was undertaking a passenger flight from Yerevan, Armenia, (CIS) to Sochi, Russia, (CIS) at night in instrument meteorological conditions and crashed into the Black Sea near Sochi Airport. The Interstate Aviation Committee (IAC) was advised of the accident on May 3, 2006, at 02 h 15 min Moscow time.

The IAC's final report concluded that the crash resulted from controlled flight into terrain while attempting a climbing maneuver after an aborted approach to Sochi Airport at night, with weather conditions below the established minima. While performing the climbout with the autopilot disengaged, the captain, while under stress, made nose-down control inputs due to a loss of pitch and roll references.

Subsequently the captain's pitch inputs were insufficient to prevent the accident. Along with the inadequate control inputs by the captain, contributory factors to the accident were the lack of necessary monitoring of the aircraft descent parameters (pitch attitude, altitude, vertical speed) by the copilot and the absence of proper reaction by the crew to the EGPWS warnings.

The high degree of cooperation between the French and Russian investigators ensured that the lessons learned in the course of this investigation, both in technical and human terms, could subsequently be applied in case of another accident. These lessons were able to be applied only 3 months later at Irkutsk.

3.2 Irkutsk

On July 8, 2006, at 22 h 44 min UTC as it was landing at Irkutsk Airport, an A310 registered F-OGYP, operated by OAO Aviakompania Sibir, landed, overran the runway end at approximately 180 km/h and at a distance of 2,140 m and on a magnetic bearing of 296° from the aerodrome reference point, collided with the perimeter fence. It then broke apart and burst into flames. As a result of the accident, 125 people died, including both pilots and 3 cabin crew, while 60 passengers and 3 cabin crew suffered physical injuries of various degrees of severity.

The investigation into the accident was conducted by a commission appointed by the Interstate Aviation Committee (IAC). Specialists from the Federal Transport Oversight Authority, Rosaviatsia, Rosaeronavigatsia, Irkutsk Airport, the airlines Aeroflot—Rossiskiye avialinii and Sibir, as well as the accredited representative from the BEA as state of design, manufacturer and registry (France), and from the NTSB, who represented the state of the engine developer and manufacturer (U.S.A.), as well as their advisers from Airbus and P&W, participated in the investigation.

During the course of the investigation, the commission requested information about the cabin reconfiguration carried out by Lufthansa Technik (Germany). In accordance with ICAO Annex 13, this information was provided via the BFU (Bundesstelle für Flugunfalluntersuchung), which also appointed an accredited representative.

The IAC completed the technical investigation in May 2007 and concluded—

The cause of the accident to the A310 F-OGYP operated by Siberia airline was erroneous and uncontrolled actions by the crew during rollout after landing in a configuration with one thrust reverser deactivated. After touchdown, the captain, while acting on the reverse thrust lever of the right engine, inadvertently and in an uncontrolled manner moved the throttle lever of the left engine, whose thrust reverser was deactivated, from the "idle" to significant forward thrust position. Inadequate monitoring and call-outs of aircraft speed and engine parameters by the copilot did not allow the crew to perform the necessary actions, either of moving the left throttle back to idle or of shutting down the engine. The crew had enough time to recognize the situation.

4. IAC—BEA: Two organizations, two approaches

4.1 The Interstate Aviation Committee (IAC)

The Interstate Aviation Committee (IAC) was established in December 1991 pursuant to the Intergovernmental Agreement on Civil Aviation and Use of Air Space, which was concluded by 12 newly independent states (CIS) with a view to

- preserving common aviation rules and airworthiness standards,
- maintaining a unified system for certification of aviation equipment and its manufacturers, international categorized aerodromes and their equipment,
- conducting independent investigation of aircraft accidents, and
- coordinating the efforts in the area of civil aviation development and harmonize the national programs development of air traffic organization systems.

The IAC operates on the basis of, and in full compliance with, applicable international law and national laws of the member states, exercising the powers vested in it by presidential and governmental decrees and appropriate legislative acts. Its headquarters is located in Moscow.

The principal aim of the IAC is to ensure safe and orderly development of civil aviation and efficient use of air space by the states that are party to the Agreement.

The Interstate Aviation Committee investigates all aircraft accidents that involve aircraft from its member states whether they occur on their territories or elsewhere, as well as other aircraft accidents covered by the appropriate international agreements. IAC activities related to investigations fully conform to recommended international practices, in particular Annex 13.

4.2 The BEA

Created in 1946, the BEA is attached to the Ministry of Transport. The BEA carries out investigations and issues its reports in a completely independent manner. Its offices and technical services are located in the Paris Region at Le Bourget Airport. It also has regional offices in Toulouse, Bordeaux, Rennes, and Aix-en-Provence.

In addition, in the context of Annex 13, the BEA represents France in investigations carried out abroad for any accident or incident involving

- an aircraft of French design or manufacture or registry (for example Airbus and ATR airplanes, Eurocopter helicopters).
- an aircraft operated by a French airline (Air France, Corsair...).
- French passengers.

The European directive on aviation accident investigations specifically forbids that investigations aim to apportion blame or liability to persons or companies involved in the event.

4.3 Different working procedures

The IAC and the BEA work according to the standards and recommendations set by Annex 13 as well as to internal procedures, which may differ. Some examples of these specific features include:

The IAC designates a Commission of Inquiry, which that plays the role of investigator-in-charge in a collegial manner: Its members may or may not come from the IAC, but they are generally chosen for their specialized technical knowledge. The investigator-in-charge directs this Commission, which itself supervises subcommissions and working groups. The latter work independently and provide reports to the Commission.

Accredited representatives have access to all of the information gathered by investigators, but they are not invited to work within the sub-commissions or working groups.

The Final Report includes an additional paragraph, compared with the format recommended by the ICAO, which is entitled "Shortcomings" and groups together all of the failings identified by the Commission in the course of the investigation and acts as a bridge to the safety recommendations that follow.

In the case of a major investigation, the government Commission that is usually created to deal with the aftermath of an accident and to arrange support for the families of the victims has to be informed relatively rapidly on the causes of the accident. Thus, the IAC has to provide the "Conclusion" of the investigation report before the consultation procedure on the whole draft final report is fully completed by foreign parties to the investigation.

The IAC's reports are mainly intended for those in the aeronautical world, and it organizes a conference specifically for them at the end of the investigation. Only the final sections of the report are usually made public, the rest of the report being supplied upon request.

For the investigation into the accident that occurred at Irkutsk, the BEA nominated an accredited representative in its capacity as state of design, manufacture, and registry. Airbus provided technical advisers for the Accredited Representative. In addition, since the responsibility for continuing airworthiness for A310s had been transferred from the DGAC to the European Aviation Safety Agency, the BEA kept the Agency informed throughout the investigation.

5. Challenges

5.1 Environmental challenges

In an international investigation involving five investigative bodies (the IAC, the BEA, the NTSB, the AAIB, and the BFU), there were numerous challenges. Initially they were environmental, especially during the first few days of the investigation. The accident site (Irkutsk, in eastern Siberia) was a long way from the headquarters of each of these investigative bodies, which complicated communications. As an example, the distance between Irkutsk and Moscow, where the IAC's HQ is located (and thus the laboratories where the CVR was read out), is 8,000 kilometers and there is a 5-hour time difference.

Further, Russia is a country where European Union and U.S. citizens can only enter with a visa. Getting hold of a dozen visas on a Sunday was one of the challenges that the IAC had to overcome in order to bring in the accredited representatives and their advisers.

Russian is one of the six official ICAO languages and was naturally the working language in Irkutsk during work on gathering the facts. Within the BEA-Airbus team, few investigators spoke any Russian, and among the members of the Commission and sub-commissions present in Irkutsk, few investigators spoke English.

Lots of the difficulties in communication and incomprehension were caused by this absence of a common language. For example, the evening work progress meetings were held in Russian, and even if the BEA-Airbus team members were invited to attend, they could not understand the information shared by the members of the Commission of Inquiry.

5.2 Challenges inherent in cultural differences

During 2006, in the space of 4 months, the IAC had to investigate three major accidents that caused the deaths of more than 400 people. The IAC and the CIS aviation system were subjected to enormous media pressure, which obliged them to keep up a very demanding pace. This pressure was naturally passed on to the BEA, which thus had to respond to the pace. The IAC sometimes had the impression that the BEA was slow in responding to its requests, which seemed to it to be urgent, while for its part the BEA sometimes had the impression that this sustained pace implied some things being overlooked.

Understanding a different aeronautical system was also a challenge that had to be taken up by both sides. For the IAC, this meant understanding the relationship between Airbus, the DGAC, and the EASA, as well getting to grips with the A310's systems, its documentation, and its ergonomics—so different from that of Russian airplanes. For the BEA it meant understanding the relationship between Sibir, Rosaviatsia, and the FTOA, as well as the airplane's operational environment in Russia.

The report had to be translated into English and the translation validated by the IAC in order to have a common document to work with. Some concepts essential to an understanding of the report turned out to be very hard to translate, such as, for example, the Russian word "Kontrol," which simultaneously means "observation, monitoring, and feed back." Using an English version as a basis for discussion also meant that the IAC duplicated its work, since it had to take into account all of the comments made on both the Russian and English versions.

Communicating facts to outside organizations was also a major challenge in this investigation. After the FDR readout, the airplane manufacturer relayed to the IAC and to the BEA the pressure that it was under from operators to communicate data. The IAC was not yet ready to communicate this data. Equally, the IAC, due to public pressure, had to communicate the "conclusions" of the investigation very early on, and the BEA had to comment on the findings and the conclusion of the report before having access to the factual and analytical sections.

Investigative cultures differ, and these differences came to light in the final report and the comments that the BEA made during the consultation phase. The report includes, for example, in the part entitled "Additional Information," some points of view—thus not factual—expressed by specialists who participated in the investigation. On the other hand, some comments made by the BEA were quite unexpected and presented the IAC with some difficulties in integrating or adding them to the report.

6. Cooperation

The approach decided on from the very beginning of the investigation was complete openness. Each investigative body had access to all the data. The investigators passed on any new data significant to the understanding of the event as soon as they got it.

Subsequently, the IAC took the time, despite heavy media pressure and the urgency of publishing the report rapidly, to consult the BEA before communicating any facts relating to the event. Airbus communications, with its operators on elements relating to the investigation, were done on the basis of a consensus reached between Airbus, the IAC and the BEA. The final report was then considered at a preparatory meeting in the presence of the accredited representatives before being sent out for consultation. Finally, at the request of the BEA, the IAC organized a review meeting with the accredited representatives and the advisers from Airbus in order to discuss the integration of the various comments.

Both the BEA and the IAC remained patient and open-minded throughout the investigation—initially, during the fact-gathering phase in Irkutsk, then when faced with the BEA's supposed "slowness" and the IAC's supposed "overlooking" things, and finally during the various revisions to the final report.

The difference in culture implied long meetings, during which certain paragraphs could be discussed for several hours, but all of the participants maintained their desire for a consensual approach. In fact, the key to successful cooperation is certainly the capacity and the will to listen to one's interlocutors, to understand the cultural and historic differences, and to make compromises.

This desire for cooperation and consensus was present throughout the investigation. It made it possible to complete the investigation and publish the report within 10 months of the accident. All of the participants reached a common understanding of the event and, in addition, the BEA and the NTSB had no further comments to make on the final report following the various consultations. The IAC published the most important parts of the report (the analysis, the findings and the conclusion, the shortcomings, and the safety recommendations) on its website.

The best example of this cooperation concerns the safety recommendations. The BEA proposed several improvements to the safety recommendations written by the IAC, so as to extend the application of some of them to operators outside the CIS and for others to be addressed to all airplane manufacturers, underlining the fact that some themes were specific neither to the CIS nor to the Airbus A310. In the final wording of its safety recommendations, the IAC took into account all of the comments. ◆

Endnotes

1 The third was the accident on Aug. 22, 2006, to a Tupolev 154 operated by Pulkovo Airlines in Ukraine (CIS).

International Cooperation Paves the Runway for a Safer Sky

By Guo Fu, East China Administration, CAAC

Guo Fu is an accident investigator with the General Administration of Civil Aviation of China (CAAC) and is now the deputy director of the Aviation Safety Office of East China Administration of CAAC. Guo Fu graduated in 1982 from 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 has a master's degree in public administration from Shanghai Jiaotong University.

Abstract

As one of the effective means of safety management activities, safety investigation plays an active role in improving aviation safety and accident prevention. With the rapid development of aviation and the influence of globalization, international investigation cooperation becomes more and more important nowadays. In this presentation, you will see the real importance of international cooperation in accident/incident investigation, and how investigation and safety management benefit from international cooperation.

1. Introduction

It is common sense that the purpose of an accident/incident investigation is to prevent the same occurrence from repeating—so to promote safety, it's important that the investigation can locate or access the cause(s), and reveal findings in order to alert the whole system or industry to take action. And it is obvious that an investigation is one of the most effective ways to improve safety.

With an annual average growth rate of more than 16% of total air traffic volume within last 20 years in China, the number of occurrences is increasing accordingly. In addition to the routine preventive measures adopted, we take investigation as one of the most critical means in safety management, and investigate both accidents and incidents. We are not experienced enough in investigation aspects, though China is one of the fast-growing aviation markets.

Annex 13 provides us with not only standards or basic principles, and guidelines for investigation, but a cooperative mechanism as well. Our investigation practices are abided by both international and domestic regulations and standards. Therefore, our investigation benefits a lot from international cooperation.

2. The role of investigation

According to the basic management theory, aviation safety management activities can be classified into three different areas or phases in terms of feedforward management, concurrent management, and feedback management. We all know that the purpose of feedforward management is to prevent anticipated unsafe events from happening by setting up certification criteria, policies, operational standards, procedures, manuals, training programs, maintenance programs, budgets, and etc., that are mainly based on previous experiences or lessens learned, and set guidelines or processes for implementing a plan, or achieving organizational objectives. Concurrent management is applied to monitor or oversee operational activities in processes and ensures immediate, corrective actions be taken if any below-standard condition, deviation from the standard, or any violation is observed during operation so that performance is back on track and the plans are properly implemented or objectives achieved. Thus, it can also be called simultaneous management. Feedback management examines results or consequences of operation, finds, or accesses to, and analyzes the causes of deviation from standards, and then makes guidelines for corrective actions or suggestions. Meanwhile the lessons learned will be fed back for modifying or adjusting standards, procedures, policies, programs, even regulations to prevent reoccurrence.

All these activities provide a safe operation platform, which acts just as a solid foundation for a safe operation. Symbolically speaking, the foundation is supported by tripods composed of feedforward, concurrent, and feedback management. It will collapse if one of the supports fails. From the aviation point of view, a solid foundation can be taken as a concrete runway for safe flight. Therefore, you can never image that a flight would safely takeoff or land if a section or part of the runway fails.

Aviation safety investigation is a kind of safety management, which falls into the feedback management category. The purposes and functions of the investigation are just the same as those of feedback management. Hence, the investigation activities are as equally important as other safety management measures and play a major role in aviation safety management.

Case 1: An MD-11F cargo flight accident in Shanghai, China.

In an investigation, we collect evidence, check all the relevant aircraft systems and its operational support equipment and facilities, gather all the information associated with an incident or accident, review all the relevant documents, procedures, standards and regulations, and try every means to find out, or access the causes of an event. We make safety recommendations in order to alert the whole system or industry to take actions to prevent or improve on the basis of findings, including any defect or latent unsafe condition found in the fields of management, design, manufacturing, equipment, operation and maintenance, and human factor issues in, or lessons learned from an event.

With all these measures practiced, the investigation functions as one of the most effective tools of safety protection, and helps the aviation industry promote safety.

3. Cooperation in investigation

In Annex 13 to the Convention on International Civil Aviation, the most frequently used words are the state of occurrence, the state of registration, the state of the operator, the state of design, and the state of manufacture, which shows a very clear picture that an aviation investigation is a multinational endeavor, and we can also find the obligations and the rights are shared among all these nations in the Annex. From these points of view, the Annex provides us with not only standards or basic principles and guidelines for investigation, but a cooperative mechanism as well. So, it sends a strong signal that investigation cooperation is the international standard for aviation safety investigation.

We have many reasons for cooperation in the conduct of an investigation. Though ICAO plays a key role in enhancing cooperation, there are many other factors that drive the investigation itself to seek for international cooperation. Aviation is a complex system that is an interacting combination, at any level of complexity, of people, material, machines, tools, software, facilities, and procedures[1]. Furthermore, with the affect of globalization and rapid development in aviation, the investigation will be influenced by different factors, such as new technologies introduced in aviation, technical expertise or know-how, different cultural backgrounds, language, political systems, etc. It is evident that an investigation has become a global challenge that needs global cooperation and solutions. One nation's resources sometimes are not adequate to fulfill the requirements of an investigation. Only when an internationally cooperative relationship is established can an efficient and beneficial investigation be achieved.

To investigate an occurrence, we need help and assistance from

- investigation authorities with resources and power to help coordinate and communicate,
- investigators and experts of other nations with knowledge of their nation's safety regulations and policies, operational standards, expertise or know-how of the aircraft and its equipments or systems, and
- other operational supportive facilities, from organizations with special investigation equipments or facilities—otherwise, we couldn't have a good investigation.

4. Investigation practices in China

In this part, you will see that investigation practices in China benefit from international cooperation in terms of technical support and coordination.

4.1 Rules to follow

We have many rules to follow if we conduct an air safety investigation in China. They include both international and domestic standards. In addition to Annex 13, our investigation will be in compliance with the following regulations:

- Law of Civil Aviation of PRC
- Law of PRC on Work Safety
- Civil Aircraft Flight Accident & Incident Investigation (CCAR395)
- Civil Aircraft Flight Incident (MH2001-2004)
- Procedure of Civil Aircraft Accident Investigation (MD-AS-2001-001)
- Classification Standard for Aircraft Flight Accident (GB14648-93)
- Classification for Ground Accidents of Civil Aviation (GB18432-2001)
- Response to Aircraft Accident and Family Assistance (CCAR-399)
- Civil Aviation Safety Information Management (CCAR-396)

A two-leg investigation system is adopted in our investigation practices. According to our regulations, an investigation will be conducted by different organizations depending on the consequences of an event. Traditionally speaking, the investigation function is shared between the CAAC and the State Council or its authorized department. To be more specific, the State Council is responsible for the investigation into a significant major air transport accident and major air transport accident, while CAAC investigates accidents and incidents. Usually a major accident investigation used to be organized by a temporary organization set up by the State Council, but things have changed since the State Administration of Work Safety (SAWS) was established in 2001.

The SAWS is an affiliated organization of the State Council, and it acts as the executive office of the Work Safety Committee of the State Council. One of its major functions is to supervise the national work safety and conduct or coordinate investigation of significant major accidents, and major accidents occurring within the territory of mainland China. However, its actual investigation activities involve other accident investigations, including general aviation accident investigation and ground aviation accident investigation. SAWS will conduct these types of investigation when it has enough professionals to do so.

The aviation geographical purview of mainland China is divided by seven regional administrations. Within CAAC, the investigation is arranged according to the geographical purviews of the regional administrations. Each regional administration is responsible for conducting an investigation when the following has occurred in its region:

- An incident involving a commercial air transport, or a general aviation aircraft.
- A ground accident.

For a major accident, or foreign carrier accident investigation, it is the general CAAC's (headquarters) responsibility to investigate. It can also delegate its investigation authority to relevant regional administrations accordingly.

4.2 Investigation regulation introduction

CCAR395, Civil Aircraft Flight Accident & Incident Investigation, outlines all the requirements for the investigation. The main contents are organization of investigation, investigator, notification, investigation, and report. One of the most important features of the regulation is cooperation, which reflects the spirit of Annex 13. Actually, the main contents of the regulation are quite similar to those of Annex 13. The following is the important information of the regulation.

4.2.1 Scope of investigation

It is required to investigate both the accident and incident by the regulation. Although definitions of the accident and incident are almost the same as those in Annex 13, there are more detailed classifications for the levels of accident and incident, and items are explained. For instance, Civil Aircraft Flight Incident (MH2001-2004), gives the definition of incident and lists items considered as the precursor of the accident. There are two different types of accidents in our classifications—one is flight accident, and the other is ground aviation accident. Classification Standard for Aircraft Flight Accident (GB14648-93) defines and classifies the flight accident and so does the Classification for Ground Accidents of Civil Aviation (GB18432-2001) in a similar way.

4.2.2 Basic principles for investigation

Four basic principles must be abided by if an investigation is conducted.

- *Independent*: Investigation shall be conducted independently—no 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, and company's management policies, and regulator's rules and regulations and 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.

4.3 Investigation practices and cases

4.3.1 Investigation organization

In most cases, an investigation team will be formed immediately upon receiving an occurrence according to the authorization. The size of the team will depend on the consequence and significance of the occurrence. A full go-team will be comprised of investigators from flight operation, airworthiness, ATS, aeronautical meteorology, aviation security, airport management, flight recorders, failure analysis, ground handling, weight and balance, aviation medical, survival factors, human factors, safety management, and some peripheral groups involved—for example, site protection, site clean, and aftermath assistance need to be coordinated.

4.3.2 Investigation process

The investigation process usually has three phases, from notification through final report. We may describe them as rescue and evidence collection; facts, preliminary report, and analysis; conclusion and recommendation. The requirements of the notification, preliminary report, and format final report are just the same as those of Annex 13.

We must inform the authorities of the state of manufacture, the state of registry, the state of the operator, and ICAO accordingly, even though the field representatives of the manufacturer are ready to offer help under most cases. And most of the time we have speedy responses with willingness to provide assistance from the relevant authorities. In our practices, we have received assistance from many foreign investigative authorities both in accident and incident investigation. There is no doubt that we have shared a good experience working together with our international partners during an investigation. It is obvious that results of the cooperation are fruitful and beneficial to the aviation industry.

Case 2: A CRJ-200 passenger flight that crashed in Baotou, China.

Usually, several different kinds of reports will be finished and submitted during the investigation, but four are commonly adopted. They are the group report, the preliminary report, the draft final report, and the final report. Each group must finish its group report after field investigation. It is done by the group chairman with the signature of every participant of the group, and a different opinion will be attached if there is any. The preliminary report is compiled by the team leader and is based on all the group reports and contains the factual information associated with the event. It is asked to be submitted within 30 days after the occurrence. The draft final report is approved by the team leader before it is sent to relevant organizations for review. Before the final report is released, all the comments or suggestions received will be reviewed and corrections or amendments to the report will be taken if they are accepted, or attached if denied.

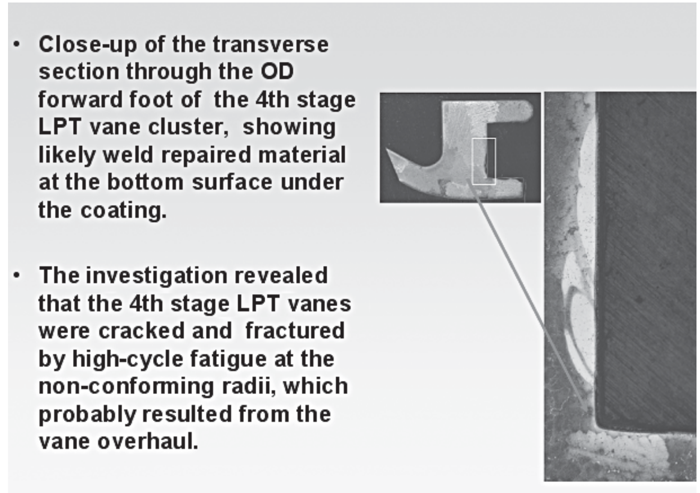
We have received much valuable assistance and international cooperation from our foreign partners in safety investigations, which made our investigations successful. The following case introductions will show how valuable cooperation is in a safety investigation and for safety improvement.

4.4 Cases

4.4.1 MD-11 cargo accident on April 15, 2005, in Shanghai, China

On April 15, 1999, an MD-11F departed at Shanghai HongQiao International Airport, operating as a regularly scheduled international cargo flight with two pilots and one flight technician on board. It crashed at a construction site 3 minutes after lifting off. The airplane was totally destroyed by high-energy impact force and a post-crash fire.

After the accident, the Civil Aviation Administration of China (CAAC) forwarded notification of the accident to the state of



manufacture, the state of registration, the operator, and ICAO. A joint investigation team was formed in accordance with the provisions of Annex 13. The investigation received technical support from the relevant investigation authorities, aircraft manufacturer, engine manufacturer, airlines, and component manufacturers during the investigation.

The team made a thorough search of the crash site, and found the memory circuit board of the solid-state cockpit voice recorder (SSCVR) and pieces of tape from the quick access recorder (QAR) in addition to all recovered engines, control systems and surfaces, and other most important components.

The SSCVR's memory circuit board, all collected pieces of QAR tape, and the electronic engine controllers (EEC) were sent to the United States for data retrieval. The whole contents of the SSCVR and EEC were successfully retrieved in the NTSB lab and engine manufacturer's lab, respectively, which helped investigators understand what had happened in the cockpit and the engines' performance before the crash. A joint bulletin of the accident, signed by the three parties, was released in three nations on April 27, 1999, and excluded the possibilities that the accident was caused by any explosion, sabotage, or ATC mishandling.

Members of the joint investigation team and their advisors gathered at the Boeing flight safety facilities in Long Beach, Calif., for flight simulation tests. The simulation was performed more than 100 times.

The accident scenario was at last understood on the basis of all the analyzed, collected factual information; tests conducted; recorded information retrieved; and key systems, parts, or components examined.

The probable cause of the accident was the flight crew's loss of altitude situational awareness resulting from an altitude clearance wrongly relayed by the first officer and the crew's overreaction with abrupt flight control inputs.

With all the help and assistance from our foreign partners, we could then reconstruct the accident scenario and better understood the accident.

4.4.2 CRJ-200 accident on Nov. 21, 2004, in Baotou, China

On Nov. 21, 2004, a CRJ-200 aircraft departed Baotou Airport at 08:21 (Beijing local daylight time) for a scheduled passenger flight from Baotou to Shanghai, and 1 minute later it crashed in a park nearby.

The investigation was instituted and organized by SAWS. CAAC was on the technical investigation team since it was a significant major accident. The technical investigation team was comprised of the state of occurrence, the state of aircraft manufacture, and the state of engine manufacture.

One of the probable causes of the accident was wing contaminated with frost. At the beginning of the investigation, it was very hard for most of us to believe that frost contamination would result in such a tragedy though we knew that ice or snow would impair the wing's performance if it was contaminated with them.

Through the discussion and demonstration of performance of supercritical airfoils without leading edge devices by the experts of manufacturer, we understood why contamination is so critical to those airfoils. A nationwide cold weather operation training campaign was adopted with the help of our Canadian colleagues, and the cold weather operation program was revised and implemented to prevent the same disaster from happening again. All these corrective measures have raised both management's and frontline personnel's concentration on the contamination issues.

4.4.3 Engine IFSD incident investigation

On March 3, 2007, a Boeing 747-200, enroute from PVG to KIX, experienced No. 2 engine IFSD followed by an audible loud boom and a drop in engine parameters. The aircraft returned to PVG and landed uneventfully. This event is considered to be an incident as per Civil Aircraft Flight Incident of CAAC.

Since we focus on aircraft with a relatively long time of service, this aircraft had experienced three IFSD within 4 months. In order to investigate the cause of this IFSD event, a notification was sent to the state of engine manufacture, and an investigation team was formed with the experts from the engine manufacturer since the state of manufacture appointed a non-travel accredited representative.

In the investigation, we found that one cluster of the fourth stage LPT stator of the engine exhibited displacement and outer shroud forward OD hook fracture, which resulted in the cluster's rubbing against the fourth stage LPT rotor blades and consequently rupturing some of the blades, and the ruptured fly-away blades cut away all the blades/vanes on the fourth, fifth, and sixth stage. Several other fourth stage LPT blades displayed fatigue in the airfoil fracture just above the root platform. Further lab examination revealed that the vane clusters' displacement/fatigue fractures were resulted from their sharp radii at the OD forward foot due to improper engine overhaul.

The advantages of the manufacturer's involvement were not only that it knew its product and was able to provide expertise in the investigation, but also that it took immediate actions or gave professional instructions if problems were found.

Though incident investigation seems not as urgent as accident investigation to some extent, we can still promote aviation safety by revealing defects found in the system and making safety recommendations. We also can prevent the accident from happening by investigating the incident since we define an incident as a precursor of accident in Chinese.

5. The challenges ahead

Through cooperative efforts, the aviation community has resolved many problems that impair safety, but we still have to face those safety-related challenges. From the investigator's point of view, the biggest challenge now is human-factors-related issues, which account for a large amount of occurrences. That is why we need the whole community to work hard to provide an operation environment that will reduce human-factors-related issues to the greatest extent. In some cases, one nation's competence is not enough to resolve problems confronting us since they are global challenges.

The cockpit meter/feet change-over switch offers a very successful solution to different ATC altitude assignment adopted in different nations to prevent a flight crew's confusion while flying between nations using different altitude assignment systems. In addition, language is another worldwide issue for those pilots whose mother tongue is not English, since it is the aviation language. Though we can train pilots and standardize radiotelephony in air-ground communication, we still have some occurrences associated with language difficulty.

Therefore, it is strongly recommended that the international aviation community step up and widen cooperation to take effective measures to improve the operational environment by both software and hardware. We need to not only rationalize the standards, procedures, and policies, but optimize technologies in order to find technical solutions as well. We share information, experience, knowledge, and lessons learned by seminars, conferences, training and reachout programs. We can resolve big issues by creating small gadgets or new technologies.

6. Conclusion

From the above discussion, we may conclude that safety investigation lays a solid foundation for the safe operation and safe flight, along with other safety management activities, and thus plays a fairly significant role in improving aviation safety. As its scope is being widened, international cooperation will play an increasingly active role in promoting investigation efficiency by sharing expertise, experience, and information. As a result, no matter what kind of investigation (accident or incident) it is, we will make a huge difference to our aviation safety record if we embrace the globalization trend and strictly follow the international standards in investigation with a cooperative attitude. The whole aviation community will surely benefit from investigation cooperation, which will function as one of the powerful driving forces to move the aviation industry in a favorable direction. ◆

Endnote

1 Barry Strauch: Investigating Human Error: Incidents, Accidents, and Complex Systems.

Winter Operations and Friction Measurements

By Knut Lande, Inspector of Accidents, Accident Investigation Board, Norway—AIBN (CP0140)

Knut Lande has background as a mechanical and aeronautical engineer, fighter pilot, test pilot, offshore helicopter pilot, project pilot, and chief technical pilot, with more than 10,000 flying hours in more than 50 types of airplanes and helicopters. During his test pilot period in the Royal Norwegian Air Force Material Command, he was involved in friction testing measurements and correlation trials with fighter aircraft on snow-covered runways. As chief technical pilot, he was a member of the JAA Performance Working Group and a member of the JAA Human Factors Steering Group. Lande is a member of the Society of Experimental Test Pilots and has presented papers at several aviation conferences in Europe and the U.S. In 2000, he started working as an inspector with the Aircraft Accident Investigation Board of Norway and is involved in the investigation of accidents and incidents related to slippery runways, in addition to investigations related to all types of airplanes and helicopters.

Summary

The Accident Investigation Board Norway (AIBN) has investigated 24 accidents and incidents related to winter operations and friction measurements during the last 8 years. In Norway there seems to be an increase in the frequency of these types of mishaps, even though friction measurements have been used for more than 50 years.

The Chicago Midway accident of Dec. 8, 2005, where a Boeing 737-700 slid off the departure end of the runway, indicates that the winter challenges are international. The similarity of the Norwegian mishaps and the Midway mishap is that operations performance computers (OPC) were used to calculate the aircraft stopping distances. Behind the OPC computations are two uncertain variables: the measured friction coefficient (FC) with its measuring tolerance and the airplane braking coefficient.

Trials of runway friction measurements on winter contaminated runways started at Oslo Fornebu and Gardermoen Airports during the late 1940s by the airport manager Ottar Kollerud. He correlated the results with similar measurements in airplanes. Early on, he concluded that the aircraft deceleration was about 50% of the vehicle deceleration. Hence, a correlation was established that the airplane braking coefficient (ABC) was half of the measured friction coefficient. This was later called the Kollerud method.

Later trials in the U.S. and Canada have indicated different correlation factors, but in general agreement with Kollerud's results.

These early trials in Norway led to further international trials that again led to the development of internationally agreed (ICAO) measurement methods and equipment. This was the basis for the ICAO SNOWTAM format and friction table.

Today, there are several correlation algorithms available, but there is no internationally agreed method of correlating measured FC to the ABC. Complicating the picture, there are numerous approved friction measurement devices giving different results on each measurement on the same contamination, but related to only the same SNOWTAM table.

The AIBN accident and incident investigations have shown that the trust in friction measurements and use of FC in aircraft landing performance calculations are not justified due to the lack of scientific data. The AIBN can document that use of measured FC on wet snow and ice is very uncertain. Further, the ICAO SNOWTAM table, which gives the FC in 1/100th, is only accurate to 1/10th at best. The AIBN suggests that the SNOWTAM table be modified and an agreed correlation algorithm be adopted. Finally, the AIBN fully supports the U.S. NTSB in its recommendation to stop giving credit for use of thrust reversers when calculating the actual landing distance on snow- and ice-contaminated runways just before landing.

Accidents and incidents in Norway related to winter operations and friction measurements

Due to the Norwegian climate with freezing temperatures and snowfall during the winter season, and the difficulty of removing the contamination, Norwegian aircraft operations have been allowed to continue on snow- and ice-contaminated runways. Further, many of the Norwegian airports are located along the coast causing frequent freezing and melting of snow and ice on the runways. The practice of operating on contaminated runways seemed to function relatively well over the years with very few runway excursions. In Norway, friction measurements on snow- and ice-covered runways have been performed on a regular basis since 1949. Over the years the friction numbers from these measurements have been used successfully by aircraft commanders in a conservative way, and very few runway excursions occurred as a result of slippery runways. In recent years, however, the airlines have initiated performance calculations based on use of operations performance computers where the measured FC is used as input for actual landing distance calculations.

Since 1999, the Accident Investigation Board of Norway (AIBN) has received 24 reports related to operations on slippery runways. Most of these excursions were minor incidents, but there have been some accidents and serious incidents as well. Based on a seemingly increase in reported incidents, the AIBN has initiated a special investigation into these incidents.

Recent accidents and serious incidents in Norway include
2-11-2000—ENHF DH-8-103 slid off the runway during landing. AIBN REP 23/2002
Wx: METAR ENHF 2050Z 01013G24 260V080 9999 SCT010 01/M02 Q0967=

Runway status: Rwy covered by compact snow and ice with 3-4 mm of slush on top, rwy sanded. Measured FC 32-34-33 (Griptester/GRT). Actual ABC or effective FC was in the order of 0.05 (Poor).

3-14-2000—ENML F-27-50 slid off the runway during landing. AIBN REP 17/2001
Wx: METAR ENML 2020Z 32016KT 9999 VCSH FEW010 SCT020
BKN035 01/M01 Q1002
Runway status: Rwy covered by compact snow with 1-3 mm of wet snow on top, rwy sanded. Measured FC 47-47-44 (Skiddometer/SKH). Actual ABC was Poor.

5-11-2000—ENTC DC-9-87 slid off the end of the runway during landing AIBN REP 77/2000
Wx: METAR ENZV 1920 28009KT 2000 SHSNGS XX012 M02/ M03 Q1020 TEMPO 0500 + SHSNGR VV005=
Runway status: Rwy covered by wet snow and slush from recent showers. No measured FC. Actual ABC was Poor.

1-6-2003—ENVD DH-8-103 slid off the runway during landing AIBN REP 33/04
Wx: METAR ENVD 1250Z 17009KT 0700 BCFG IC VV 004 M14/ M16 Q1014 ARCTIC SEAFOG=
Runway status: Frost and ice on the runway, partly covered by snow, sanded Measured FC at 1150Z were 48-52-48 (Griptester/GRT). Actual ABC was Poor.

11-25-2004—ENEV A320 slid off the runway during take off. Under investigation.
Wx: ENEV 25 2050Z 34006KT 9999 –SHSN SCT015 BKN030 M04/M06 Q1018
Runway status: Rwy covered by sanded ice with 8 mm of dry snow on top. Measured FC at 1950 was 34-32-32 (Skiddometer/SKH).

1-30-2005—ENEV B737-400 loss of directional control during landing but the Commander succeeded in keeping the aircraft on the runway. Under investigation.
Wx: METAR ENEV 301350Z 21026G42KT 9999 VCSH SCT 015 BKN025 02/M01 QNH 965 hPa WIND 1 400 FT 23050G64KT=
Runway status: Rwy covered by wet ice, sanded. Measured FC was 24-25-26 (Skiddometer/SKH).

3-26-2006—ENTO A321 slid off the end of the runway after landing. Under investigation.
Wx: METAR ENTO 261850Z 03009KT 9999 –SN FEW003 SCT005 BKN M02/M03 Q1007=
Runway status: Rwy covered by 8 mm of wet snow. Measured FC was 32-33-31 (Skiddometer/SKH).

Common factors during Norwegian incidents

- Specially prepared winter runway according to regulations (sanding/gritting).
- Runways contaminated by compact snow or ice.
- Some times covered by loose slush or wet or dry snow on top of compact snow or ice.
- Wet or moist contamination.
- Runway sanded.
- Runway friction coefficient measured with approved equipment.
- Use of ICAO SNOWTAM table.
- Acceptable FC.
- Landing data calculated by a cockpit performance computer.
- Small spread (< 3 K) between OAT and dew point (moisture, including below freezing).

Some international highlights related to winter operations and measured friction coefficients

- 1946-49—Airport Manager O. Kollerud performed friction tests at Oslo Airports Fornebu and Gardermoen using GMC/ Decelerometer.
- 1950s—Todays SNOWTAM table was developed in cooperation with Scandinavian Airlines.
- 1955—ICAO Circular 43-AN/38, Kollerud method enclosed.
- 1964—ICAO-SNOWTAM format developed.
- 1965—BV-6 in use at Oslo Airport Fornebu.
- 1976—FFA BV-11 correlation trials with aircraft.
- 1978—FFA high pressure tire/BV-11/SFT/F-5B trials at RNoAF Kjeller Air Base.
- 1987—ICAO working paper AN-WP/6081-Runway braking action.
- 1992—Dryden Report.
- 1992-2000—Transport Canada/Boeing/ICAO trials with friction-measuring equipment and braking trials with aircraft.
- 1997-2004—Joint Winter Runway Friction Measurement Program (JWRFMP).
- 2003-2007—Norwegian Safe Winter Operations Program (SWOP, a final report will be available later in 2007).

Some Norwegian winter trials on contaminated runways

- Car/stop watch—Tests at Oslo Fornebu from 1946.
- GMC truck/decelerometer—Tests at Oslo Fornebu and Gardermoen from 1949.
- Tapley meter—Tests at Oslo Fornebu in 1957. In use from 1959.
- Skiddometer BV-6—Tests at Oslo Fornebu during 1963-64. In use from 1965.
- Mu meter—Tests at Oslo Fornebu and Bergen Flesland in 1969.
- Skiddometer BV-11 (SKL)—Tests at Oslo Fornebu from 1969. In use from 1972.
- Saab Surface Friction Tester (SFT)—Modified electronics/measuring wheel 1973.
- SFT—In use with high-pressure tire 1976.
- Tests with SKH, SFT, and F-5B—Tests at Kjeller Air Base with high-pressure tire in 1978.
- Griptester (GRT)—Tested during 1994 and introduced later.

Scandinavian trial project "*Slippery Runways*" during 1972-75

This was a Scandinavian trial involving the Norwegian and Swedish CCAs and Scandinavian Airlines during three winter seasons. The results showed large differences between the pilots' experienced braking action (airplane braking coefficient, ABC) and measured FC due to

- large time lapse between the measured numbers and landings.
- runways with smooth macro/micro texture.
- use of Tapleymeter on runways with snow, slush, and frost.
- precipitation in the form of snow, super cooled rain, and hail at runway surface temperature of freezing close to zero °C.
- short runways in combination with precipitation and low visibility.

Norwegian aviation regulations

The Norwegian aviation regulations are based on ICAO Annexes and JAA/EASA regulations. Hence, runway design, winter preparations, friction measurements, and reporting conform to international standards as laid out in ICAO Annex 14 and ICAO Doc. 9137 AN/898 Airport Services Manual, Part 2, Pavement Surface Conditions, Fourth Edition, 2002.

Norwegian Aeronautical Information Publication (AIP Norway) From AIP Norway, EN AD 1.2-2 (Reference 3):

"Winter maintenance

2.1 General

2.1.1 All Norwegian aerodromes may experience winter conditions of variable frequency and duration. The CAA Norway's requirements for maintenance of the movement area at Norwegian aerodromes are based upon ICAO SARPS and covers the following:
Inspections for identifying contamination (rime, snow, slush, ice, etc).
Snow clearing for the removal of contamination.
Treatment for obtaining the best possible friction.
Reporting of the conditions.

2.3.3 For the removal of contamination and for the treatment of the movement area the following mechanical means are used:
Snow ploughs
Sweeper blowers
Snow blowers
Spreaders for liquid and solid chemicals
Spreaders for sand.

2.5 Reporting

2.5.1 The international SNOWTAM format is used for reporting the winter conditions at the movement area. The format is described in ICAO Annex 15, Appendix 2.

2.5.2 The conditions at the movement area are reported to the ATS using a special format from which the ATS will issue a SNOWTAM.

2.5.2 H Friction

The level of friction on a runway may be reported as measured or estimated. If the aerodrome operator can not answer for the friction level or if the conditions exceeds those acceptable for the measuring devices, then the number 9 shall be reported. Measured friction level may only be reported when the conditions are within those acceptable for the measuring device. Measured friction level is reported for each third of the runway as viewed from the threshold having the lower runway number and is reported in 2 digits (0 and point is omitted) followed by the sign for the friction-measuring device. Ref. item 2.6 and 2.7 below for further information. The friction may be estimated by a qualified person. Estimated friction level is reported for each third of the runway as viewed from the threshold having the lower runway number and is reported in 1 digit according to the following table:
5 Good friction level—0.40 and above
4 Medium/good friction level—0.36-0.39
3 Medium friction level—0.30-0.35
2 Medium/poor friction level—0.26-0.29
1 Poor friction level—0.25 and below
9 Not to be estimated

2.6 Friction-measuring devices and acceptable conditions

2.6.1 The following friction-measuring devices are accepted for use at Norwegian aerodromes:
GRT—Grip Tester
SFH—Surface Friction Tester, high-pressure tire
SKH—Skiddometer BV 11, high-pressure tire
RUN—Runar
VIN—Vertec Inspector
TAP—Tapleymeter

2.6.2 In general, there is great uncertainty related to measurement carried out under wet conditions. The snow and ice is then at its melting point. For instance is TAP not accepted under wet conditions. Ref. is made to item 2.7 below for more information.

2.6.3 A measured friction level is associated with the measuring device and can not be used as an isolated number. The acceptable conditions for the measuring devices are
SKH/SFH:
Dry snow up to 25 mm
Dry compact snow any thickness
Dry ice any thickness
Slush up to 3 mm
Wet snow up to 3 mm
Wet ice
GRT/RUN/VIN:
Dry snow up to 25 mm
Dry compact snow any thickness
Dry ice any thickness
Slush up to 3 mm
Wet snow up to 3 mm
TAP:
Dry snow up to 5 mm
Dry compact snow any thickness

2.7 SNOWTAM format item H

The table used under item H, with associated descriptions, was developed in the early 1950s from friction data collected only on compact snow and ice. The friction levels should not be regarded as absolute values, and they are generally not valid for other surfaces than compact snow or ice. Nevertheless it is accepted that friction level may be reported when conditions with wet snow or slush up to 3 mm depth are present and a continuous measuring device is being used. A numerical expression regarding the quality of the friction levels reported in the SNOWTAM can not be provided. **Tests show that the accuracy indicated in the table can not be provided using today's friction-measuring devices. While the table uses numbers with two digits, the tests show that only numbers with one digit can be of operational value.** Utmost caution should, therefore, be taken when using the reported friction levels, and the use of the table must be based upon the aircraft operators own experience."

Friction measurements

In 1946 the airport manager of Oslo Airport started friction testing on a compact snow- and ice-covered runway using a decelerometer mounted in a truck to measure the deceleration of the vehicle. The results were correlated with similar measurements in aircraft like the DC-3, DC-4, and DC-6.

In the ICAO Circular[1] *Ice and Snow on Runways,* Attachment B, we find the *Report on the procedure for correction of minimum runway length under winter conditions at Oslo Airport, Fornebu*[2], by airport manager Ottar Kristian Kollerud. This report was based upon tests carried out under winter conditions at Oslo Airport Gardermoen and operational experience from Oslo Airport Fornebu. Kollerud concluded that the effective braking action for the aircraft was found to be half the braking action for the 10-wheel GMC truck. *Aircraft* $\mu_{eff} = 0.5$ *Measured* μ.

Using a large truck was found to be impractical for various reasons, and when the Nordic countries Finland, Sweden, Denmark, and Norway in 1959[3] agreed upon a standardized device, the decelerometer *Tapleymeter* was chosen. However, there was a belief that more accurate and reliable results could be obtained by using another principle of measurements.

In 1962[4], at the seventh session of the ICAO, Aerodromes, Air Routes and Ground Aids Division, representatives from Sweden[5] participated. Two of these representatives became central in further developments of friction-measuring devices and associated procedures and regulations. From the report:

"One state reported that a vehicle had been developed that provided the incipient skidding friction coefficient in a graphical form with an accuracy of 0.01 and required a short runway occupancy time."

However, one experienced that the different principles gave different results when measuring at the same surface conditions and the need for correlation and harmonization arose. With the best intention, new friction-measuring devices of different makes where introduced and used operationally by states.

When Canada in 1970[6] introduced the use of a friction-measuring device, it choose the *James Brake Decelerometer*. Transport Canada developed the Kollerud method further[7] and developed the James Brake Index (JBI) tables, later renamed to Canadian Runway Friction Index (CRFI) tables and further developed upon findings from the JWRFMP.

From JWRFMP findings[8]:—Exclusive of aircraft type, plotted against the CRFI, one found that the value of the CRFI can be used to predict the minimum aircraft braking coefficient in general terms using the equation: $MuR = 0.40 \times CRFI + 0.02.$

The "recommended" aircraft braking coefficient, MuR, is to be used in the equation for stopping distance, and is bounded by a conservative maximum value of 0.34 on a bare and dry surface (CRFI = 0.80) and a minimum value (rolling resistance) of 0.02 on a surface with nil braking (CRFI = 0.0).

Correlation between friction-measurement devices and between friction measurements and aircraft braking

In 1974 ICAO published[9] the final report from the first international program for correlating friction-measuring devices. The objective of the program was "*to define the degree of correlation that exists between various types of equipment used in the measuring of runway braking action.*"

From the conclusions:

"In the evaluation of the reduced test data the following was noted:

1. Some degree of correlation exists among the devices tested.
2. Correlation varies widely between equipment pairs and with changes in surface textures.…
3. A lack of precision is evident among measuring devices tested. Even greater lack of precision is evident at the lower test speeds (under 40 mph) and on the lower friction surfaces.
4. The inverse DBD SDR (1/SDR) can be included in the comparison tables and in the correlation classification."

The aircraft was brought into the loop and research activities continued in Sweden and Scandinavia and the Aeronautical Research Institute of Sweden concluded[10] in 1980 that "if reporting of brake numbers to pilots is of importance, it is necessary to continue the development of both measuring vehicles and applying processes."

In the U.S., there were several test and research activities. New

Snow/Ice/Sanded Ice Friction Correlation.-

For snow/ice-covered runway surfaces, the low shear strength snow and ice becomes the sacrificial surface of the tire tread rubber and snow-ice friction pair. Thus, the friction-speed characteristics of pneumatic rubber tires developed during braked or yawed rolling on snow/ice-covered runways are determined by the physical properties of snow and ice. Research shows that the shear strength of snow and ice increases with decreasing snow and ice temperature and vice versa. Research also shows that the friction-speed gradient of braked and yawed rolling tires is approximately zero (friction coefficient constant with speed). It is assumed that friction changes from tire size, vertical load, and inflation pressure are minimal for snow/ice-covered runway conditions (pressure-melting effects are minimal).

Snow/Ice-Covered Runway Correlation Equation.-

Using this approach, the following equation has been derived to estimate the aircraft MU-EFF developed on a snow/ice-covered runway from a braked or yawed rolling runway tester friction measurement.

Predicted Aircraft Braking $(MU\text{-}EFF)_A$

$$(MU\text{-}EFF)_A = \left[0.2(MU)_T + 0.7143(MU)_T^2\right] \qquad \text{(Equation 11)}$$

$(MU)_T$ Friction Tester or Decelerometer Test MU

Subscript: A Aircraft; T Friction tester, Decelerometer

It should be noted that Equation 11 assumes that the aircraft tire and the runway friction tester tire have identical friction values on a snow/ice-covered runway. The lower MU-EFF value for the aircraft stems from friction losses due to the efficiency of the aircraft antiskid controlled braking system. Because of the snow/ice/sanded ice and aircraft tire/ground vehicle tire relationships, it becomes possible to use ground vehicles equipped with mechanical or electronic decelerometers, such as the Taply Meter and Bowmonk to adequately measure runway friction on snow/ice/sanded ice-covered runway surfaces.

Figure 1. NASA formulae for predicted aircraft braking (Mu eff).

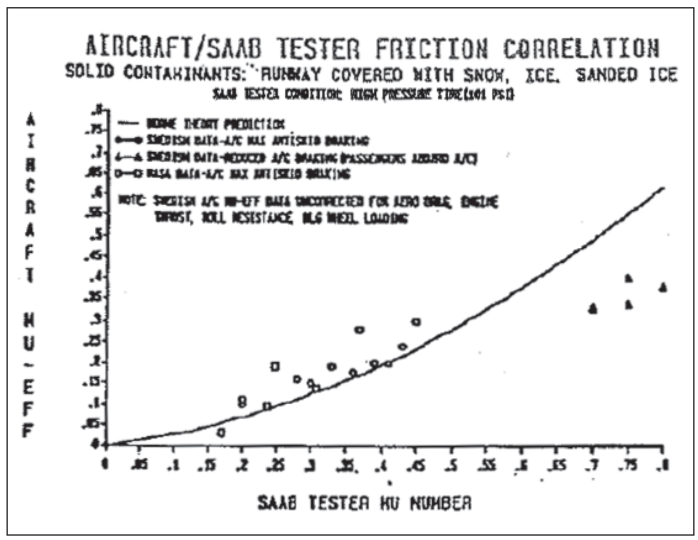


Figure 2. NASA Aircraft/SAAB tester friction correlation.

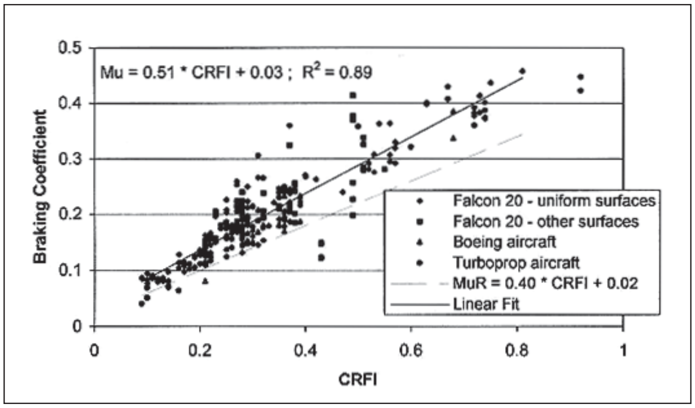


Figure 3. Canadian Runway Friction Index (CRFI).

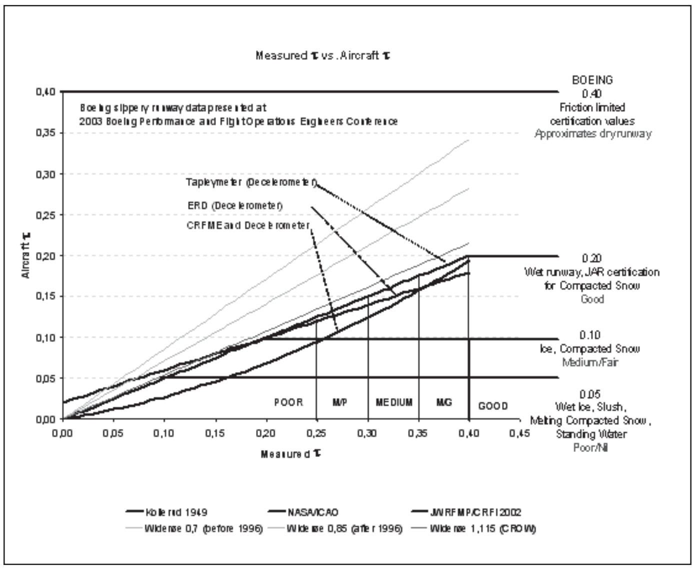


Figure 4. Different correlation curves between measured and aircraft μ.

correlation charts were developed. In March 1988 NASA published[11] correlation charts based upon findings from a joint FAA/NASA research program.

Figures 1 and 2 are from a paper prepared for the Air Line Pilots Association, International, by Walter B. Horne, 1990[12].

AIBN comments to the NASA correlation curve in Figure 2 is that it is not obvious that the friction test data correlate with the curve, taking into account the uncertainty of the measured FC. See Figures 3 and 4, and Table 1.

In 1990 NASA published a report[13] referring to the same research program and among the major test findings were:

"For wet-runway conditions, the estimated aircraft braking performance from the ground-vehicle friction measurements was within ± 0.1 friction coefficient value of the measured value, except for some rain-wet data."

"For snow- and ice-covered runway conditions, the estimated aircraft braking performance from the ground-vehicle measurements was within ± 0.1 friction coefficient value of the measured values."

The next major research program was the Joint Winter Runway Friction Program (JWRFMP).

Through JWRFMP, the Canadian Runway Friction Index, CRFI, was further developed and is in operational use in Canada. The CRFI method is used only in Canada. See Figure 3 and References 4 and 7.

Through ASTM, as part of the JWRFMP, an International Runway Friction Index (IRFI) has been developed. The ASTM Standard E 2100-04[4] defines and prescribes how to calculate IRFI for winter surfaces. IRFI is a standard reporting index to provide information on tire-surface friction characteristics of the movement area to aircraft operators. The IRFI method typically reduces the present variations among different GFMDs from 0.2 down to 0.05 friction units.

If we summarize the situation of today, we find that the accuracy one was reported to have in 1962 are five times better than the accuracy one is told to get using the ASTM standard of today (See Table 1). No states are using this standard.

AIBN comments regarding implementation of a IRFI is that Norwegian experience shows that all of the approved friction-measurement devices in use show a similar accuracy/uncertainty and a possible difference falls within the data scatter. Hence, it is considered of no value to correlate one device to another.

Correlation algorithms available today:

Kollerud:
All airplane types—μb = μf x 0.5

DeHavilland (Bombardier):
DH-8-100/300—μb = 0.6 x μ measured cont / μ measured dry
DH-8-400—μb = 0.5 x μ measured cont / μ measured dry

NASA/ICAO:
All airplane types—$\mu b = \{0.2 \times \mu f + 5/7 \times (\mu f)^2\}$

Transport Canada:
All airplane types (CRFI)—μb = 0.02 + 0.4 x μf

Figure 4 shows a comparison between the different correlation curves. From the Figure, some significant conclusions may be drawn:

- With an uncertainty of the order of ± 0.10, a measured FC of 0.30 (MEDIUM) may for all practical purposes be between 0.20 (POOR) and 0.40 (GOOD).
- Depending on the correlation curve in use, measured 0.30 (MEDIUM) may give an airplane braking coefficient (or Effective μ) between 0.07 (POOR) and 0.13 (MEDIUM).
- Depending on which correlation curve in use, the landing distance required (LDR) may differ significantly.

Norwegian CAA (CAA-N)

Figure 5 includes a CAA-N-approved correlation curve for the B-737 based on Boeing data in Table 5.

Friction measurement uncertainties

The ICAO SNOWTAM table does not contain any tolerances or uncertainties. The measured FC values are used as measured to a $1/100^{th}$ accuracy.

Over the year, several trial results have indicated that there is an uncertainty in the measured friction values. Table 1 show some documented measured FC uncertainties.

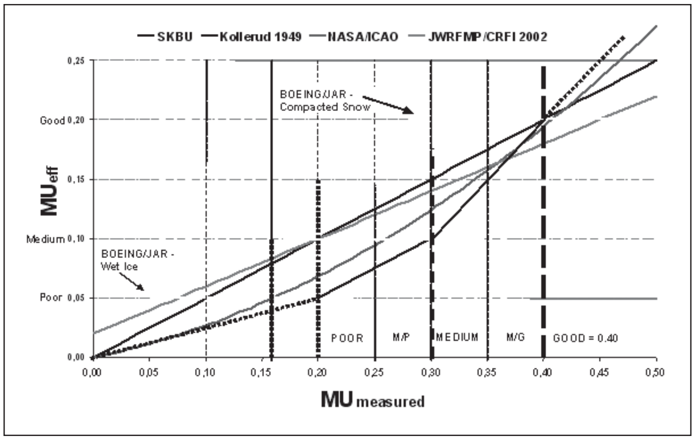


Figure 5. CAA-N-approved B-737 correlation curve (black line).

YEAR	Organization	Accuracy—Uncertainty	Remark
1962	ICAO	± 0.01	Reported by a state
1974	ICAO	± 0.20, ± 0.15	Wet surfaces
1974	ICAO	± 0.15, ± 0.10	Compacted snow and ice surfaces
1990	NASA	± 0.10	Aircraft in the loop
2005	ASTM	± 0.20 ! ± 0.05	Use of ASTM standard E2100-04

Table 1. Friction measurement uncertainty.

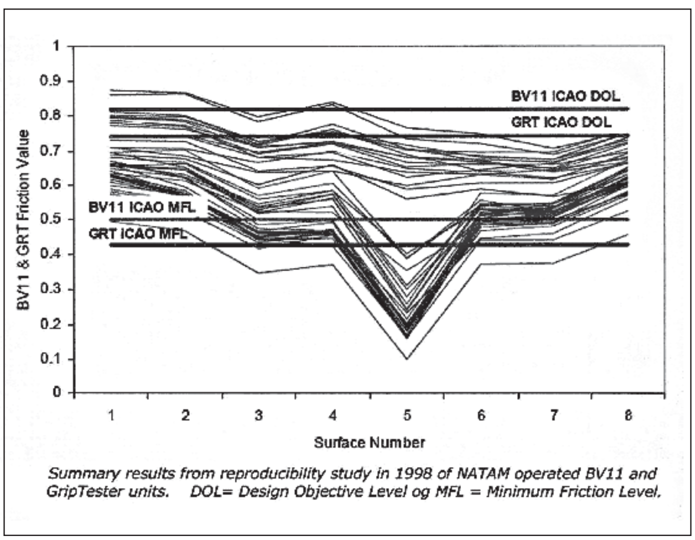


Figure 6. Norwegian wet runway FC measurement results with SKH and GRT on different MTD surfaces.

Figures 6 and 7 show some results from Norwegian wet runway testing by Avinor from testing SKH (BV-11) and GRT on different runway surface textures identified by individual surface numbers[15]. As can be seen from the Figure, the uncertainty is of the order of ± 0.10-0.20. Based on these test results, Avinor discontinued the practice of measuring runway friction values by use of wet runway friction measurements as per ICAO Doc. 9137, Airport Services Manual, Part 2, Chapter 3. Norway has filed a deviation to ICAO with regard to the recommended procedure of maintaining the design objective level (DOL) and the minimum friction level (MFL) for runways by wet runway friction measurements.

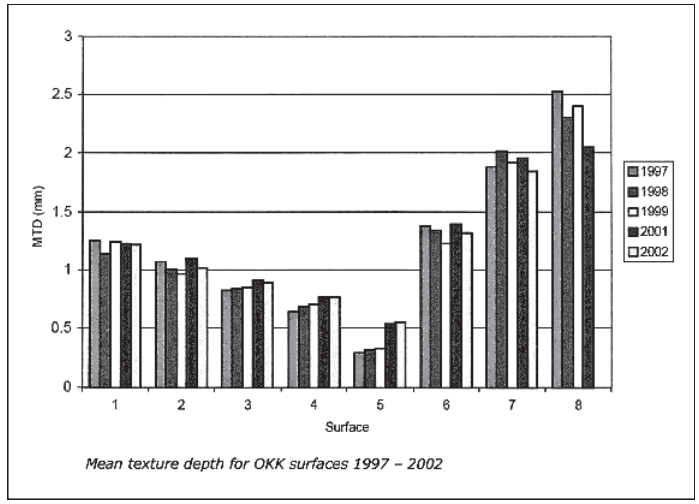


Figure 7. Norwegian Avinor MTD runway friction test surfaces (See Endnote 16).

JAR OPS regulations

JAR-OPS 1 Subpart G AMC/IEM G-Performance class A

IEM OPS 1.485(b)
General—Wet and contaminated runway data
See JAR-OPS 1.485(b)

"If the performance data has been determined on the basis of runway friction coefficient, the operator should use a procedure correlating the measured runway coefficient and the effective braking coefficient of friction of the airplane type over the required speed range for the existing runway conditions."

IEM OPS 1.490(c)(3)
Takeoff—Runway surface condition
See JAR-OPS 1.490(c)(3)

1. "In the case of a contaminated runway, the first option for the commander is to wait until the runway is cleared.…"
2. "An adequate overall level of safety will only be maintained if operations in accordance with JAR-25 AMJ 25X1591 are limited to rare occasions...."[16]

We see that EASA and European Aviation Authorities approve the use of measured runway friction coefficient and correlation between the measured runway coefficient and the effective braking coefficient of the airplane type.

The following is from an NTSB factual report of investigation of the Boeing 737-700 accident[17] at Chicago Midway:

"A report[18] produced by The Winter Runway Friction Measurement and Reporting Group[19] addressed correlation between DECs and CFMEs, and noted—Extensive tests and trials of various friction-measuring equipment carried out to date by the FAA and Transport Canada confirm that as long as such equipment is working properly and calibrated in accordance with manufacturers' instructions, all of them will provide similar friction readings for any of the allowable surface contaminant conditions. Thus, the so-obtained friction values can be considered accurate and reliable, and entirely suitable for the intended purposes. This makes the process very convenient and easy to use, because it is not necessary to specify what equipment was used to obtain such information when transmitting such friction readings to the various users. Any of the approved friction-measuring equipment will give the same results under similar surface conditions. Furthermore, this applies irrespective of whether one uses a CFME or DEC type of equipment. The only difference between the results obtained from these two generic types of equipment is that the former provides a continuous record of friction over any desired length of pavement, while the latter gives what is known as the spot value of friction, which represents the short length of the pavement over which the friction is measured. The above difference in the fundamental way in which the friction measurement is obtained is, however, of no operational consequence, because in any case such readings are taken over the entire length of the runway and then averaged for each third of it (the touch down, the midpoint, and the rollout zones). Thus the actual friction-measuring process and the kind of equipment used is entirely transparent to the ultimate user of such information, who is simply provided with a single friction value for each of the three zones. This eliminates any possibility of misunderstanding and misinterpretation and [en]sures consistency in the friction-taking process as well as in its ultimate use."

Correlation of friction tests with aircraft braking performance

FAA

The FAA's policy is that it is not possible to predict aircraft braking performance from mu values obtained from runway friction surveys. FAA's *Aeronautical Information Manual* (AIM) asserts:

"No correlation has been established between mu values and the descriptive terms 'good,' fair,' 'poor,' and 'nil' used in braking action reports."

Similarly, FAA Advisory Circular (AC) 150/5200-31A, *Airport Winter Safety and Operations,* states:

"While it is not yet possible to calculate aircraft stopping distances from friction measurements, data have been shown to relate to aircraft stopping performance under certain conditions of pavement contamination and are considered helpful by pilots' organizations."

The FAA position was restated in Cert Alert 95-06, Oct. 1, 1995, *Reporting Braking Action and Friction Measurements*:

"The FAA does not support this table* because there is no correlation between braking action and mu value. Braking action is subjective whereas mu value is quantitative. A pilot should know how the aircraft will react to a given mu value. Whereas what is considered 'good' braking action for one person may be 'poor' or 'nil' to another."

* These comments are related to Ground Friction Reading Correlation Table, presented by Thomas J. Yager at the International Aviation Snow Symposium in Buffalo, NY, 1988. See Note 11.

FAA considers that the actual airplane FC is an objective, quantitative value, whereas the pilot experienced braking action is a subjective assessment. However, the measured FC is instrument

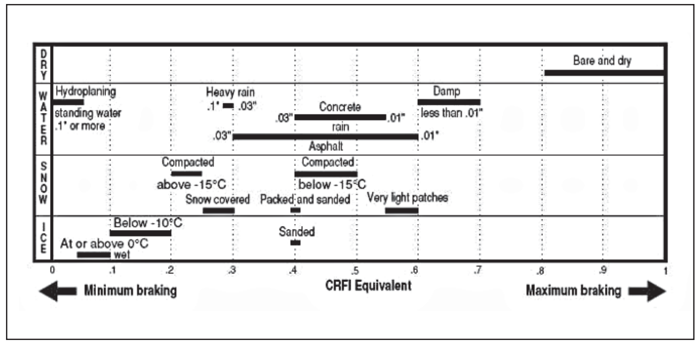


Figure 8. CRFI equivalents.

specific, and there is no approved correlation between various measuring devices and different airplane braking coefficient (ABC).

And in Cert Alert 05-01, 1/14/2005, *Airport Winter Operations (Friction Measurement Issues)*:

"Although the International Civil Aviation Organization (ICAO) has published a comparison table for "mu" readings and braking action, the FAA is not in harmony with ICAO on this determination and publication. The FAA has no approved publication that provides a comparable assessment rating between "mu" readings and braking action. Further, the FAA feels that there is currently no conclusive correlation between braking action and mu value. Braking action is subjective and dependent on may factors, whereas mu value is an objective measurement. Either mu values or braking action reports are acceptable for reporting pavement conditions to the notice to airman (NOTAM) system. However there is no correlation between the two. THEY ARE NOT INTERCHANGABLE!"

ICAO

ICAO Annex 14, Aerodromes, Attachment A, provides a comparison table between "measured friction coefficient" and "estimated braking action." The text preceding the table cautions:

"The table below with associated descriptive terms was developed from friction data collected only in compacted snow and ice and should not, therefore, be taken to be absolute values applicable in all conditions. If the surface is contaminated by snow and ice and the braking action is reported as 'good,' pilots should not expect to find conditions as good as on a clean dry runway (where the available friction may well be greater than that needed in any case). The value 'good' is a comparative value and is intended to mean that airplanes should not experience directional control or braking difficulties, especially when landing."

Canadian Runway Friction Index (CRFI)

In Canada, a method of measuring and reporting friction on contaminated runways has been in use for about 30 years. Runway friction values obtained from decelerometers are reported as Canadian Runway Friction Index (CRFI) values, and are included in surface condition reports and NOTAM information. (See Figure 3.)

In addition, Transport Canada has published (Reference 4) average equivalent values of CRFI produced by typical runway surface conditions and may be used as a guide when CRFI numbers are not available. As can be seen from Figure 8, it is not

Contaminant	Default Friction Value μ
Standing Water and Slush	$= -0.0632\left(\frac{V}{100}\right)^3 + 0.2683\left(\frac{V}{100}\right)^2 - 0.4321\left(\frac{V}{100}\right) + 0.3485$ where V is groundspeed in knots Note: For V greater than the aquaplaning speed, use μ = 0.05 constant
Wet Snow below 5mm depth	0.17
Wet Snow	0.17
Dry Snow below 10mm depth	0.17
Dry Snow	0.17
Compacted Snow	0.20
Ice	0.05

Note: Braking Force = load on braked wheel x Default Friction Value μ

Note: For a specially prepared winter runway surface no default friction value can be given due to the diversity of conditions that will apply.

Table 2. EASA contaminant default friction values.

possible to accurately correlate a type of contamination to a specific reading of CRFI.

EASA Certification[20]

From the CS-25 Book 2 is extracted:

"7.3 Braking friction (all contaminants)

On most contaminant surfaces the braking action of the airplane will be impaired. Performance data showing these effects can be based on either the minimum conservative 'default' values, given in Table 2 or test evidence and assumed values (see paragraph 7.3.2). In addition, the applicant may optionally provide performance data as a function of airplane braking coefficient or wheel braking coefficient.

7.3.1 Default values

To enable airplane performance to be calculated conservatively in the absence of any direct test evidence, default friction values as defined in Table 2 may be used. These friction values represent the effective braking coefficient of an anti-skid controlled braked wheel/tire.

7.3.2 Other than default values

In developing airplane braking performance using either test evidence or assumed friction values other than the default values provided in Table 2, a number of other brake-related aspects should be considered. Brake efficiency should be assumed to be appropriate to the brake and anti-skid system behavior on the contaminant under consideration or a conservative assumption can be used. It can be assumed that wheel brake torque capability and brake energy characteristics are unaffected. Where the tire wear state significantly affects the braking performance on the contaminated surface, it should be assumed that there is 20% of the permitted wear range remaining. Where limited test evidence is available for a model predecessor or derivative this may be used given appropriate conservative assumptions.

7.3.3 Use of ground-friction-measurement devices

Ideally it would be preferable to relate airplane braking performance to a friction index measured by a ground friction device that would be reported as part of a surface condition report. However, there is not, at present, a common friction index for all ground friction measuring devices. Hence it is not practicable at the present time to determine airplane performance on the basis of an internationally accepted friction index measured by ground friction devices. Notwithstanding this lack of a common index, the applicant may optionally choose to present takeoff and landing performance data as a function of an airplane braking coefficient or wheel braking coefficient constant with ground speed for runways contaminated with wet snow, dry snow, compacted snow, or ice. The responsibility for relating this data to a friction index measured by a ground friction device will fall on the operator and the operating authority."

Airbus Industrie view[21]

From an Airbus Industrie document, "Getting to Grips with Cold Weather Operations," Airbus Industrie, Flight Operations Support, Customer Services Directorate, 1999 (Reference 5), is extracted:

"C3.4.2 Difficulties in assessing the effective μ

The two major problems introduced by the airport authorities evaluation of the runway characteristics are:

—The correlation between test devices, even though some correlation charts have been established.

—The correlation between measurements made with test devices or friction-measuring vehicles and aircraft performance. These measurements are made with a great variety of measuring vehicles, such as Skiddometer, Saab Friction Tester (SFT), mu meter, James Brake Decelerometer (JDB), Tapley meter, Diagonal Braked Vehicle (DBV). Refer to ICAO, Airport Services Manual, Part 2, for further information on these measuring vehicles.

The main difficulty in assessing the braking action on a contaminated runway is that it does not depend solely on runway surface adherence characteristics.

What must be found is the resulting loss of friction due to the interaction of the tire/runway. Moreover, the resulting friction forces depend on the load, i.e., the aircraft weight, tire wear, tire pressure, and anti-skid system efficiency.

In other words, to get a good assessment of the braking action of an A340 landing at 150,000 kg, 140 kt with tire pressure 240 PSI, the airport should use a similar spare A340.... Quite difficult and pretty costly!

The only way out is to use some smaller vehicles. These vehicles operate at much lower speeds and weights than an aircraft. Then comes the problem of correlating the figures obtained from these measuring vehicles and the actual braking performance of an aircraft. The adopted method was to conduct some tests with real aircraft and to compare the results with those obtained from measuring vehicles.

Results demonstrated poor correlation. For instance, when a Tapley meter reads 0.36, a mu meter reads 0.4, a SFT reads 0.43, a JBD 12….

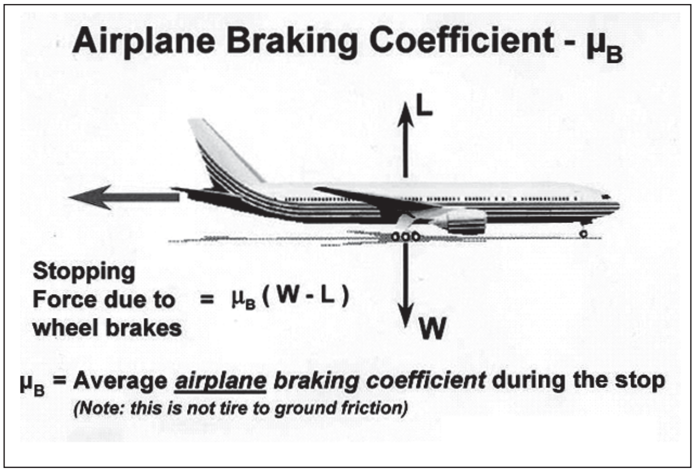


Figure 9. Boeing airplane braking coefficient (ABC).

Airplane Braking Coefficient - μ_B

- Typical dry values from Boeing certification testing
  - μ_B = 0.35 to 0.41
  - Maximum manual braking, anti-skid limited region
- Boeing slippery runway data (PEM/JAROPS 1)
  - RTO - μ_B = 0.05, 0.1, 0.15, 0.2
  - Landing - μ_B = 0.05, 0.1, 0.15, 0.2
- AC 91-6B and AMJ25X1591
  - Wet can be approximated by 1/2μ_B dry max - fair
  - JAR certifications, Compact snow - μ_B = 0.20
  - Wet ice - μ_B = 0.05 - nil

Table 3. Boeing-defined airplane braking coefficients.

To date, scientists have been unsuccessful in providing the industry with reliable and universal values. Tests and studies are still in progress.

As it is quite difficult to correlate the measured μ with the actual μ, termed as effective μ, the measured μ is termed as 'reported μ.'

In other words, one should not get confused between:
1. Effective μ: The actual friction coefficient induced from the tire/runway surface interaction between a given aircraft and a given runway, for the conditions of the day.
2. Reported μ: Friction coefficient measured by the measuring vehicle.

Particularities of fluid contaminants
Moreover, the aircraft braking performance on a runway covered by a fluid contaminant (water, slush, and loose snow) does not depend only on the friction coefficient μ.

As presented in chapters C2.2 and C2.3, the model of the aircraft braking performance (takeoff and landing) on a contaminated runway takes into account not only the reduction of a friction coefficient but also
—the displacement drag.
—the impingement drag.
These two additional drags (required to be taken into account by regulations) require knowing **the type and depth of the contaminant.**

In other words, even assuming the advent of a new measuring friction device providing a reported μ equal to the effective μ, it would be impossible to provide takeoff and landing performance only as a function of the reported μ. Airbus Industrie would still require information regarding the depth of fluid contaminants.

C3.4.3 Data provided by Airbus Industrie
Please refer to § C6 for further details on contaminated runway performance provided by Airbus Industrie.

Hard contaminants
For hard contaminants, namely compacted snow and ice, Airbus Industrie provides the aircraft performance independently of the amount of contaminants on the runway. Behind these terms are some effective μ. These two sets of data are certified.

Fluid contaminants
Airbus Industrie provides takeoff and landing performance on a runway contaminated by a fluid contaminant (water, slush, and loose snow) as a function of the depth of contaminants on the runway.

For instance, takeoff or landing charts are published for '1/4 inch slush,' '1/2 inch slush,' '1/4 inch water,' and '1/2 inch water.' For loose snow, a linear variation has been established with slush.

In other words, pilots cannot get the performance from reported μ or Braking Action. Pilots need the **type and depth of contaminant** on the runway.

Correlation between reported μ and braking performance **Please, bear in mind:** Airports release a friction coefficient derived from a measuring vehicle. This friction coefficient is termed as 'reported μ.'

The actual friction coefficient, termed as 'effective μ' is the result of the interaction tire/runway and depends on the tire pressure, tire wear, aircraft speed, aircraft weight, and anti-skid system efficiency.

To date, **there is no way to establish a clear correlation between the 'reported μ' and the 'effective μ.'** There is even a poor correlation between the 'reported μ' of the different measuring vehicles.

It is then very difficult to link the published performance on a contaminated runway to a 'reported μ' only. The presence of **fluid contaminants** (water, slush and loose snow) on the runway surface **reduces the friction coefficient** and may lead to **aquaplaning** (also called hydroplaning) and creates an **additional drag.** This additional drag is due to the precipitation of the contaminant onto the landing gear and the airframe and to the displacement of the fluid from the path of the tire. Consequently, braking and accelerating performance are affected. The impact on

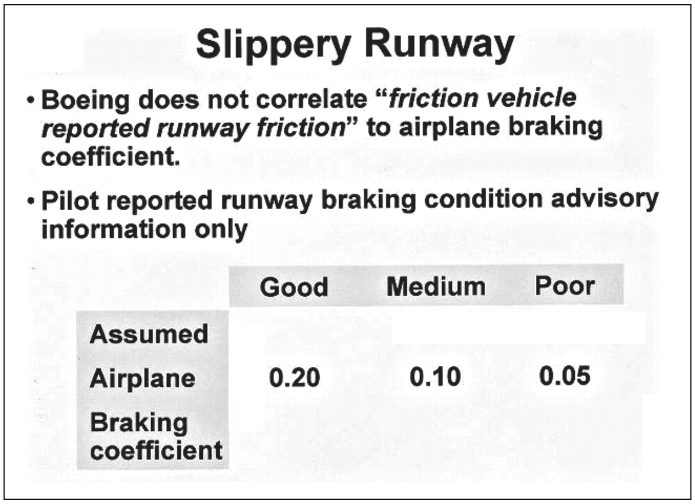


Table 4. Boeing's ABC default values for slippery runways. We see that Boeing's view is in line with the FAA and is based on Boeing's test values for fixed default values for dry, wet, good, medium, and poor braking action.

the accelerating performance leads to a limitation in the depth of the contaminant for takeoff. **Hard contaminants** (compacted snow and ice) only affect the braking performance of the aircraft by a reduction of the **friction coefficient.** Airbus Industrie publishes the takeoff and landing performance according to the **type of contaminant**, and to the **depth** of fluid contaminants."

Boeing's view[22]

From a Boeing presentation on contaminated and slippery runways, 2001 (Reference 6), the following information is extracted: Boeing does not correlate *"friction vehicle reported runway friction"* to airplane braking coefficient.

AIBN investigation results

During the last 8 years, the AIBN has received 24 reports on accidents and incidents related to slippery runways and measuring and reporting of friction coefficient (FC). Some of these reports led to separate investigation reports, while the rest are covered by an AIBN special investigation into "Winter Operations and Friction Measurements."

This investigation is ongoing, but several of the findings are reflected in recent reports from the AIBN on serious incidents in Norway. The investigations have uncovered weaknesses and unsubstantiated recommendations and guidelines related to operations on contaminated and slippery runways as indicated below:

ICAO Doc. 9137, Airport Services Manual, Part 2 Pavement Surface Conditions, Fourth Edition 2002

From several investigations into accidents and serious incidents involving runway excursions on slippery runways, the AIBN questions the information and recommendations in ICAO Doc. 9137, Airport Services Manual, Part 2. The information related to friction measuring devices and correlation with airplane braking coefficients does not reflect the Norwegian winter conditions, with a coastal climate with changing winter conditions, in comparison with the American continental climate. The SNOWTAM table is based on friction measurements on dry, compact snow and ice and is not validated on wet conditions. Further, the table does not contain any tolerances and it is proven through testing that the uncertainty is of the order of ± 0.10 at dry conditions and of the order of ± 0.20 at wet conditions.

Further, the AIBN has found that there is not any noticeable fixed correlation between the different friction-measuring devices. Norwegian experience shows that all the approved friction measurement devices in use in Norway are subject to the uncertainties referred to above. The individual tolerances fall within the general data scatter. Hence, it is not realistic to correlate one to another.

Airplane Braking Coefficient	Pilot Reported Braking Action	Runway Description
0.4	Approximates dry runway	Friction limited certification values
0.2	Good	Wet Runway, Jar certification for compact snow
0.1	Medium/Fair	Ice, Compacted snow
0.05	Poor/Nil	Wet Ice, Slush, Melting Compacted Snow, Standing Water

Table 5. Boeing-defined ABC vs. runway descriptive contaminants.

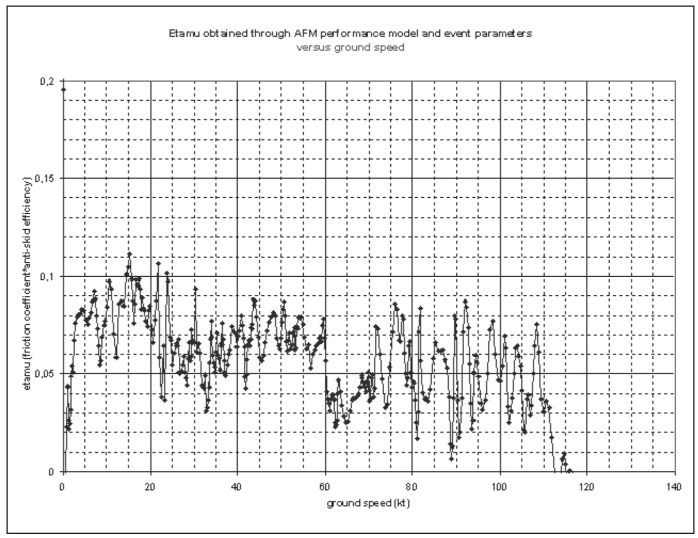


Figure 10. Effective airplane (ABC) based on FDR data from an Airbus 321.

EASA contaminant default friction values

The AIBN has found that the EASA contaminant (airplane braking coefficient or effective Mu) default values as listed in Table 3 are not substantiated, except the 0.20 value for dry compact snow and 0.05 value for wet ice. These two values were first established by Kollerud's testing in Norway during the late 1940s.

The listed values of 0.17 (see Table 2) for wet snow below 5 mm, wet snow, dry snow below 10 mm, and dry snow do not agree with Norwegian experience. The AIBN has found that wet snow below 10 mm has resulted in ABCs of the order of 0.05 (braking action poor by Boeing definition), and dry snow

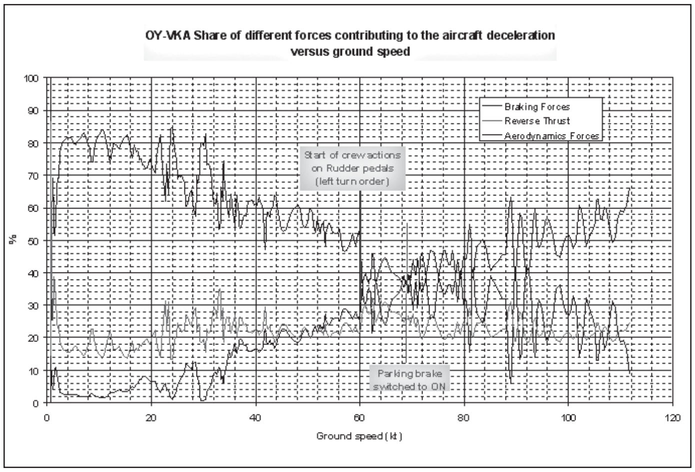


Figure 11. Distribution of the three braking forces: spoilers, reverse thrust, and wheel braking.

has resulted in ABC of 0.10 (braking action medium by Boeing definition).

The relation for standing water and slush in Table 2 may give a correct Default friction value for water but not for slush during landing. The viscosity of water may not be substituted by the viscosity of slush. Norwegian experience is that the ABC (or effective airplane mu) is not velocity dependent during landing breaking. The airplane effective mu must be related to gliding friction rather to rolling friction and is normally of the order of 0.05 (BA poor). Further, the relation may be more relevant for takeoff conditions than for landing.

Airbus Industrie Policy

Airbus Industrie policy is based on EASA CS 25 and is equating slush, wet, and dry snow to an equivalent depth of water based on the definition of *"fluid contaminants."* Airbus states that *"the aircraft braking performance on a runway covered by a fluid contaminant (water, slush, and loose snow) does not depend only on the friction coefficient* μ*"* and that *"the displacement drag and impingement drag require knowing the type and depth of the contaminant."*

The AIBN has found that the above statements may be true for the takeoff conditions but are not correct for the landing conditions. Further, the AIBN has found that so-called *"fluid contaminant"* (slush, wet, and dry snow) results in effective mu on the order of 0.05-0.10. Slush and wet snow often result in ABC of 0.05 (or FC 0.20 poor), and dry snow give an ABC on the order of 0.10 (or FC 0.30 medium).

Figure 10 shows the effective airplane μ deduced from the actual FDR data from an A321 that slid off the runway during landing on 8 mm of wet snow (see page 32, serious incident 3-26-2006). The measured FCs were 32-33-31 (medium). As can be seen from the graph, the average effective (or airplane braking coefficient in Boeing terminology) was on the order of 0.05 (poor) from 110 to 60 kt by use of maximum manual braking. When used in an operations performance computer, such erroneous FCs would calculate a LDR to be about half of the actual. This incident highlights the danger of using the method of "fluid contamination" as used by Airbus.

The problem of braking on a slippery runway is related to a speed below the normal reverse thrust cut out speed of 70-80 kt. This is where the effect of spoilers and reverse thrust is reduced and braking to a stop is based on wheel braking alone. Hence, the effect of displacement drag and impingement drag is not any longer adding to the braking force. The AIBN has found that the use of "fluid contaminant" procedures have led to runway excursions in Norway with Airbus A320/321 airplanes and considers this practice to be dangerous.

Figure 11 shows the relative distribution of braking forces versus ground speed for an Airbus 321.

Airbus does not promote a correlation between measured FC and ABC.

Boeing's policy and Norwegian application

The AIBN has found that Boeing's policy reflected in Tables 4 and 5 has proved itself as a sound and practical method as a basis for operating on contaminated and slippery runways. Based on Norwegian experience operating B-737 on contaminated runways in Norway, the AIBN believes the Boeing-supplied ABC data may be correlated with a limited ICAO SNOWTAM table.

A Norwegian B-737 operator has received approval by the Norwegian CAA to correlate these FCs with the ICAO SNOWTAM table (Figure 5). Hence, the ABC value of 0.05 is correlated with the ICAO value of 0.20, 0.10 with 0.30, and 0.20 with 0.40. A line through these points results in a correlation curve that is more conservative than the other available correlation curves.

The AIBN believes that by using a table based on the Boeing ABCs correlated with the ICAO FC values of 0.20, 0.30, and 0.40, realistic airplane braking performance may be expected. For example, by measured FC 0.34, one will report an FC of 0.30, giving an ABC of 0.10. The AIBN has concluded that this method will result in higher margins operating on slippery runways.

The AIBN considers this curve to be the most conservative correlation curve in use today and has proven its value during the last 7 years in Norway. We can see that the curve is similar in shape to the NASA/ICAO curve. However, when including a general uncertainty on the measured FC values, the AIBN considers that a limited applied correlation table is more relevant. This is shown in Table 6.

Based on the Canadian JWRFMP test data, the AIBN also considers that propeller airplanes may be given a slightly higher ABC at the same FC. This is indicated in Figure 3.

EASA/JAR OPS 1

JAR OPS 1, Subpart G AMC/IEM OPS 1.485(b), *"General-Wet and Contaminated Runway data,"* allows an operator to use an authority-approved correlation between measured FC and airplane braking coefficient (ABC).

EASA CS 25 Book 2, paragraph 7.3.3, *"Use of Ground Friction Measurement Devices,"* allows use of correlation between FC and ABC by stating, *"The responsibility for relating this data (takeoff and landing performance data) to a friction index measured by a ground friction device will fall on the operator and the operating authority."*

The AIBN considers that it is neither practical nor advisable that individual operators are authorized responsibility for relating take off and landing performance data to a measured friction index. Such procedures must be issued by the local aviation authority and published in the national AIP.

Credit for the use of thrust reverser during actual landing calculations

The Chicago Midway accident (B-737-700, Dec. 8, 2005) highlighted the inclusion of thrust reverser credit for actual landing calculations. In a letter from the NTSB to the FAA, Ref. A-06-16 dated Jan. 27, 2006, the NTSB issued an immediate safety recommendation (Reference 8):

"If the reverse thrust credit had not been factored into the stopping distance calculations made by the OPC, it would have indicated that a safe landing on Runway 31C was not possible under a braking condition of either fair or poor. The Safety Board is concerned that the landing distance safety margin is significantly reduced on a contaminated runway when the reverse thrust credit is allowed in landing stopping distance calculations. As a result, a single event, the delayed deployment of the thrust reversers, can lead to an unsafe condition, as it did in this accident. The Safety Board concludes that the safety margin must be restored to those airplanes for which the reverse thrust credit is currently allowed in landing performance calculations. Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration: Immediately prohibit all 14 Code of Federal Regulations Part 121 operators from using the reverse thrust credit in landing performance calculations. (A-06-16) Urgent —Acting Chairman Rosenker and Members Engleman Conners, Hersman, and Higgins concurred with this recommendation."

Based on similar experiences in Norway, the AIBN fully supports the NTSB safety recommendation. Figure 11 shows the relative effect of each braking device during a Norwegian A321 runway excursion incident. As can be seen from the graph, the reverse thrust amounts to 20-25% of the total braking force. Given the uncertainty of calculating the actual LDR on contaminated and slippery runways, the AIBN considers that the 20-25% should be used as a safety margin.

Figure 12 shows the B-737-700 OPC-calculated ground distance with and without use of reverse thrust. The AIBN considers it advisable to use auto brake setting max or max manual braking when planning and landing on a slippery runway.

Crosswind limitations on slippery runways

The AIBN has found that Norwegian airlines use crosswind limitations that are not based on manufacturer advisory data. The limitations may be based on the airline's own experience and have received authorization by the CAA-N. The main reason for this is that there is no certification requirement to include such information in the airplane flight manual. If it is included, it is only advisory data.

Further, the AIBN has found that the airlines use the AFM maximum demonstrated crosswind limitation for reported FC above 0.40. This is in conflict with the caution in ICAO Annex 14, Aerodromes, Attachment A:

"If the surface is contaminated by snow and ice and the braking action is reported as 'good,' pilots should not expect to find conditions as good as on a clean dry runway."

The AIBN considers that the AFM-listed maximum demonstrated crosswind should only be used on dry runways. With wet or contaminated runways, the crosswind limits should be reduced.

Figure 13 shows CAA-N-approved crosswind limitations versus measured FC for B-737 and DH-8 airplanes superimposed

RWY status	Jet ABC	Prop ABC	SNOWTAM	Code	
Dry	0.40	0.40			
Wet	0.20 or TBD	0.20 or TBD			
Cont FC					
0.4	0.2	0.2	Good	5	
0.3	0.1	0.15	Medium	3	
0.2	0.05	0.1	Poor	1	Wet/Moist conditions

Table 6. AIBN-suggested applied correlation table for FC vs. ABC based on Norwegian investigations.

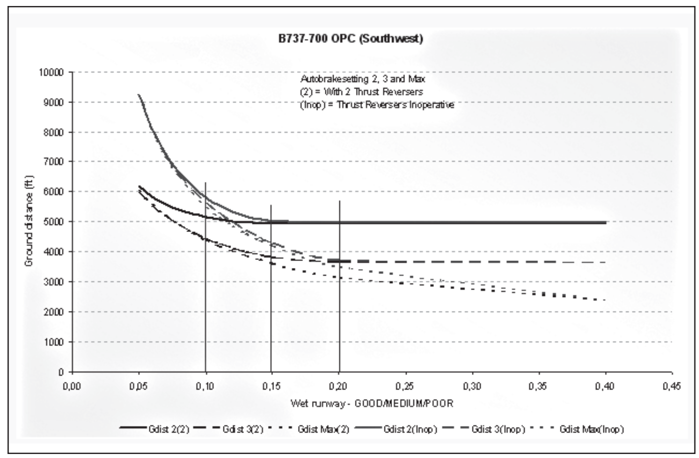


Figure 12. B-737-700 OPC-calculated ground distance with and without use of thrust reversers.

on limitations published in AIP Canada.

Temperature measurements

As indicated in the list of recent accidents and serious incidents in Norway, the measured air temperature (OAT) and dew/frost point (DP) may be a significant indicator of runway slipperiness. The AIBN has found that in most cases of runway excursion due to winter contamination and slipperiness, the dew/frost point spread (the difference between air temperature and dew/frost point) has been < 3 K. This is an indication of moisture in the air, and this information together with TAF and METAR information may be a pilot indication of runway slipperiness. However, OAT and DP are measured 2 m above the surface and is not an accurate indication of the surface temperatures. Therefore, there is a need for measurement of the surface temperatures of the contaminant. The AIBN considers that infrared temperature measurements could be used for this purpose (Reference 9).

AIBN findings

Norwegian air traffic winter operations have been performed successfully and safely during the last 60 years, with only sporadic runway excursion incidents. Friction measurements have

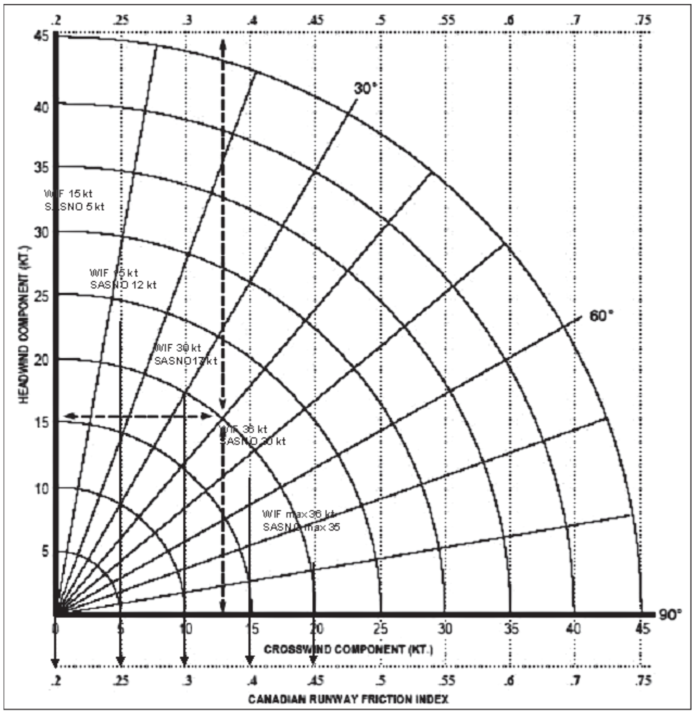


Figure 13. Norwegian crosswind limitations superimposed on AIP Canada crosswind limitations vs. CRFI.

been in regular use during the last 55 years in Norway. During the last 8 years, however, The AIBN has recorded an increase in reported runway excursion incidents related to operations on contaminated and slippery runways.

AIBN investigations have indicated that a possible causal factor for this increase is that Norwegian airlines have introduced operations performance computers to allow pilots to "accurately" calculate an optimum payload or takeoff and landing weight on the available runway. Previously, the measured FC was used in a conservative way by the aircraft commanders, while today it is used directly as an input to the landing performance calculations.

With a documented uncertainty of the order of ± 0.10, it is quite clear that the landing distance required (LDR) may be longer than calculated. A crew may be given an FC of 0.40 (good) that may actually be more like 0.30 (medium). From the formulae for stopping distance $S= V^2/2a$, where $a=\mu*g$, it is easy to see how much longer the RLD could be.

The AIBN has found that the results from the Norwegian trials during the 1940s and 1950 still hold. Ottar Kollerud concluded that the measured FCs were only reliable on dry, compact snow and ice and not on wet contaminants. Further, Kollerud established that the airplane braking coefficient was half of the measured FC. The Canadian JWRFMP test data have resulted in a similar correlation curve, and NASA has found a slightly more conservative correlation curve. (See Figures 3 and 4.) CAA-N has approved still another correlation curve based on Boeing data on slippery runways. (See Figure 5.)

Based on the investigations in Norway, the AIBN has concluded that the use of friction-measurement devices and correlating the measured FC with the ABC are both practical and safe, provided

- Measured FC on dry compact snow and ice.
- Measured FC may be erroneous with wet or moist or loose contaminant on top of compact snow and ice.
- Use of FC restricted to 0.40 (good), 0.30 (medium), and 0.20 (poor) only.
- Correlating the above FC with the Boeing ABCs of 0.20 (good), 0.10 (medium), and 0.05 (poor).
- Accept the use of all the approved friction-measurement devices with an uncertainty of up to ± 0.10 (based on Table 1).
- Sanded wet, compact snow and ice, or sanded loose slush, wet or dry snow on top of compact snow and ice is treated as poor (FC=0.20, ABC=0.05).
- Sanded contaminated runway with dew point spread < 3 K is treated as poor (FC=0.20, ABC=0.05).

The ICAO SNOWTAM table was developed based on friction measurements on dry, compact snow and ice by use of decelerometers. Later ,continuous friction-measurement devices have been introduced. In spite of the initial restriction related to measurements on wet contamination, these devices have been allowed to be used on wet contamination.

Further, the measuring limitations for the individual measurement devices were based on one layer of contamination and not one layer of one type of contamination on top of another type. In these instances, the measuring device measures its own FC related to the top layer whereas the airplane wheel will be subjected to a different FC. Often the top layer of contaminant will act as a lubricant between the airplane wheels and the underlying layer.

Other significant findings in the AIBN investigations are

- Measured FC of 0.30-0.35 on fresh snow has correlated to an ABC of the order of 0.05.
- Measured FC of 0.40-0.45 on sanded compact snow and ice has correlated to an ABC of the order of 0.05 during wet conditions or with dew point spread < 3 K.
- Measured FC of 0.30-0.35 on sanded loose slush and wet or dry snow on top of compact snow and ice has correlated to an ABC of the order of 0.05.
- Measured FC of 0.30-0.35 on sanded wet, compact snow and ice has correlated to an ABC of the order of 0.05.
- Measured FC in medium range on so-called "dry" fresh snow has correlated to an ABC in the poor range.
- Measured FC in medium-to-good range in so-called "dry" winter conditions at air temperatures below freezing with a frost point spread < 3 K has correlated to an ABC in the poor range.
- Measured FC in medium-to-good range in so-called "dry" winter conditions at air temperatures below freezing, with crosswind and drifting snow and ice particles polishing the compact snow and ice has correlated to an ABC in the poor range.
- Sanding on wet compact snow and ice has reduced effect on braking action.
- Sanding on loose masses of slush, wet, or dry snow on top of compact snow and ice has reduced effect on braking action.
- The airplane braking coefficient on snow and ice is affected by the tire temperature.
- Actual LDR calculations should be based on no thrust reverser.
- There is a requirement for correct measurements of the contaminant surface temperature and dew/frost point.

Conclusions

Preliminary findings from the AIBN investigations include, but are not limited to The information in ICAO Doc. 9137, AN/898 Airport Services Manual, Part 2, Pavement Surface Conditions,

Fourth Edition, 2002, is outdated, including the following items:
- The correlation chart/table between friction-measuring devices on compacted snow- and/or ice-covered surfaces is not substantiated. Practical experience in Norway does not support the ICAO correlation values between different friction measuring devices on snow- and ice-contaminated runways.
- The SNOWTAM table lists CF with two decimal digits and does not specify any measuring tolerances. Document research indicates that the tolerance or uncertainty is on the order of ± 0.10. Hence the table should only list the numbers 0.20, 0.30, and 0.40.
- The SNOWTAM table was developed during the 1950s and is based on tests on dry, compact snow and dry ice using a decelerometer. These tests indicated that the correlation between measured CF and airplane braking coefficient (ABC) was unreliable on wet snow and ice covered surfaces. AIBN investigations show that all measuring devices are unreliable on wet snow-and ice-covered surfaces.
- All the approved friction-measurement devices may be used provided an uncertainty of the order of ± 0.10 is respected.
- The calculated LDR for actual landing conditions should be based on no thrust reverser (safety margin).

Recommendations

Based on preliminary findings during these investigations, the AIBN considers it urgent to revise the Norwegian regulations and practices related to winter operations and have issued the following safety recommendations to CAA-N:
- "AIP Norway and BSL E include Norwegian regulations regarding friction-measuring equipment and measurement areas. The AIBN has determined that the actual friction numbers often deviate from measured/reported numbers. Experience has shown that none of the approved friction-measuring devices is reliable during damp/wet conditions, including temperature conditions with a difference of 3°C or less between air temperature and dew point temperature. The AIBN is, therefore, of the opinion that reported friction during damp/wet conditions should be reported as poor. The AIBN recommends that the civil aviation authority considers altering the measurement areas for the approved friction measuring devices in AIP Norway and BSL E. (Immediate safety recommendation SL 06/1350-1).
- The investigations of the AIBN show that the various airlines use different correlation curves/tables. Investigations show that several of these correlation curves are based on uncertain foundations and that they provide very inaccurate/unreliable braking values for the relevant aircraft types. The ICAO SNOWTAM table for measured friction numbers is based on measured numbers in hundredths and depends on the type of friction-measuring device that has been used. AIBN investigations show that the various friction measuring devices provide different numbers on the same surface. AIP Norway describes the use of friction-measuring equipment in general and warns against such large uncertainties in measurements that the accuracy of reporting should not be higher than tenths. Based on these circumstances, the AIBN recommends that the civil aviation authority considers simplifying the SNOWTAM table by eliminating the intermediate levels so that one is left with the areas good, medium, and poor, as well as removing hundredths and excluding the use of interpolation between the areas. (Immediate safety recommendation SL 06/1350-2).
- AIBN investigations show that performance data for landing on slippery runways using engine thrust (reversing) has been published for newer aircraft types (e.g., Airbus and newer Boeing aircraft). Such data have not been published for older aircraft types. The investigations further show that the effect of reversing engines is limited to approximately 25% of all available braking force and that this braking force should constitute a backup when landing on slippery runways. The AIBN recommends that the civil aviation authority should consider not allowing the inclusion of engine reversing in the calculated relevant (within 30 min prior to landing) stopping distance on slippery runways. (Immediate safety recommendation SL 06/1350-3).
- AIBN investigations show that the airlines' crosswind limitations in combination with slippery runways are far too optimistic. The investigations have also confirmed that for certain aircraft types, these tables do not derive from the manufacturer of the aircraft, but have been prepared by individual airlines based on experience. None of the side wind tables has been approved by the authorities. Transport Canada has published one such table of side wind versus friction numbers. This is far more conservative than the tables used by Norwegian airlines. The AIBN recommends that the civil aviation authority assesses the airlines' side wind limitations in relation to friction coefficients/braking action, and also considers whether these should be approved by the authorities. (Immediate safety recommendation SL 06/1350-4)." ◆

References

1. Micrometeorological processes on a runway contaminated by frozen water. Reinhard Mook, 2006.
2. ICAO Doc. 9137 AN/898 Airport Services Manual Part 2, Pavement Surface Condtions, Fourth Edition 2002.
3. AIP Norway, valid November 2004.
4. AIP Canada, valid January 2004.
5. Getting to Grips with Cold Weather Operations, Airbus Industrie, Flight Operations Support, Customer Services Directorate, 1999.
6. Contaminated and Slippery Runways, Boeing Company, Performance Engineer Operations, Flight Operations Engineering, 2001.
7. LTR-FR-183 Evaluation of Aircraft Braking Performance on Winter Contaminated Runways and Prediction of Aircraft Landing Distance Using the Canadian Runway Friction Index, Transport Canada Publication No. TP 13943E, June 2002.
8. Letter from the NTSB to the FAA, Safety Recommendation, conf A-06-16, dated Jan. 27, 2006.
9. The Significance of Winter Operated Runway Surface Temperature. Reinhard Mook, 2007.

Endnotes

1 ICAO Circular 43-AN/38.
2 March 1954.
3 Inter-Nordic meeting, Stockholm, Oct. 13 and 14, 1959.
4 ICAO Doc 8298-AGA/593, Aerodromes, Air Routes and Ground Aids Division, Report of the seventh session, Montreal, Nov. 13–Dec. 14, 1962.
5 J. Wessel (Delegate), G. Antvik (Alternate), J-O Ohlson (Alternate), G. Kullberg (Adviser).
6 Department of Transport, Air Services, Civil Aviation Branch, Aerodromes, Information Circular 0/6/70, 23rd February—Use of James Brake Decelerometer.
7 Transport Canada, Commercial and Business Aviation Advisory Circular No. 0164, 1999.11.03—Canadian Runway Friction Index.
8 TP 13943E - Evaluation of Aircraft Braking Performance on Winter Contaminated Runways and Prediction of Aircraft Landing Distance Using the Canadian Runway Friction Index, June 2002.
9 ICAO, Program for correlating equipment used in measuring runway braking action, Final report, 22/2/74 Joint evaluation program of equipment used to measure runway braking action undertaken by: Canada, France, Sweden,

Union of Soviet Socialist Republics, United Kingdom, and United States.
10 FFA Memo 121, Studies of contaminated runways, K. Fristedt and B. Norrbom, Stockholm 1980.
11 NASA Technical Memorandum 100506, Summary report on aircraft and ground vehicle friction correlation test results obtained under winter runway conditions during joint FAA/NASA runway friction program, Thomas J. Yager, William A. Vogler, and Paul Baldasare, Langley Research Center, March 1988.
12 Correlation Between Aircraft/Ground Vehicle Runway Friction Measurements, Walter B. Horne, prepared for the Air Line Pilots Association, International, 1990.
13 NASA Technical Paper 2917, Evaluation of two transport aircraft and several ground test vehicle friction measurements obtained for various runway surface types and conditions—A summary of test results from joint FAA/NASA runway friction program, Thomas J. Yager, William A. Vogler and Paul Baldasare, Langley Research Center, 1990.
14 ASTM Standard E2100-04, Standard Practice for Calculating the International Runway Friction Index.
15 Avinor Notice 5:2003, Geir Lange, 2004.
16 AMJ 25X1591 is replaced by CS 25.1591 and AMC 25.1591.
17 Survival Factors Group Chairman's Factual report of Investigation, NTSB, May 15, 2006.
18 An Evaluation of Winter Operational Runway Friction Measurement, Section 3.3, Jan. 25, 1995.
19 Comprised of representatives from the FAA, Transport Canada, NASA, Airports Council International, American Association of Airport Executives, Regional Airline Association, Air Transport Association, and ALPA.
20 CS-25 Book 2, AMC 25.1591, Amendment 2.
21 Getting to Grips with Cold Weather Operations, Airbus Industrie, Flight Operations Support, Customer Services Directorate, 1999.
22 Contaminated and Slippery Runways, Boeing Company, Performance Engineer Operations, Flight Operations Engineering, 2001.

Utilization of the Web-Based GIS to Assist Aviation Occurrence Investigation

By Tien-Fu, Yeh, Wen-Lin Guan, and Hong T. Young, Aviation Safety Council, Taiwan

***Tien-Fu, Yeh** is a flight recorders engineer with the Aviation Safety Council.*

***Dr. Wen-Lin Guan** is the director of Investigation Laboratory with the Aviation Safety Council.*

***Dr. Hong T. Young** is the managing director of the Aviation Safety Council. He was the coordinator of National Taiwan University Commercial Pilot Training Program by the Civil Aviation Authority (CAA) and deputy chairman of the Department of Mechanical Engineering of the National Taiwan University.*

Abstract

The computer's computing and graphic techniques are rapidly developing, which urged the related applications to relay on the Geographical Information System (GIS), and produced an application product of the Digital Earth.

In the past, precise resolution of satellite imageries and terrain data have been expensive and not open to public access. In 2005, Google, Inc., merged the Keyhole Inc., and developed two free web-based GIS browsing programs (Google Map and Google Earth), which are based on the Internet platform, and provided users to remote access of the 3-D digital worlds with precise satellite imageries, terrains, and relevant contents.

In order to carry out the aviation occurrence investigations, the Aviation Safety Council (ASC) of Taiwan is applying the site survey data to reconstruct the sequence of occurrence events and flight animation.

This article describes the GIS application experiences and cost-effective processing procedures for ASC investigators. Furthermore, in order for investigators to use GIS easily on investigation tasks, and to dismiss the complicated GIS data edit and management, the authors have developed the programs to translate commercial GIS data formats into the web-based GIS. This article explains several occurrences in the last section.

Keywords: GIS, Aviation Occurrence, Google Earth, Web-Based GIS

I. Introduction

In the past, Geographical Information System (GIS) was one of the complicated, expensive, and user unfriendly systems. But in the last decade, the computer's computing and graphic techniques have rapidly developed so that GIS became a popular technique, and the relevant commercial software with graphic interface, and is easy to adopt into routine transportations. The computer platforms include PDA, mobile phone, and home-used computer, rather than the high-end computer.

"Digital Earth" has developed extremely fast. There are so many resources available on the Internet, i.e., World Wind, Google Map, Google Earth, Virtual Earth, and so on. To date, Google Earth collects worldwide precise satellite imageries, with great computing capability. Anyone with a free browser can access the world via Internet, and the wonderful searching function is based on place name, street, landmark, lat/long position, and specific keywords. In addition, Google Earth provides the interactive functions for users to build-up the place marks, add the transportation paths, and create 3-D models that enhance the GIS applications into a stage of more extensiveness and reality[1].

ASC was officially established on May 25, 1998, and has investigated more than 30 aviation occurrences. From an early stage, GIS had become the on-scene investigative tool, but the massive geo-spatial data meant investigators could only process them on a high-cost computer workstation that was locked by a single license, which prohibited its widespread use at ASC. In the current stage, in order to solve this problem, the web-based GIS became the solution. Google Earth is the platform for ASC investigators to browse the geo-spatial data.

II. Descriptions of GIS applications at ASC

ASC is not only applying GIS to aviation occurrences investigation, but also to validate the investigative authority. Explanations are as follows:

Justify the investigative authority

According to the Aviation Occurrence Investigation Act, Article 6, "W*hen an aircraft occurrence of an aircraft of any nationality arises in the territory of the Republic of China (hereinafter referred to as ROC), the ASC shall undertake the investigation. When an aviation occurrence*

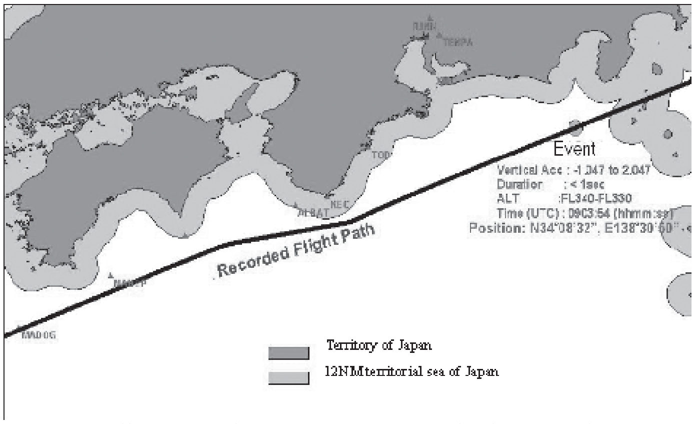


Figure 1. Illustrates the occurrence site in high seas—the investigation authority thus belongs to ASC.

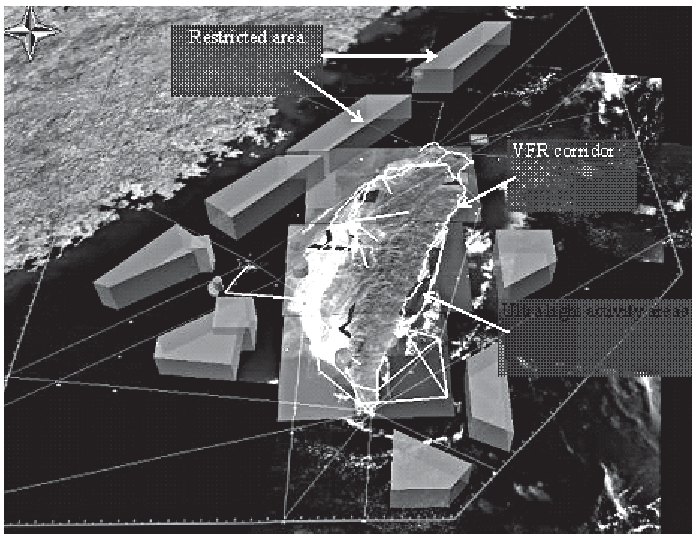


Figure 2. Demonstrates the result of superposing the geo-spatial data (terminal control area, restricted areas, VFR corridors, ultralight activity areas, and radio frequencies).

of an aircraft registered in the ROC or operated by an airline incorporated in the ROC arises on the high seas or in the territory not subject to any state's jurisdiction, the ASC shall undertake the investigation."[2]

On March 28, 2005, 1803 local time (0903 UTC), EVA Air Flight BR2196, an Airbus A330-203, carried 251 passengers and 16 crewmembers from Chiang Kai-Shek International Airport, Taipei, ROC, to Narita International Airport, Tokyo, Japan. The aircraft encountered severe turbulence during its initial descent at an altitude of 34,500 ft. The cabin ceiling of this airplane was damaged; also 46 passengers and 10 crewmembers were injured, including one with a broken neck[3].

After the occurrence notification, ASC obtained the flight data recorder and basic weather forecast information. According to the flightpath of the FDR recording, GIS was used to superpose the waypoints, flight routes, and flightpath. Based on those data, and superposing the relevant Flight Information Regions (FIRs), and the range of the country's territorial sea (i.e., 12 nm), the program can then determine the investigative authority. For example, Figure 1 illustrates the GIS analysis result; the result indicates that BR2196 occurred in high seas and out of Japan's territorial sea, which means the occurrence investigation authority belongs to ASC.

Reconstructing the temporal and spatial relationships of occurrence

The individual clues on the occurrence site will furnish the initial directions for investigation; preserving the evidence at the occurrence site is a key action for further analysis and validation. But the major occurrence site is very difficult to fully preserve, i.e., the airport operator expects to re-open airport operation as soon as possible; aircraft crash site located in the seas or lake with adverse effects, including current and wind. ***"Digitizing the whole occurrence site" is the perfect dream for the forensic investigators!***

The use of computer graphics to reconstruct the events sequence of occurrence (called flight animation) is well known driven by flight data (FDR, QAR), GPS data, and ground-based surveillance radar data[4]. In general, three charts are frequently used by investigators to illustrate the aircraft occurrence site with different scales—occurrence site chart (osc), occurrence perspective chart (opc), and wreckage distribution chart (wdc). The "osc" displays the symbol of north, relative positions of site and nearby airport, access ways, ground navigation facilities, and scale bar. The "opc" presents the flightpath, ground obstacles, terrain profiles, and relevant impact marks or ground scars. The "wdc" shows the locations of major components of the aircraft, with the attribute of damage conditions (failure modes, fire and explosive evidence, and so on.). So, the hand sketches are time consuming and inaccurate. ***GIS is a systemic and sensible tool to record and present the geo-spatial evidence for the forensic investigators!***

In 2004, ASC developed the three-dimensional GIS (3-D GIS) for occurrence investigation, to present the geo-spatial data and assist the visual simulation. Those commercial GIS system assisted programs developed by ASC investigators could handle different formats of the terrain data, 3-D display of massive satellite images, superposing the occurrence survey data—treetops, ground scars, flightpath (based on FDR, GPS, or radar data) and interactive to visualizing the occurrence geo-data together. ***3-D GIS became the powerful tool to present the sequence of occurrence events.***

Relationship of flightpath and LLWAS data

A windshear alert system for low level horizontal windshear is disclosed. The ground-based Low Level Windshear Alert System (LLWAS) is based upon a network of anemometers placed near runways throughout the geographic area covered by an airport, for the purpose of detection of low-level horizontal windshear and microbursts. Typically, LLWAS consist of 12 to 16 anemometers placed near runway areas and extended to cover about 3 nm. To date, there are two LLWAS installed in Taiwan's civil airports—Taipei SongShan Airport and Taiwan Taoyuan International Airport[5].

In past occurrence investigations, weather-related occurrences were complicated to analyze, such as the relationships of surface winds, flightpath drift, and an aircraft's lateral operation. ASC has been using a module called "tracking analyst" under the ArcGIS platform to dynamically present the multiple anemometers data of LLWAS and 3-D flightpath. The 3-D flightpath is then reconstructed from FDR recorded parameters (ground speed, magnetic heading, drift angle, altitude). All of the FDR recorded parameters are selectable to dynamic link with geo-spatial data (satellite images, terrain, ILS beams, weather charts, Jeppesen charts). Figure 3 illustrates the LLWAS

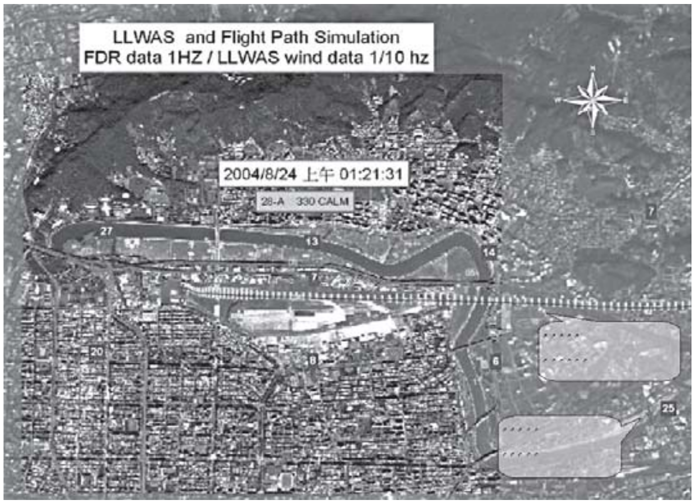


Figure 3. Superposition of LLWAS data and flightpath (an MD-82 encountered severe windshear at 120 ft AGL).

data of SongShan Airport. The data will update every 10 seconds, and the 3-D flightpath will update every 1 second. The entire superposing of GIS data is programmable to display or change the levels of transparency[6].

Therefore, integrating the 3-D flightpath and LLWAS data is useful to evaluate the aircraft's maneuvers dynamically, especially for conditions the FDR does not record—the wind, windshear, or gust exist on the final approach routes and the flightcrew and onboard doppler radar can not detect and pre-caution.

Digitizing the charts of aeronautical information publication

The Aeronautical Information Publication (AIP) is a publication issued by or with the authority of a state and contains aeronautical information of a lasting character essential to air navigation. AIP is designed to be a manual containing thorough details of regulations, procedures, and other information pertinent to flying aircraft in the particular country to which it relates. The structure and contents of the AIPs normally have three parts—GEN (general), ENR (en route), and AD (aerodromes). The document contains many charts; most of these are in the AD section where details and charts of all public aerodromes are published.

For the purpose of occurrence investigation, those charts related to en routes and aerodromes are difficult to analyze because they are without the standardized tools to superpose with weather data and flight data. Figure 2 demonstrates the ASC developed tool, to superposing the geo-spatial data (terminal areas, VFR corridors, ultralight activity areas, and restricted areas).

In 2002, ASC contracted a project to translate Taipei FIR AIP into GIS layers, which were accessed by en routes, airport codes, or pre-selected attributes. Those Taipei FIR AIP data are compatible with commercial GIS platforms (Mapinfo, ArcGIS, Global Mapper, etc.). In 2006, most of Taipei FIR AIP data were translated into KML format, which is a new standard format of the web-based GIS.

Figure 4 shows the 3-D GIS results of ArcGIS and Google Earth. The geo-spatial data of Taipei FIR includes waypoints, airways, VFR corridors of helicopters, restricted areas, and ultralight activity areas. In Figure 3, the basic satellite maps consist of LandSat downloaded images (ground resolution about 15 meters[7]), and precise SPOT-5 images (ground resolution 2.5 meters). All of those layers are independent to access and modification. The relevant attributes of Taipei FIR are available to click via the mouse's function.

III. Advanced applications of Google Earth

Google Earth combines the power of Google Search with satellite imageries, maps, terrain, and 3-D buildings to integrate the worldwide GIS data at your fingertips so that the forensic investigators can import interesting place marks, site images, and 3-D models into Google Earth using the self-developed programs to batch import the geo-spatial data with KML or KMZ formats. The practical problems and solutions are described as follows.

Coordinate systems conversion

In Taiwan, most of GIS data are based on geodetic coordinate systems of TWD 67, TWD 97, and WGS84; but Google Earth only accepts the WGS84. Therefore, any users of Google Earth need to find or self-develop the multiple coordinates conversion program to overcome this problem. To date, ASC has developed a program to convert the coordinate systems among TWD67, TWD97, UTM, and WGS84[8].

KML/KMZ format and translation

KML (Keyhole Markup Language) is an XML-based language for managing three-dimensional geo-spatial data in the program of Google Earth. The word Keyhole is an earlier name for the software that became Google Earth; the software was produced in turn by Keyhole, Inc, which was acquired by Google in 2004. The KML file specifies a set of features (place marks, images, polygons, 3-D models, textual descriptions, etc.) for display in Google Earth. Each place always has a position (longitude and latitude). Other data can make the view more specific, such as tilt, heading, and altitude—which together define a "camera view." KML files are very often distributed as KMZ files, which are zipped KML files with a .kmz extension.

There are two commercial software programs available to translate the GIS data into KML format. ArcGIS version 9.2 or higher[9] allows users to export GIS data in KML format for viewing in the Google Earth. Any geo-spatial datapoint, polyline, or polygon dataset, in any defined projection, can be exported. Features of export to KML can be exported as either 2-D features or 3-D features "extruded" upwards by an attribute or z-value. The stand-alone program called "GPSBABEL"[10] can convert waypoints, tracks, and routes between popular GPS receivers and mapping programs.

In Taiwan, many general aircraft, national aircraft and ultralight aircraft have installed the handheld GPS receiver, so the "GPSBABEL" is a great tool to download and convert the flightpath of GPS data into KML format.

3-D modeling of Google Earth

Recently, there have been many free 3-D models available for Google Earth, such as famous buildings in the world, specific models (aircraft, ground obstacle, airport terminal building, wreckage), and transportation builds (train stations, airports, harbors). All of those 3-D models could be searched and downloaded free from the website of 3-D Warehouse (http://

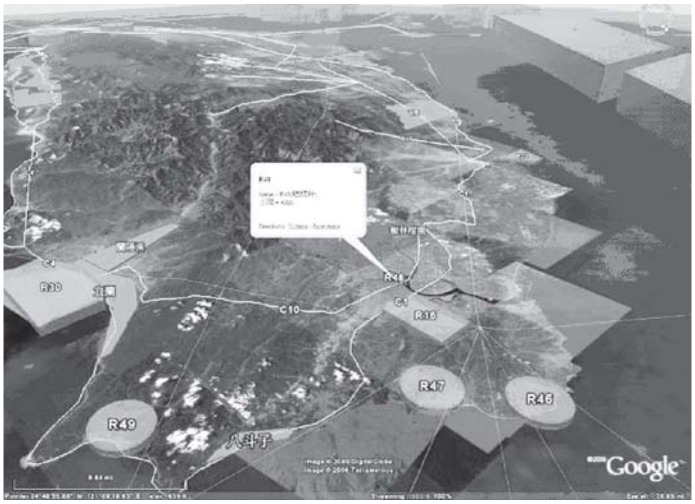


Figure 4. Demonstrates the web-based GIS result of superposing the geo-spatial data (satellite imageries, terrain, waypoints, airways, restricted areas, VFR corridors, and ultralight activity areas).

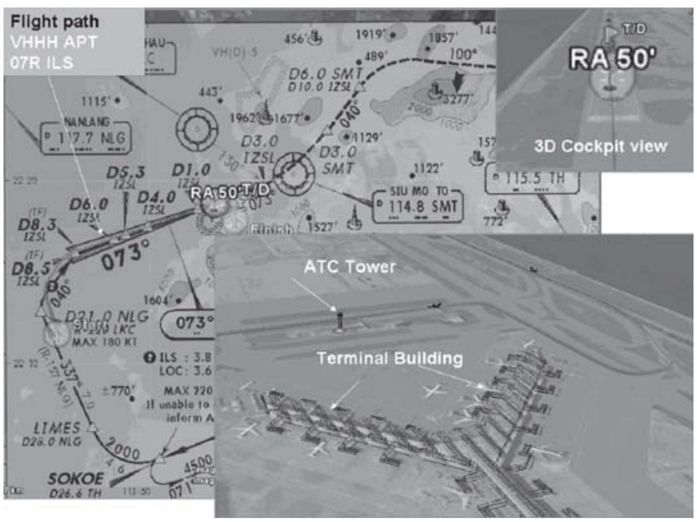


Figure 5. Superposition of flightpath on the Jeppesen chart with 50 ft and T/D place marks and 3-D building models.

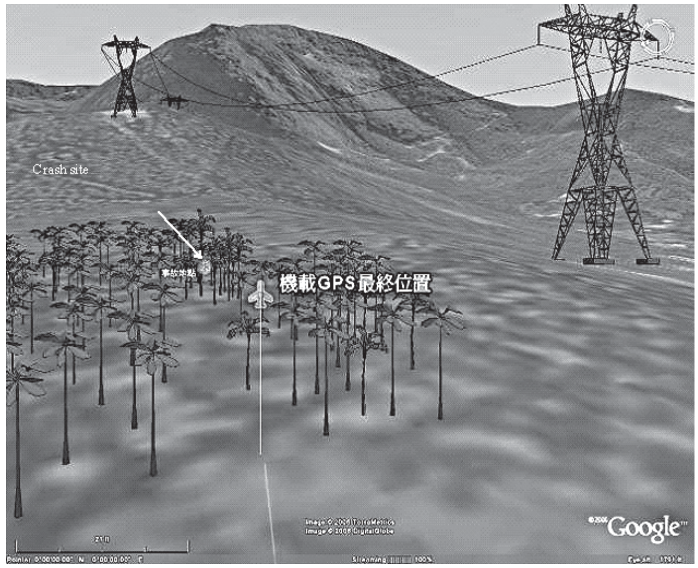


Figure 6. Illustrates the aircraft crash site environment using web-based GIS.

sketchup.google.com/3-Dwarehouse/). But the latest version, 4.x, of Google Earth has not yet provided the 3-D modeling functions, so it needs another program—"Google SketchUp" to create and translate the 3-D model into Google Earth. Google SketchUp version 6 is a 3-D modeling software tool that allows designers and planners to explore, communicate, and present complex 3-D concepts. Its import and export capability gives you the speed and functionality for use in a professional workflow.

IV. Results and discussion

Application in the terminal area of the airport

Most typical aviation occurrences take place in the terminal area of the airport, sometimes accompanied by thunderstorms or slippery runway conditions. From the flight operational point of view to an occurrence investigation, those essential questions include Which approach mode (IFR or VFR) was selected by the flight crew? Which one of the Jeppesen charts was applied? Between the approach path of 1,000 ft AGL and 50 ft, did the aircraft pass though the runway threshold higher than 50 ft? Where was the touchdown point? How to identify the ground scars and tire marks that had remained on the runway surface or mud grass?

According to the reliable and accurate flightpaths, investigators could answer those questions mentioned above, but they need an interactive platform to integrate all of the factual information in order to validate those answers. Now, Google Earth provides the major features to align with imported flightpaths, (a) add several place marks, i.e., deviated altitude and airspeed from reference glide path, aircraft relative position when radio altitude is 50 ft, touchdown point and tire marks on the runway; (b) image overlay, i.e., doppler weather radar chart, weather satellite image, and Jeppesen charts. All the image overlays are determinated by two known positions, but if the original chart is without the position information of latitude and longitude or is not the WGS84 coordinate system, it could be inaccurate to superpose with Google Earth's build-in image and terrain; (c) create and import the simple 3-D models, i.e., terminal building, tower, ground facilities, FIR models, and relevant aircraft models. Therefore, ***KML is similar to HTML and allows users to edit the "virtual" occurrence site via available factual data to evaluate the sequence of occurrence events***.

Figure 5 shows the flightpath of an MD-90 approaching Hong Kong international airport via Runway 7R. The place marks and 3-D models include the place marks of the 50 ft and touchdown point, the Jeppesen ILS chart, the ATC tower, and terminal building.

Applications in the crash site

When an aviation occurrence occurs in the mountain area, the initial stage of investigation will be to survey the wreckage distribution, the fire burned areas, and impact marks on the treetops and terrain surface. According to the site surveying data, the investigators could determinate the aircraft's final maneuver. Did the aircraft collide with the terrain at high or low speed? The follow-up could launch the investigation directions on weather, maintenance, flight operational, and structural or engine failure, etc.

The process to reconstruct the sequence of occurrence events is very tedious, time-consuming, and wastes computer resources. Google Earth handled the most complicated data of satellite imageries and terrain data, it allows the user to create the 3-D models, then superpose them with collected geo-spatial data. For instance, building the electricity tower patterns nearby the aircraft crash site, in which the electric wires are immediately connected between the electricity towers. Finally, based on site surveying data (collected by differential GPS and a laser-ranging device) the treetops, broken wooden geometry, and 3-D flightpath are reconstructed (see Figure 6, page 49).

Conclusions

The objective of occurrence investigation is to prevent recurrence of similar occurrences. It is not the purpose of such investigation to apportion blame or liability. Therefore, developing investigation techniques shall have the features of reliability and practicality that lead individual evidence to present consistent analysis result. ASC continues to develop the GIS and flight animation system. The results show that web-based GIS has become the important platform to evaluate the sequence of occurrence events, where the investigator could interactively browse the geo-spatial data on PC, with the features of portability and 3-D visualization.

There are two major concerns for further development of the web-based GIS to assist the aviation occurrence investigation system—(a) improving the KML or KMZ manual translation into batch processing of the geo-spatial data, and (b) enhancing the functions of the geo-data dynamically play back and integration, etc. ◆

References

1 Technical Paper, "Things You Should Know About Google Earth," Educause Learning, 2006.
2 "Aviation Occurrence Investigation Act," Aviation Safety Council, website: http://www.asc.gov.tw/prescript_files/aoia(1).pdf.
3 Occurrence Press Release, "EVA Airways Flight BR2196 A330-200 Encountered Turbulence During Descent at an Altitude of 34,500 Ft," website: http://www.asc.gov.tw/asc_en/accident_list_2.asp?accident_no=109.
4 Neil Campbell, "Flight Data Analysis Using Limited Data Sets," 2004 International Society of Air Safety Investigators Seminar, Aug. 2004, Canberra, Australia.
5 Wen-Lin Guan1 and Kay Yong, "Review of Aviation Accidents Caused by Wind Shear and Identification Methods," Journal of the Chinese Society of Mechanical Engineers, Vol. 23, No. 2, 2002, Taipei, Taiwan.
6 Tian-Fu, Yeh, Ming-Hao, Young, and Wen-Lin Guan, "Applications of Remote Sensing Techniques into the Aviation Occurrence Investigation," 2005 Intelligent Transportation Society Conference, Aug. 2005, Shanghai, China.
7 Landsat satellite image download website: https://zulu.ssc.nasa.gov/mrsid.
8 Tian-Fu, Yeh, Ming-Hao, Young, and Wen-Lin Guan, "Developing and Applications of the Multi-Coordinate Translations for the Purpose of the Aviation Occurrence Investigation," 2004 GPS Application Conference, Nov. 2004, Tainan, Taiwan.
9 ArcGIS Data Export tool, website: http://arcscripts.esri.com/details.asp?dbid=14273.
10 GIS Data Export into Google Earth Tool, website: http://www.gpsbabel.org.12NM territorial sea of Japan.

Use of Reverse Engineering Techniques To Generate Data for Investigations

By Peter Coombs, Senior Inspector of Accidents, AAIB, U.K.

***Peter Coombs** has served as an engineering investigator with the U.K. Air Accidents Investigation Branch since 1972. He has investigated accidents and incidents to most classes of aircraft including large public transport airliners, transport helicopters, military combat aircraft, and many general aviation types. Before joining the AAIB, he trained with the British Aircraft Corporation, gaining experience in manufacture, development and maintenance on a variety of airliner types. He then became a design engineer on the Concorde SST. He gained a master's degree in aircraft design in 1971 and holds pilot's licenses on single and multiengined GA aircraft and helicopters. He is also a flying instructor.*

Figure 1

Background

Accident investigation has traditionally relied on a variety of sources of evidence. One of the most important has been analytical data supplied by type certificate (TC) holders or original equipment manufacturers (OEMs).

Such information is particularly important in those complex investigations involving structural failure. A number of problems with these sources of data have, however, been encountered in recent years.

With mature aircraft types, archived design data in the possession of TC holders may not be readily accessible. If it is available, it may be in a form not easily identified, understood, and manipulated by their structural, aerodynamic, or systems specialists. These people will probably be more used to operating with state-of-the-art design tools. They are often inexperienced in the use of earlier methods of technical analysis and design data recording systems, routinely utilized in the past in the development processes of aircraft and their components. This assumes that the relevant data can actually be located and identified, a situation which cannot always be guaranteed.

A process of "corporate amnesia" has become common amongst manufacturers, brought about by lengthening aircraft service lives and shortening career spans of design/development engineers within one employer. Some manufacturers seek out long retired engineering specialists to attend meetings with investigators in often vain attempts to recapture long forgotten design data. Others seem reluctant to part with information they probably possess, either because they find it technically embarrassing in the context of the accident or for reasons about which we can only speculate. The problem seems to be at its greatest when the accident under investigation occurs far from the home territory of the type certificate holders.

The above phenomenon can be unfortunate in circumstances where the compliance of the subject aircraft with the design requirements, or in some respects the adequacy and relevance of those design requirements to the accident circumstances, have come into doubt.

On a number of recent investigations, where structural failures have occurred, a process of "reverse engineering" has been carried out by the AAIB, under the supervision of the author, to combat these difficulties. This has been done in order to establish important parameters that might previously have fallen in the province of the type certificate holder, but where inadequate data have come from that source.

The two investigations summarized here have been to aircraft in very different categories, suffering very different accident causes. Similarities in the investigative process for each were, however, considerable.

The first of these events was to a medium-sized, offshore, public-transport helicopter. This suffered a lightning strike resulting in damage to a composite tail-rotor blade, which ultimately led to failure of the tail rotor gearbox attachment making continued flight impossible.

Although the gearbox fell from the pylon at the end of the flight, somewhat miraculously the hydraulic pipes did not initially fracture. Instead, they continued to support the mass of the gearbox for a brief period. This preserved the longitudinal balance of the aircraft, enabling a successful autorotation to take place into a rough sea. Shortly afterward, the pipes failed and the gearbox fell away and sank to the sea bed. The aircraft drifted downwind until it also sank. Figure 1 shows the aircraft some time between the loss of the gearbox and the final sinking, shortly after all the passengers and crew evacuated.

The occupants escaped by dingy and were subsequently rescued. Surprisingly, we were successful in recovering both airframe and tail rotor gearbox from two separate locations, both at depths in excess of 700 feet (see Figures 2 and 3).

Recordings of the timing and location of the critical lightning strike were obtained using meteorological recording equipment, as was a time referenced recording of the final radio distress call,

Figure 2

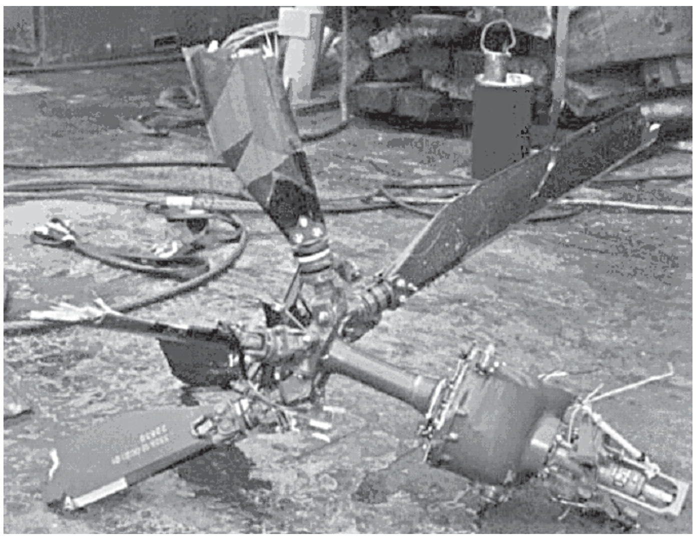


Figure 3

made as the aircraft ditched, following the failure of the normal tail rotor gearbox attachment.

The second accident was a fatal event to a four-seat metal GA aircraft, which suffered the unusual phenomenon of a failure of the outboard section of a wing, in a download sense. This occurred while flying in smooth air in daylight visual meteorological conditions. The wreckage is shown in Figure 7, and an aerial view of the separated wing is shown in Figure 8.

A good quality radar recording and a reliable meteorological after-cast enabled the airspeed history to be calculated with an acceptable degree of accuracy. It was noted with some concern that the speed, at the time of the failure, was significantly below the maneuver speed of the aircraft.

Both investigations resulted in development of methods that could be utilized in whole or more probably in part during future investigations, regardless of the size of aircraft involved. Both investigations required precise assessment of strength and loadings in localized areas of structure.

The first also required assessment of loading applied as a result of tail rotor imbalance acting in conjunction with the dynamic response characteristics of the tail boom and pylon structure of the rotorcraft. These characteristics significantly raised the stress levels in the gearbox attachments resulting from rotor imbalance.

The second investigation, to the GA aircraft, took advantage

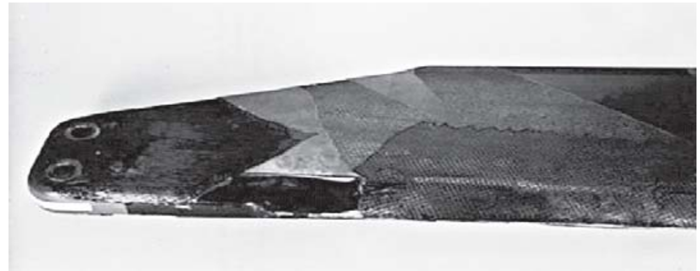


Figure 4

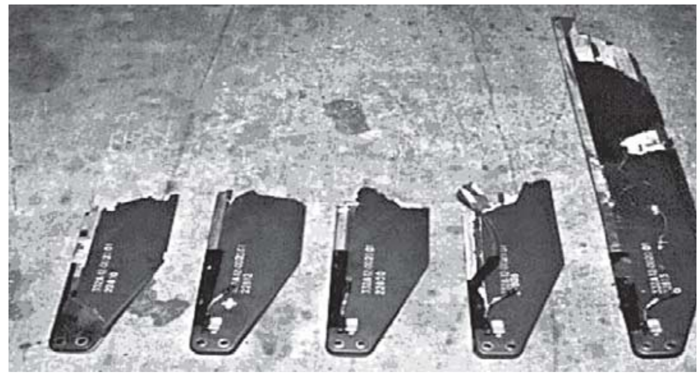


Figure 5

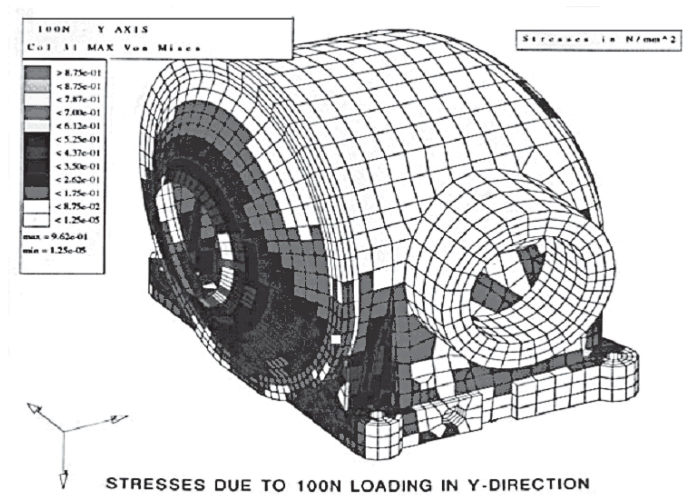


Figure 6

of state-of-the-art techniques to establish structural strength and aerodynamic loading figures. These were thought to be more accurate than those available to the original aircraft designers.

The expertise required to carry out the detailed calculations in support of these investigations was provided by a number of specialist analytical companies in the U.K. These have generally grown up during the past 25 years. In addition, a U.K.-based, internationally known academic establishment also supplied such assistance. The latter has a wide range of expertise through areas of structural design, flight mechanics, simulation, and dynamic load analysis. The specialist companies provide expertise in areas ranging from finite element (FE) analysis to structural dynamics. One has specific experience on maneuver load analysis of fast combat jet aircraft. They act as contract engineers to both major aircraft manufacturers and to other specialist aeronautical engineering companies in Europe and North America.

Figure 7

Figure 8

The accidents

The helicopter, an AS 332, lost part of a composite tail rotor blade as a result of a lightning strike while descending to an offshore rig. Subsequent impact destruction to the remainder of the blade (see Figure 4), as the rotor struck the tail boom during gearbox separation, disguised the amount of initial lightning damage. It can be seen in Figure 5 that four of the blades have been destroyed by this same impact mechanism, although only the one on the left has any evidence of the earlier lightning damage.

It was required to establish the level and degree of initial lightning damage on this single blade in order to determine the severity of the lightning strike that the blade suffered. This was necessary to establish the practical validity of the lightning certification requirements to which the aircraft had been qualified. The loss of the machine had cast considerable doubt on the adequacy of those requirements. It was feared that aircraft operating at low levels, in winter, in the temperate maritime conditions over the North Sea, were especially vulnerable. At the time, this was the busiest area of offshore, long-range, public-transport helicopter operation in the world.

Tests on a number of ex-service blades were carried out at a lightning test facility to establish the extent of damage inflicted by differing degrees of intensity of lightning strikes.

It was found, from wreckage examination, that imbalance following the strike had created sufficient vibration to cause one of the three gearbox securing bolts to slacken. This both concentrated cyclic bending on only two attachment lugs and altered the natural frequency of the tail boom/gearbox combination. This alteration brought this structural frequency (in cycles per second) close to the rotational speed of the unbalanced rotor with the damaged blade (in revolutions per second).

A finite element analysis of the gearbox was carried out using actual measurements of the casting to create the grid. In Figure 6, you see one of the visualizations of the gearbox showing the varying stress distribution for a unit loading. The number of cycles to failure was known, since the times of both the strike and the final gearbox separation were known from recordings. The initial event time was identified precisely using the atmospheric lightning recording equipment available to the U.K. Met Office, while the failure time was established approximately from timing of the final VHF crew distress call. The rotor speed was known from aircraft data. From these items of information, it was possible to calculate the amount of imbalance that provoked the gearbox fatigue failure and must, therefore, have been brought about by the lightning damage.

When first calculated, however, without considering the dynamics of the tail boom, the mass loss from the blade, to create this imbalance, was found to be slightly more than that resulting from damage clearly caused finally by the collision between the blade and the tail boom. See again Figures 4 and 5. This damage had quite clearly only occurred as the gearbox separated, some minutes after the strike; something was undoubtedly wrong with the calculated result.

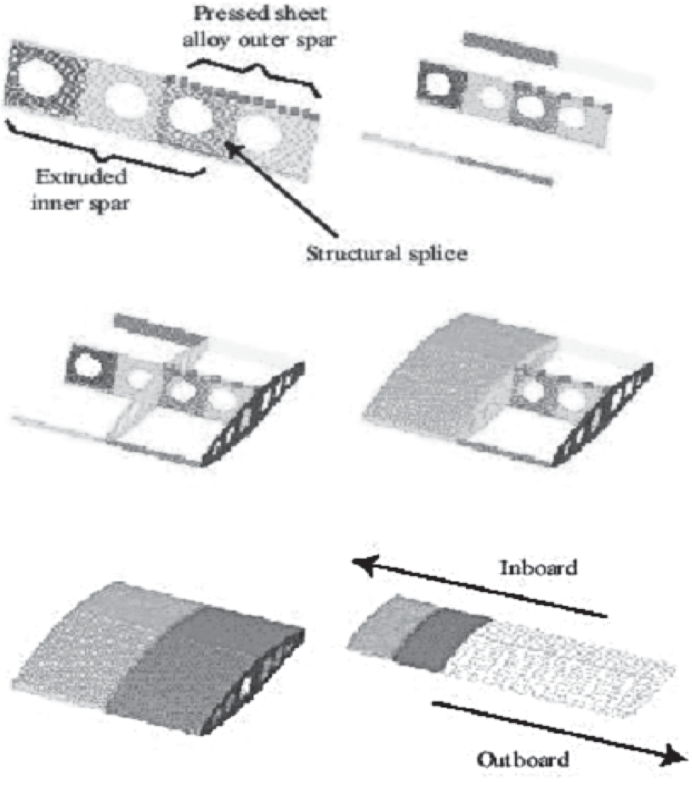
It was, therefore, decided that the dynamic characteristics of the tail boom/gearbox combination would be evaluated theoretically. This work was carried out using a manufacturer's dimensioned layout drawing of the tail boom and skin thickness measurements made on the damaged boom by ourselves. The mass of the gearbox was determined simply by weighing the salvaged unit.

The new calculated tail boom dynamic characteristics were confirmed by a resonance test of the rear structure of an in-service aircraft while on the ground and were further corrected theoretically for the predicted effect of a single, loose tail rotor gearbox attachment. By this means, it was determined that the natural frequency of the rear of the aircraft in cycles per second almost matched the rotor speed in revs/second. The cyclic forces applied to the two effective tail rotor gearbox attachments were thus found, as a result of these close frequency similarities, to be far greater than those initially calculated without taking account of the dynamics of the tail boom.

Only a small mass loss resulting from the lightning strike was now required to create loading to cause failure in the known time, and a realistic assessment of the pure lightning damage required to cause this loss could be made. By comparing this calculated mass loss with the damage inflicted by lightning tests on used blades, carried out earlier, using known electrical intensity characteristics, it was possible to determine the approximate magnitude of the lightning strike.

This, although confirming that the certification requirements then in force were realistic in terms of magnitude for that flight environment, revealed significant drawbacks in the aircraft's design process. It showed that the practical effects of bolt slackening under vibration loading, together with the similarity of natural frequency of the structure to the rotor speed, had not been adequately taken into account at the design stage. Certification compliance merely called for an absence of severe structural damage in (static) lightning test conditions. It did not call for a full assessment of the structural behavior of the rotor system and mounting after the limited lightning damage had occurred. No such assessment had apparently been carried out on this aircraft type.

In the case of the GA aircraft, a PA28R-200-2, a finite ele-



Build-up of structural components for Finite Element (FE) model

Figure 9. Finite element analysis visualization.

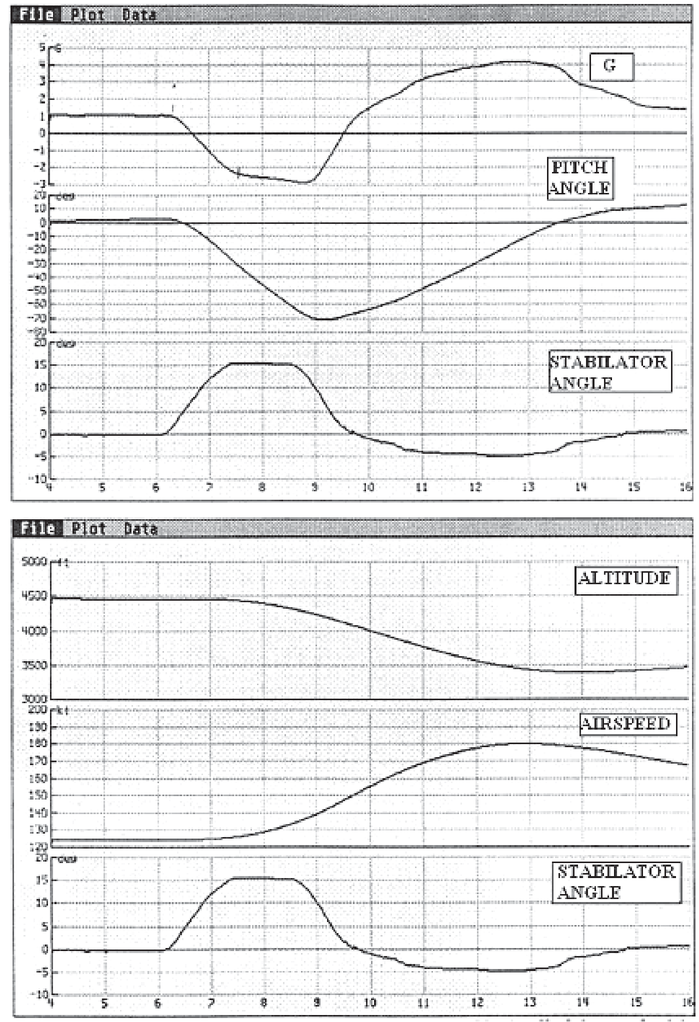
ment (FE) model of the wing bay in which the failure occurred was created using a manufacturer's layout drawing and measurements of panel thickness made on the separated wing and a further sample wing. Figure 9 shows a visualization of the model.

An evaluation of control responses was carried out, using a simple simulator, programmed with a modified NASA computer model of the aircraft type. This was done to produce a realistic series of control column displacement-time histories of pitch control inputs, creating a series of wing download-time (negative G) histories as well as other flight parameters. The control input/time sequence for the most severe effect, which seemed a reasonable pilot action, is shown in Figure 10.

The span-wise negative lift distribution was calculated and converted to engineering units. The time history resulting in the highest negative load factors achieved in the simulation series was then used to factor the distributed forces. The result was used as the varying aerodynamic force/time input to evaluate the behavior of the FE model under a varying download.

On carrying out this exercise, it was found that the theoretical wing strength from the FE analysis was far in excess of that required to carry the highest loads implied by the results of the simulations.

Up to this point, only symmetrical pitch maneuvers had been considered. It was realized, however, that even with those forces calculated for such maneuvers acting in unison with forces resulting from a large simultaneous roll control input, the load to fail the wing could not reasonably be approached, still less achieved. The reason for the wing failure thus remained entirely obscure.



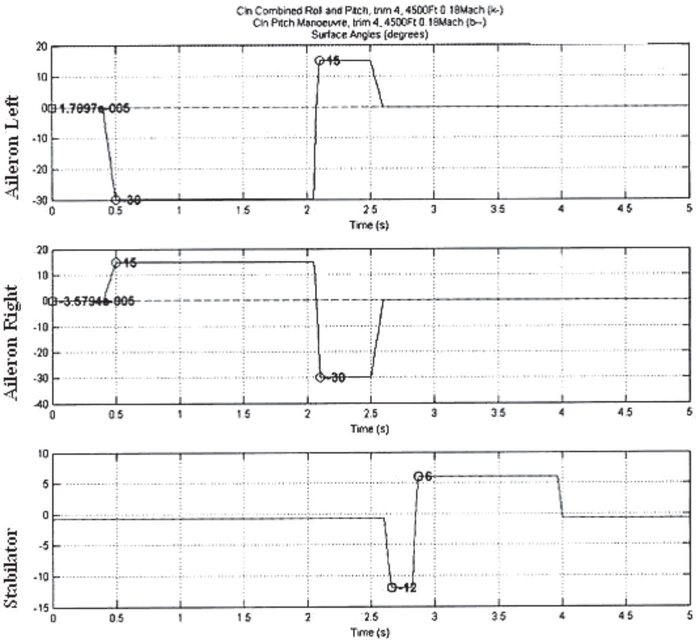
Calculated aircraft response - 15° stabilator angle for 3 seconds

Figure 10

A review of assumptions made to create the finite element model was then carried out; with a number of more pessimistic assumptions applied, the reduction in wing strength was still insignificant.

At this point, further specialist assistance was sought. The company consulted drew attention to the significance of inertia effects created by rapidly reversed control inputs. It was able to estimate the approximate mass distribution of the wing structure and also to create a NASTRAN/PATRAN model of the machine, entirely by measurement of a real example and use of published data relating to the type. This enabled maneuver loads to be calculated for continuously varying pitch and roll displacements. It proved possible then to create a maneuver/time history that resulted in failure of the finite element model as a result of full simultaneous pitch and roll control input, followed immediately by complete reversal of control inputs in both axes. Under these influences, failure loads at the wing station where the actual aircraft structure failed could just be reached at the known airspeed. The control input-time histories are shown graphically in Figure 11. Visualizations of the failure modes are shown in Figures 12 and 13.

Calculation of control forces at this speed indicated that these



Control input sequence which resulted in very high wing loads in a downwards direction

Figure 11

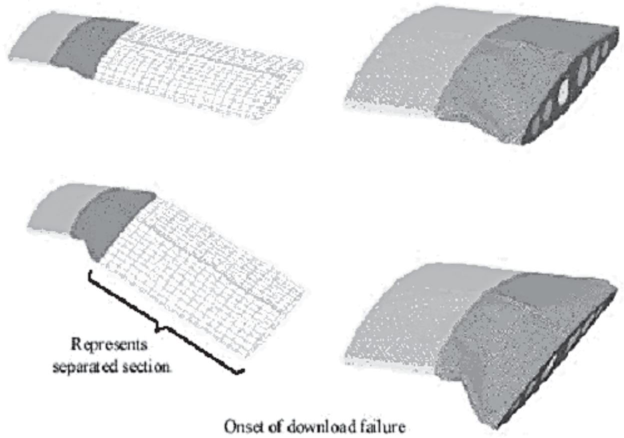


Figure 12. Finite element analysis visualization.

were sufficiently low to enable them to be easily generated by a front-seat occupant. (Control gearing was established by simply measuring control surface angular movement for corresponding control wheel travel on an example of the type borrowed for measurement purposes).

A persuasive scenario to explain the occurrence, based on the nature and seating position of the aircraft occupants, in this dual control machine was then devised.

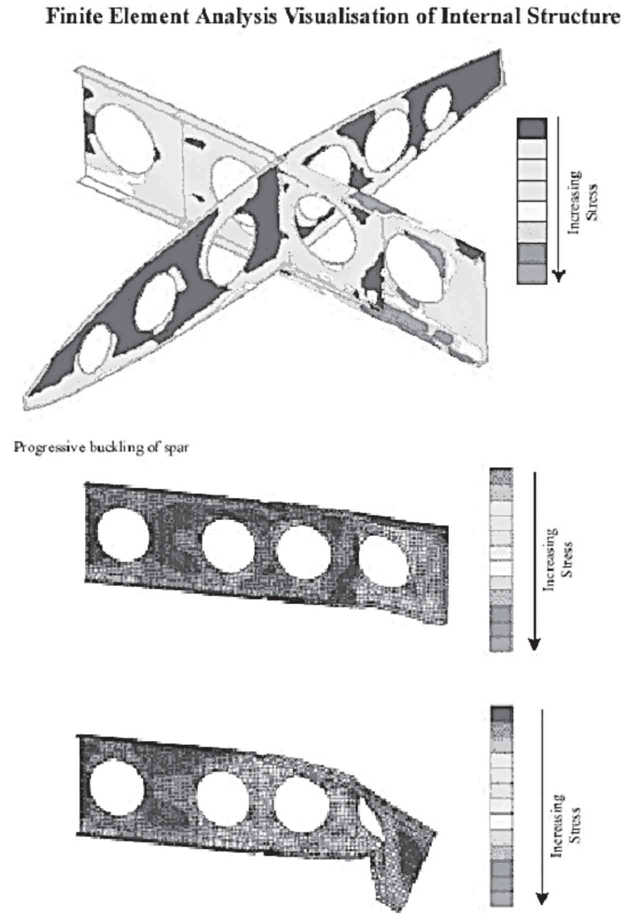


Figure 13. Finite element analysis visualization of internal structures.

Conclusions

These two investigations demonstrate the way in which capabilities from partners outside the normal areas of expertise usually called upon by investigators can be harnessed to replace data more usually found from OEMs and TC holders when such data are not readily available. Although the absence of manufacturer's data may seem at first a great handicap, the ever-increasing power of modern computers and the rising sophistication of commercially available analytical packages compensates for much of this loss. It enables data to be generated and manipulated, which produces results that are no less accurate than those achieved in the past by OEMs. These will have used methods that were state-of-the-art at the time of the aircraft's initial design but may be two or more decades old at the time the accident occurs.

Investigations carried out using such methods present a challenged to the manufacturers that frequently reengage more fully when they see that official investigative bodies are serious about finding the root causes of such intricate accidents. ◆

Using Checklists as an Investigator's Tool

By Al Weaver

Al Weaver (MO4465) is a Sr. Fellow emeritus having retired from Pratt & Whitney after a long career in promoting flight safety initiatives and expertise in accident investigation. He currently teaches the Gas Turbine Accident Investigation Course for the Southern California Safety Institute.

Abstract

This paper illustrates the importance of utilizing checklists to identify and interpret evidence in accident investigations. The author has chosen to illustrate this technique relative to the powerplant investigation following an aircraft crash. The use of checklists will be shown to ensure a comprehensive and quality examination of the powerplant system in the accident chain. Checklists can also be an effective way to share sound investigative techniques and to promote standardization.

The objective of the engine specialist's investigation into an aircraft accident is not solely to determine whether the powerplants were or were not involved in the causal chain. The specialist can learn much from the powerplants relative to the events that have occurred to the aircraft itself prior to the impact with the ground. Because of its nature, the gas turbine and its powerplant system act much like the photographer's image plate or film in capturing major events associated with the crash. This important effect will be one of the key points in the illustration of the use of checklists as an investigating tool. In fact, the checklists provide an essential guidance on how to read and interpret the information obtained through the examination of the powerplant wreckage.

Let's start with the basics relative to the accident. During the powerplant investigation, the engine specialist is expected to provide the answer to some key questions, which are listed in the "Basic Need-to-Know" checklist (Figure 1).

Additionally, the investigation of the powerplant must be integrated in the general investigation of the accident, and this requires an adequate coordination. The following checklist illustrates some tasks that may overlap with the activity of other groups within the investigation team (Figure 2). The coordination work is usually a responsibility of the investigator-in-charge, and the system experts must be aware that every step in each specialist investigation should be taken in accordance to the overall investigation plan.

To conduct the field examination, recovery, and laboratory teardown examination of wreckage parts, it is necessary to make an inventory of the components already found and those still to be recovered. The following checklist identifies the components to be examined by the engine specialist (Figure 3).

The "Inventory of Powerplant Components" checklist is typically the most time consuming in a crashed plane environment, because some of the parts may not be readily available or unrecoverable. In most cases the same information can be extracted from different parts, so the investigator can work around missing components. Only when subsequent pointers are developed the engine specialist finally decides that the locating and recovery of a missing component is absolutely critical to the investigation.

For the most part, the checklist items illustrated above are general in nature and their applicability while being typical may not be universally appropriate to a specific accident investigation need.

Let's go back to the "Basic Need-to-Know" checklist for further discussion. Each item in the list can be expanded into more detailed checklists to guide the expert in the in-depth investigation.

One of the most important tasks for the engine specialist is to determine the thrust available during the last moments of the flight. An essential step in this analysis is the assessment of the rotational speed of the engine components at impact, as detailed in the following checklist (Figure 4). The typical damage patterns for each condition are easily recognizable in Figures 5, 6, and 7. It should be made clear that these pictures are examples of extreme conditions and that the interpretation of the evidence is usually not as straightforward.

All information regarding the thrust setting must be correlated with expected aircraft operation leading up to the accident. Any difference from expectations usually acts as an indicator that a more in-depth investigation is necessary.

Once the "Basic Need-to-Know" questions have been answered, the specialist investigator can assist the overall team by assessing the principal pitch and roll axis of the plane at impact from the engine damage as mounted on the aircraft (Figures 8 and 9). The typical compact and robust construction of the engine casings is ideal for assessing major ground impact vectors and clock positions. In multiengined aircraft, a comparison of the differences in damage on each engine helps in the assessment of pitch and roll at the instant of the impact with the ground. This basic and easily available data from an initial examination can serve as a quick pointer to the general type of event, i.e., whether the crash was the result of an aircraft upset or it was a controlled flight into terrain (CFIT) type accident.

Throughout the investigation, the powerplant specialist will be looking for evidence of any malfunctions that may have contributed to the accident. If the engine is believed to have played a role in the causal chain, then significant contributing factors need to be considered. This in-depth investigation calls for more specific checklists that help the investigator in focusing on the peculiarities of each scenario (Figures 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19).

The utilization of the above checklists will go a long way in serving to standardize the specialist groups' examinations and work process. The investigator-in-charge will welcome the thoroughness of the portion of the investigation, However, simply following the checklist does not become a substitute for the need for expertise in understanding how to interpret the findings toward a checklist.

Figure 1. Basic Need-to-Know
- Position of the engine controls
- What thrust or power was being produced
- What malfunctions occurred
- What were the indications to the crew

Figure 2. Overall Investigation Plan
- Maintenance and material records
- Photography
- Field examination
- Recovery as necessary
- Laboratory teardown as necessary

Figure 3. Inventory of Powerplant Components
- Inlet
- Nacelle (including reverser where applicable)
- Fan
- Compressors
- Burner
- Turbines
- Exhaust
- Externals

Figure 4. High- or Low-Speed Checklist
- Blade airfoils

—High speed if broken into small pieces
—Low speed if complete in length
- Splaying or bending of blades to either side

—Low speed
- Spiral bending

—High speed
- Blasted appearance to airfoil edges

High speed

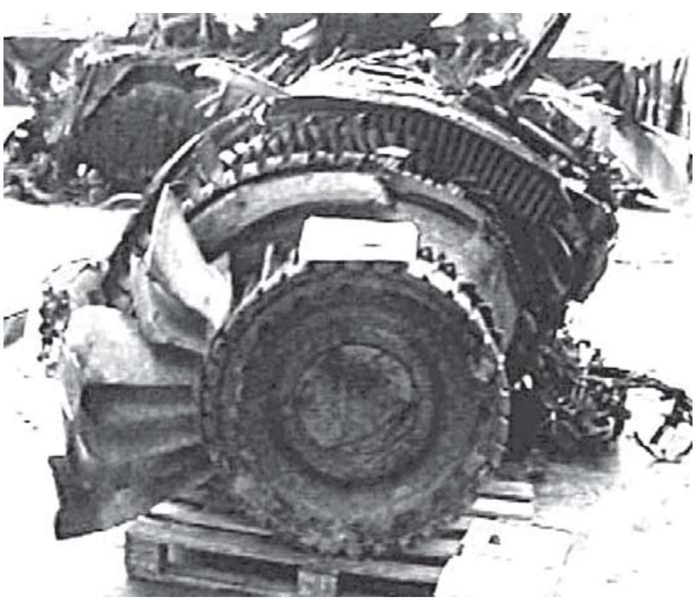


Figure 5. High-speed damage.

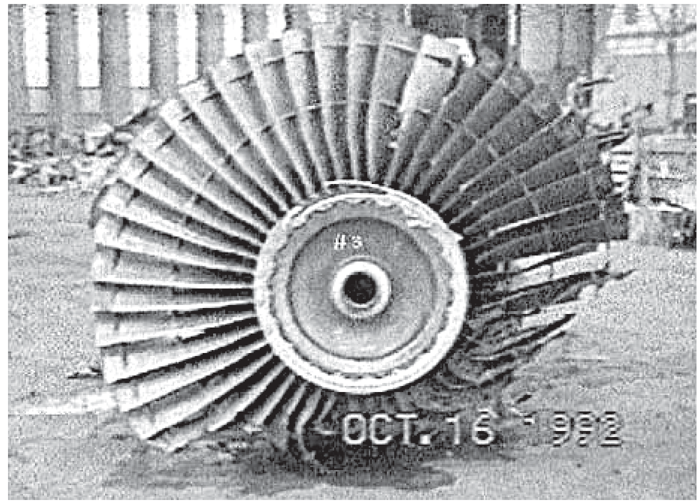


Figure 6. Low-speed damage.

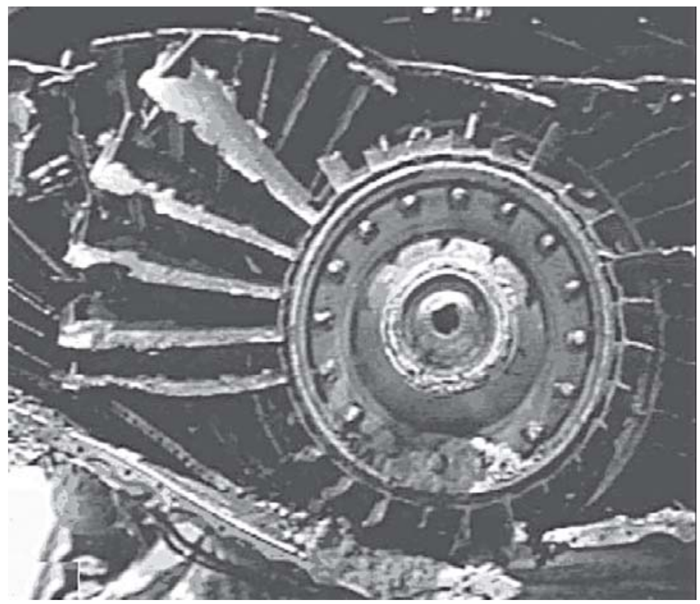


Figure 7. Low-speed impact superimposed on high-speed damage.

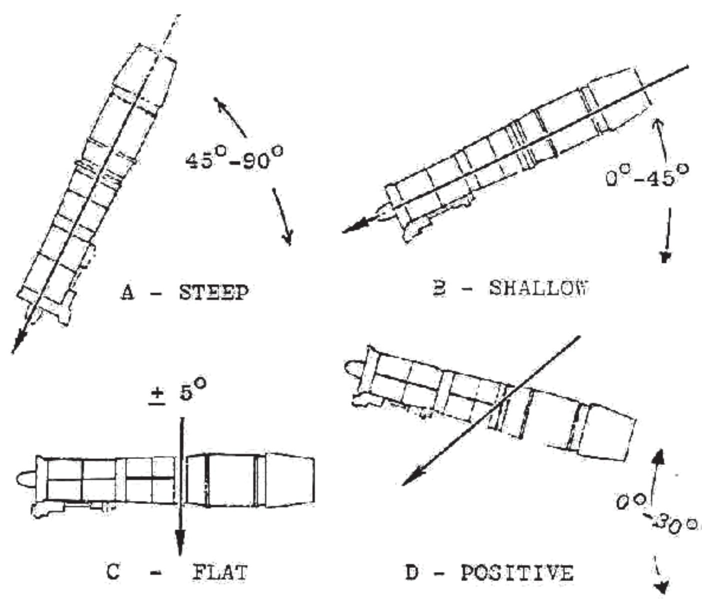


Figure 8. Angle of impact effects.

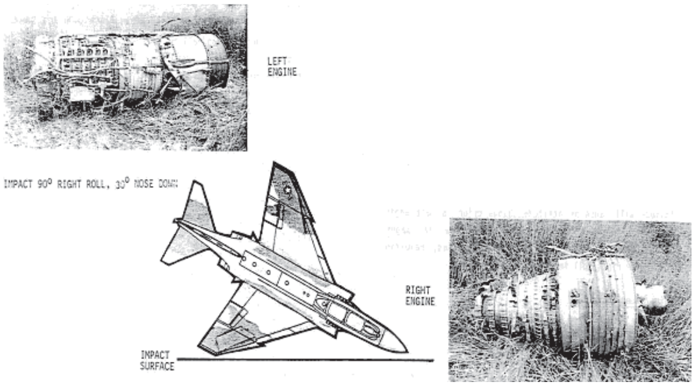


Figure 9. Roll angle effects.

Figure 10. For Engine Non-Containment
- Was there also flammable fluid present?
- Was there an ignition source?
- Was there a fire?
- Was there collateral damage to other aircraft systems?

Figure 11. For Inflight Fire Alone
- What was the flammable material?
- What was the ignition source?
- What was the condition of extinguishment?

Figure 12. For Power Loss
- Did it involve multiple engines?
- What were the crew actions?
- If inappropriate crew actions, what was their training?

Figure 13. Uncontained Rotor Burst
- Bulging outward of surrounding case
- Long tangential holes or splits
- Heavy battering to vane stator rows, fore, and aft
- Missing stages
- Engine internal parts along flightpath

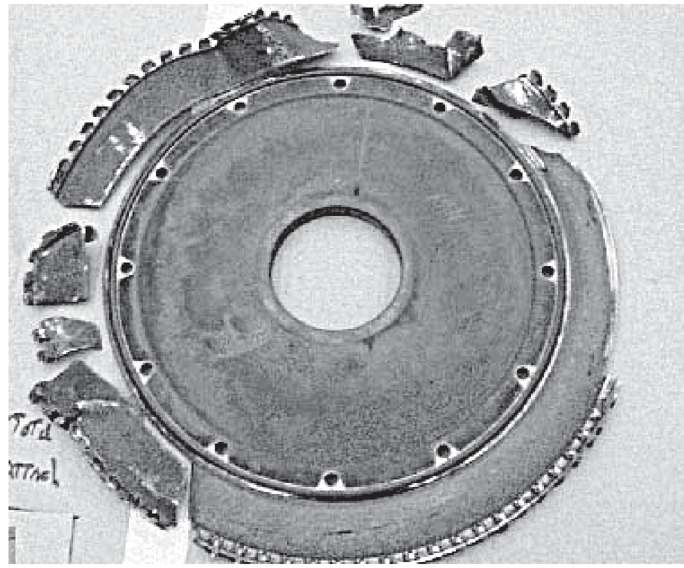


Figure 14. Example of ruptured rotor disk.

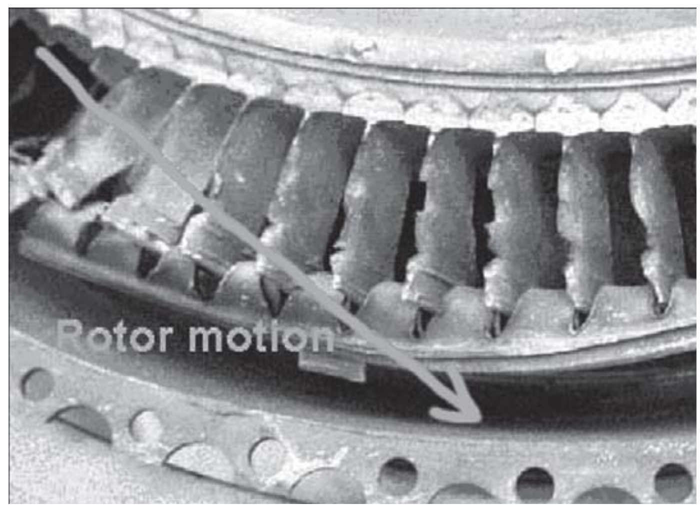


Figure 15. Trajectory path of uncontained rotor disk fragments.

Figure 16. Bird Ingestion
- Cascade damage to consecutive blades
- Soft cusps/bends/dents/twists
- Down/breast feathers/tufts caught in crevices
- Smell in fan discharge
- Aircraft strikes along leading edges

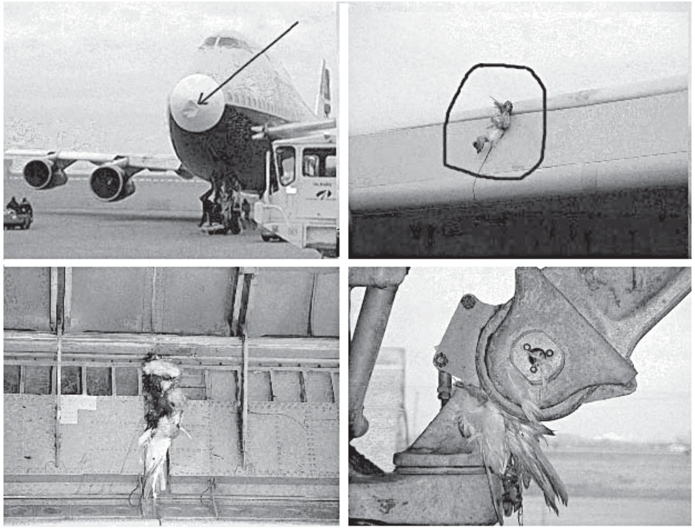


Figure 17. Examples of birdstrike locations on aircraft.

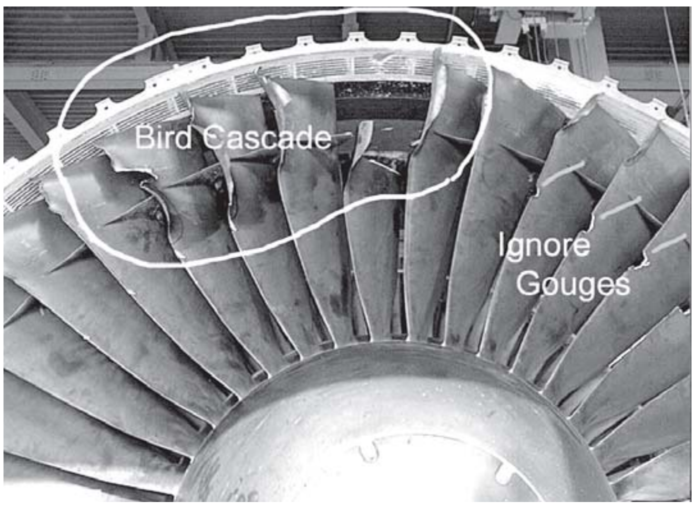


Figure 18. Bird ingestion damage.

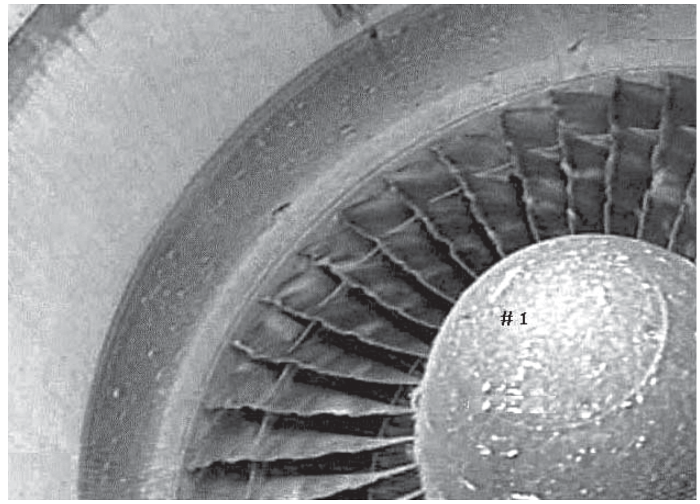


Figure 19. Hard-object ingestion damage.

Note: For assessing bird or ice (softbody) damage, it is important to ignore all hardbody damage caused by re-ingestion debris of bits of broken metal. ◆

Finding Nuggets: Cooperation Vital in Efforts to Recover Buried Data

By Christophe Menez and Jérôme Projetti, BEA—Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation civile

__Christophe Menez__ graduated in 1998 as an engineer from the Ecole Polytechnique, after an internship at California Institute of Technology (U.S.). He received a master's degree in aeronautics from the French National Civil Aviation School (ENAC) in 2000 after a 1-year exchange program with Sydney University (Australia). 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 in a number of international investigations. These include the Flash Airlines B-737 (January 2004, Sharm el Sheikh, Egypt) and the Armavia Airbus A320 (May 2006, Sochi, Russia) accidents. He has also been involved in European working groups such as the FRSG (Flight Recorders Study Group).

__Jérôme Projetti__ received a master's degree in aeronautics from the French National Civil Aviation School (ENAC). He joined the BEA Engineering Department in 2003 as a Safety Investigator. He then joined the flight recorder group and started work on developing tools for solving data recovery issues. He also undertook the development of a laboratory dedicated to onboard computer examinations. He has participated in international investigations including those concerning the Armavia Airbus A320 (May 2006, Sochi, Russia) and the MHS Eurocopter AS332 (January 2007, off the Sarawak coast, Malaysia). He is involved in electronic failure analysis working groups.

Introduction: From GPS to onboard data storage devices

By December 1993 the Global Positioning System (GPS) had achieved initial operational capability, and the U.S. Federal Aviation Administration (FAA) approved its use by civil operators. This was followed in 1995 by full operational system capability, and the industry then started to produce commercial GPS devices.

As the use of GPS devices has rapidly expanded in general aviation, and since manufacturers have equipped them with recording capabilities, they are now systematically collected by investigators after an accident. Because of the absence of flight recorders in general aviation, these small data storage devices have been viewed as a new and valuable source of information for investigations.

However, as these devices are not primarily designed for investigations, they offer no protection against the severe conditions encountered during an accident. For this reason, investigators have often found themselves in a position where the retrieval of data could not be performed using the standard direct readout procedure. Faced with this, investigators in many parts of the world have started to look for ways of accessing the data buried in damaged data storage devices.

At the BEA, GPS examinations started in 1998; initial work consisted of direct readouts when the GPS was in good enough condition, which sometimes meant carrying out repairs prior to the readout.

Data recovery from early production GPSs was all the more difficult since data saving was then performed through volatile memories. These electronic chips erase information when the power is turned off. For this reason, early systems were equipped with an additional capacitor or battery in order to preserve the data contained in the memory. After an accident, the connection to capacitor or battery is sometimes broken, resulting in total data loss.

Later-model GPSs use a non-volatile memory (NVM) for data storage, thanks to the generalization of flash memories in the 90s. In contrast to volatile memories, NVMs keep data stored even without power. From 2003 on, BEA investigators started to access GPS data by reading out the raw data contained in NVMs and, a year later, a similar operation was made possible on volatile memories. Volatile memories remain problematic because data can be lost at any moment if the power source is not maintained constantly throughout the examination.

The BEA's interest in carrying out examinations of electronic memories from onboard data storage devices—other than GPSs—came from issues encountered during investigations of accidents involving Eurocopter helicopters equipped with VEMDs (Vehicle and Engine Multifunction Display). The VEMD is an onboard computer used for flight and ground operations. It displays data and limitations related to the engine as well as the vehicle and records failure reports, flight reports, and over-limits. These recording capabilities, as well as the absence in most cases of onboard flight recorders, can make the VEMD an important source of data during an investigation.

The initial procedure used for extracting data from a VEMD after an accident was to send it to the manufacturer, Thales. However, though the procedure used to read out the contents was satisfactory for product testing, it was not suitable for investigations. The readout was made by connecting the VEMD processor card to a readout bench, sometimes coupled with a direct readout onto the VEMD screen when the VEMD was in apparently good condition.

The following weaknesses were found in this procedure:

- Such a readout is not possible if the processor card is damaged.
- There is no guarantee that the contents will not be altered, or even lost.
- A direct readout from the VEMD screen does not show data recorded during a flight which did not terminate as per manufacturer's definition (an accident flight might therefore not be displayed).

• When power is applied to a VEMD, new data are written and there is a consequent potential loss of data useful to an investigation.
• In case of data loss or direct readout failure, it is difficult to know how the loss or failure occurred.
• The application of such a method depends on the manufacturer's interest in maintaining its readout equipment.

This way of reading out VEMDs also proved to be unsatisfactory in cases where no data could be extracted. In addition, the cost to the BEA of each examination performed by the manufacturer increased our desire to find an alternative solution.

With the experience gained from reading out the contents of GPS memories, it was decided to apply the same approach to reading out the contents of NVMs contained in VEMD electronic cards.

A wide variety of data storage devices

Along with GPSs and VEMDs, plenty of other onboard data storage devices contain data that could be used for investigations. The appended table shows the wide variety of types of data storage devices examined at the BEA in recent years and illustrates the diversity of the systems that should be considered as potential information sources when conducting an investigation.

These devices have ranged from health and usage monitoring systems, collision and obstacle avoidance systems, and flight management guidance computers to PDAs and digital cameras.

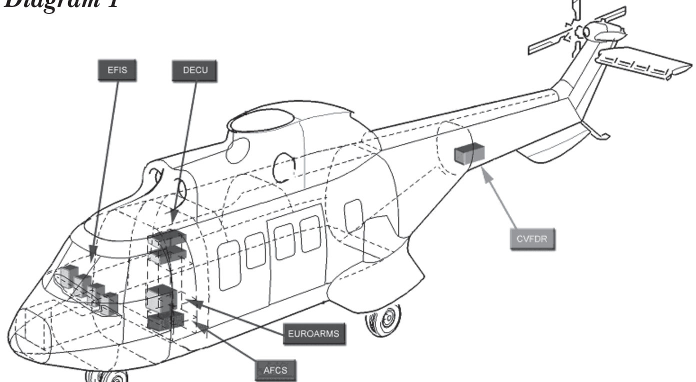
Even for similar aircraft types, there is often significant variation in the type of onboard data storage devices from one aircraft to another. There is thus a real need for investigators to be able to identify systems that can be useful for the investigation. This underlines the need for close cooperation with manufacturers.

Diagram 1 shows a Eurocopter AS332 and illustrates the complexity of identifying potential sources of information on an aircraft. New integrated avionics systems bring new challenges to investigators. Primary flight and navigation displays can also record data for maintenance purposes. They not only record screen failures but also failures transmitted by the AFCS (Automatic Flight Control System). Although a CVFDR (cockpit voice and flight data recorder) is installed, health data collected by approximately 15 magnetic and vibration sensors can be recovered using EUROARMS.

Methodology based on close cooperation with manufacturers

As mentioned in our introduction, reading out the contents of an onboard data storage device with a direct "plug-in-and-power-up" method is not advisable after an accident. Experience shows

Diagram 1



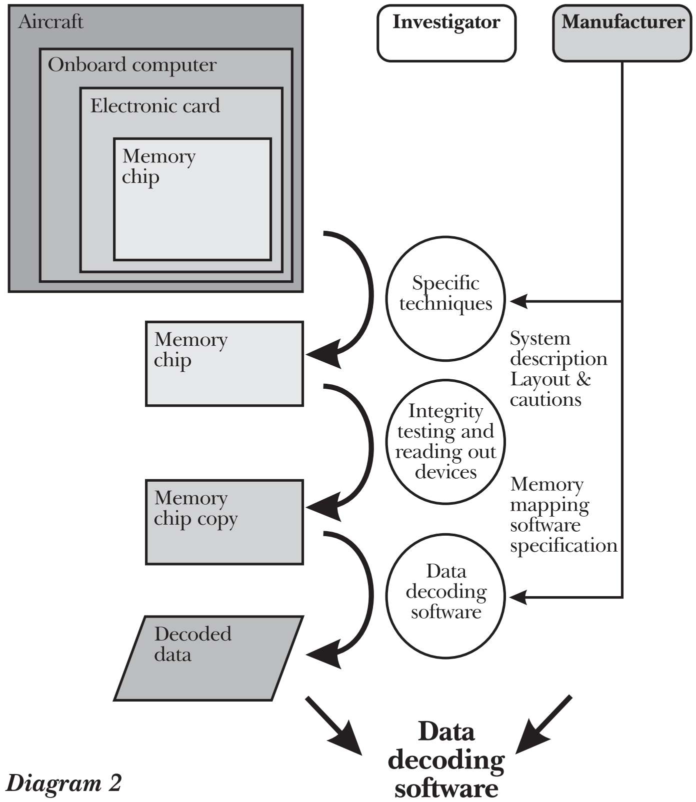


Diagram 2

that such an approach endangers the data. Moreover, direct readouts sometimes show only part of the recorded information. BEA investigators and advisers from Eurocopter encountered an interesting example of this during the analysis of data extracted from a VEMD. The T4 temperature was displayed by the VEMD screen as a three-digit number, though it is recorded with greater accuracy, resulting in any recorded temperature above 1,000° C being displayed as 999° C.

The general outline methodology is therefore:
• to identify the potential source of information,
• to remove the corresponding systems from the wreckage,
• to identify and extract the electronic cards and memories associated with data recording,
• to read out the contents of the memory chips,
• to decode the raw data, and
• to validate the results.

The decision to perform the physical examination and the memory readout at the BEA laboratory instead of using the manufacturer's equipment changed the role of the manufacturer in the investigation process. Nevertheless, this approach—rather than excluding the manufacturer—increased the necessity for close cooperation.

The Diagram 2 shows the various steps in an onboard computer examination, as well as the role of the investigator and the manufacturer.

During the first phase, the manufacturer's knowledge of the systems is essential to know which memory chips store the recorded data. With growing experience, investigators have been developing specific techniques to extract electronic memories without jeopardizing the data. However, when a new system is examined, the manufacturer possesses essential information about the specific characteristics of the system's electronic cards, their position, and the detailed precautions to take. Manufacturers can, for example, point out the presence of a volatile memory and its power source, as well as provide information on the physical composition of the protective layer on an electronic card that investigators will have to remove to access connections to the chips.

The second phase of the work consists of reading out and making a copy of the contents of the memories. By doing so, investigators ensure that raw data are preserved before any further work is carried out. Before reading out a memory, its condition must be assessed in order to ensure that the readout process won't destroy its contents. This phase includes both visual observation of its physical state (microscope, X-ray) and measurement of its electrical properties (voltmeter, oscilloscope). At the BEA, investigators have developed readout equipment to download the contents of memory chips that can be configured in accordance with the memory type. However, during this phase the manufacturer can also help by providing datasheets for obsolete memory chips or ASICs (application specific integrated circuits).

During the third phase, investigators have to convert the raw data into a comprehensible format. In order to do this efficiently, BEA investigators have developed software with a core algorithm capable of handling several types of formats corresponding to very different types of onboard data storage devices. This software can thus supply a readable format from a raw data input. The number of algorithm decoding features grows when new systems are encountered, so they are added to the software based on the description provided by the manufacturer.

Finally, when the data have been read out and, where necessary, converted into engineering units (or at least to an understandable format), investigators and the manufacturer's specialists work in parallel to validate the values obtained. This parallel work also ensures that the whole process is well understood by both parties before starting the analysis phase.

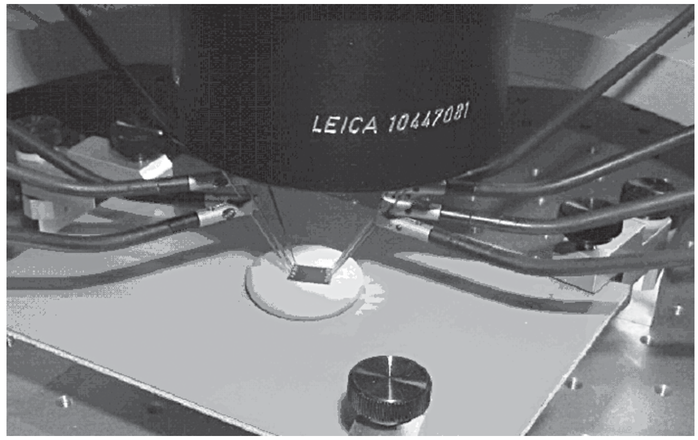
As a general rule, before examining a new system, investigators work with the manufacturer on defining a readout and decoding procedure. The procedure should then be tested on a similar data storage device before being used on the device from the accident being investigated. Throughout the examination process, an important part of the investigators' work is to identify the risk of damaging the potentially available data and to establish technical solutions to preserve it.

Example of VEMD display on takeoff.

Example 1: Accident to a Eurocopter EC120 Colibri in India in 2005

During a flight to Delhi, the engine, a Turbomeca Arrius 2F, shut down and the helicopter landed with heavy vertical impact, killing the pilot and two of the passengers. The other two passengers were seriously injured.

As per ICAO annex 13, the BEA participated in the investigation as a state of manufacture, accompanied by advisers from Eurocopter and Turbomeca. The context of the investigation was particularly difficult as the two fatally injured passengers were Indian ministers and some suspicions of sabotage arose.



Readout of NVM (6x8 mm) using probing station.

The engine examination showed that one blade in the gas generator turbine had separated from the disc, resulting in engine failure. Later, a non-standard ferrule was identified in the secondary air cooling system, and it was suspected that this had been the cause of the temperature over-limit in the engine, resulting in the blade separation, leading to the engine failure. The engine manufacturer issued an all-operator alert for all non-standard ferrules in 39 engines worldwide.

However, the VEMD data, retrieved and decoded at the BEA, threw new light on the accident scenario.

Analysis of the recorded data showed that the T4 temperature (free turbine input temperature/EGT) reached 998.5° C during the start-up phase of the flight, which is far beyond the acceptable limit of 870° C. During flight, the T4 over-limit was again recorded. Such an excessive temperature is displayed to the pilot and should result in his aborting the flight and an engine teardown. However, the pilot decided to continue the flight—the presence of ministers on board perhaps contributing to the decision-making process.

After analysis of the VEMD data, the presence of a non-standard ferrule was defined as a possible contributory factor to the accident, whereas it would probably have been identified as the probable cause of the accident without such an examination. The VEMD data showed that the decision to continue the flight after start-up was the probable cause of the accident.

Example 2: Glider accident in France in 2007

During a local flight in poor meteorological conditions, an ASW15 glider crashed into a forest 3,650 feet up in the mountains. It wasn't equipped with an ELT and the radio was unserviceable. The pilot, the sole occupant, was killed on impact and the wreckage was recovered 5 days later.

An air collision avoidance system manufactured by FLARM was extracted from the wreckage. Cooperation was established with the Swiss manufacturer, and the method followed by the laboratory was the key to successful data retrieval and analysis.

The system in question, based on GPS positioning, can record the flight track with a sample rate of 4 seconds. The internal observation stage revealed that the main board was partially

APPENDIX: Data storage devices examined at the BEA since 1998 In the "content" column, italic text indicates a non-volatile memory and bold text indicates a volatile memory.

Type	Manufacturer	Country	Examples of model	Examples of aircraft on which it was encountered	Type of content
DECU (Digital Engine Control Unit)	Sextant / Thales	France	70BMA01080 70BMA01090 70BMC01030 70BMC01031	S-76 Sikorsky SA365 Dauphin 2 EC155 B1 AS350 B3	*Calibrations* *Dated failure blocks* *Number of starts and cycles*
	Turbomeca	France	70CMB01050	AS332 Super Puma	*Failure blocks* *Last flight duration* *Number of starts and cycles*
HUMS (Health and Usage Monitoring System)	Eurocopter / Sodielec	France	EuroArms	AS332 Super Puma	**Health and usage data** *BITE*
	Smith Aerospace	UK	EuroHums	AS332 Super Puma	*Health and usage data*
BAP (Engine failure prediction computer)	Sinters	France	N/A	SA365 Dauphin 2	*Failures without time stamp* *Engine health data*
VEMD (Vehicle and Engine Multifunction Display)	Sextant/Thales	France	B19030FC03 B19030FB02 B19030SA02 B19030MC02 B316M30S1001	EC120 Colibri EC130 EC 145 EC 155 B1 AS350 B3 Squirrel	*Calibrations* *Failure reports* *Flight reports* *Over limits* *Engine check*
CAD (Caution and Advisory Display)	Thalès	France	C19243EB04	EC 145	*Failure reports* *Last flight number*
AP (Auto-Pilot)	Sfim	France	416-00297-201	EC 145	*Failure reports*
FLARM (Collision and obstacle avoidance)	Flarm Technology	Swiss	231018-13000	Gliders	*IGC (International Gliding Commission) file*
EFIS (Electronic Flight Information System)	Thales	France	SMD66H C19435BA01 C19435BA02 C19252PC08 39982973	AS332 Super Puma	*Failure reports (AFCS, FDC, HSU, PSU, NMD, PFD, VOR)*
FMGEC (Flight Management Guidance Envelope Computer)	Thales	France	B398BAM0209	A320	*BITE*
GPS	GARMIN	USA	Family VI GNS 150XL GNS 250XI GNS 430 GNS 530	Various aircraft	**Waypoints** **Routes** **GPS configuration** (No trackpoint)
			Family V GPSMAP296	Various aircraft	*Flight reports* *Trackpoints* *Waypoints* *Routes*
			Family IV GPSMAP 295 GPSMAP 196	Various aircraft	*Flight reports (GPSMAP 196)* *Trackpoints* *Waypoints* *Routes*
			Family III GPSMAP 195 GPS III Pilot GPS 12, 12XL	Various aircraft	**Trackpoints** **Waypoints** **Routes**
			Family II GPS II+,III+ GPS 45XL GPS 55 GPS 90 GPS 95XL GPS100	Various aircraft	**Trackpoints** **Waypoints** **Routes**
			Family I GPS38 GPS40 GPS45	Various aircraft	**Trackpoints** **Waypoints** **Routes**
	MLR	France	SP24XC / FX312	Various aircraft	**Trackpoints**/*Trackpoints* **Waypoints**/*Waypoints* **Routes**/*Routes*
	GARRECHT AVIONIC	Germany	Volkslogger 1.0	Gliders	*IGC file*
	Filser	Germany	LX20 LX4000 LX 5000	Gliders	**IGC file**
	ZANDER	France	SR940	Gliders	IGC file
	BENDIX KING	USA	KLN 90B	Beech 90 King Air	Waypoints Routes
	Cambridge	USA	GPS-NAV 301/302 S-NAV	Gliders	*IGC file* **Waypoints & routes (S-NAV)**
	GEONAV	Italy	GEONAV 7C	Microlights	*Trackpoints* *Waypoints* *Routes*
	MAGELLAN	USA	SKY STAR GPS 2000 PIONNEER GPS 315 SPORTRACK	Various aircraft	**Trackpoints** **(Except SKY STAR)** **Waypoints** **Routes** *Trackpoints* *Waypoints* *Routes* *(SPORTRACK)*
PDA (Personal Digital Assistant)	ASUS HP	N/A	A632 iPAQ	Gliders	Trackpoints Waypoints Various files
VHF	Becker	Germany	AR2009/25	DR-400	Last selected frequency
	BENDIX KING	USA	KX155 KA134	DR-400 F-172 Reims	*Last selected frequency*
ACCELERO	MEV	France	PGM 1212	CAP 10 B	*Number date of flight* *Flying time* *Maximal accelerations* *Over limits* *Thresholds*
VARIO	Peschges	Germany	VP6	Gliders	**Flight report**
Digital Cameras	N/A	N/A	N/A	Various aircraft	*Photographs (JPEG)* *Movies (MPEG)* *Date and time*

bent in different locations and the memory chip was disconnected from the card. It wasn't possible to connect the memory pads with a standard adaptor. A procedure was validated to obtain the raw data by using very thin probes with the aid of binoculars.

Raw data were converted into a track file from a test unit at the manufacturer's site. The protocol established ensured that this could also be done for obsolete units. Faced with a lack of other available evidence, the flight track obtained brought new light to the accident investigation.

Challenges, limits and, objectives

Working in this way requires the manufacturer to provide information on software specifications, and this is sometimes proprietary information or has not been stored because of system obsolescence. With some manufacturers, such as Garmin, collaboration has not so far proved fruitful. For such reasons, and also because the data structure is less complex than for big onboard computers, GPS examinations can often be performed by either a direct readout or a simplified version of the general methodology.

In addition to this first limitation, some difficulties have been encountered where the manufacturer has worked with a large number of component suppliers. Onboard systems and corresponding software are sometimes produced by two distinct suppliers. In some cases, investigators have to talk to several interlocutors before eventually being able to obtain a proper system description.

Work on onboard data storage devices and GPSs has proven to be very challenging. Investigators have tried to find a common way of retrieving and preserving data from a wide variety of systems, but when new systems are encountered, adaptation is necessary and requires some procedural flexibility. For example, decoding a raw file extracted from a memory chip can be performed by the manufacturer if it does not wish to share the product software description with investigators. On the other hand, if a manufacturer does not want to devote time to the investigation process, providing the necessary documents to investigators can greatly help them to get useful data.

The decision to find as much possible data at the memory chip level enabled investigators to strengthen their links with manufacturers. Working protocols that follow this approach have been established between the BEA and Eurocopter, Turbomeca and Thales.

Manufacturers have expressed great interest in this type of work, which is also beneficial for them as they can obtain more data from the tools and methods developed by investigators. Manufacturers may thus be interested in taking into account knowledge gained during onboard data storage device examinations when developing future systems. Investigators have been invited to give their opinions on data preservation for the development of a new maintenance system called SMMART (System for Mobil Maintenance Accessible in Real Time).

Investigators have also learned more through close collaboration with manufacturers than in cases where the manufacturer was the only one capable of retrieving data. Investigators are better informed about ongoing developments, and are better prepared—in case of a new accident—to exploit the manufacturer's knowledge in order to select the systems to be examined.

BEA investigators have been able to work closely with national manufacturers as well as manufacturers from neighboring countries. Cooperation in this field needs to be constantly widened, and the best way to succeed in this is to work in unison with the investigation boards of different countries around the world, who have themselves developed their own working relationships with national manufacturers. ◆

International Investigation: General Aviation Accident In Atlantic Waters

By Joseph Galliker (M03322)

***Joseph Galliker** is the president for ASC International, Inc. and develops customized airline emergency response and family assistance plans. Previously, he worked for Air Canada as a flight safety officer. His experience covers flight safety management, aircraft incident and accident investigation and handling, the development of airline emergency response and family assistance plans, as well as liaison with the investigator-in-charge on behalf of the operator. While with Air Canada, Galliker developed the first-ever seminar on emergency response management for airlines in 1984, which provided an incentive for airlines worldwide to improve their emergency response plans and their liaison with the accident investigator-in-charge. He is providing training to airlines and civil aviation authorities in Africa, the Caribbean, Asia, and Europe on airline emergency response planning and liaison with the investigation agency. Most recently he assisted in the accident investigation into a single-engine aircraft ditching short of the southern Greenland coast (2007) in the capacity of representative for the next of kin of the pilot. He lives in the Montreal area and is married with two grown children. His hobbies are private flying, sailing, and snow shoe trekking.*

Objective of this presentation

To understand the physical and financial effort involved in conducting a general aviation field investigation in the far north.

The accident and its evolution

On Feb. 2, 2007, three identical factory-new Cirrus SR20 were enroute from Goose Bay, Canada, to Reykjavik, Iceland. While diverting to Narsarsuaq, Greenland, due to weather ahead, the engine of one of the aircraft failed twice due to low engine oil pressure and loss of engine oil. Engine oil appeared on the windshield. The engine could not be restarted.

One of the two remaining aircraft in the hangar at Narsarsuaq.

Gliding from cruising altitude, the pilot was able to reach the first rock islands in the coastal waters of Southern Greenland (approx. 45 nautical miles southwest of Narsarsuaq near the "SI" NDB).

The pilot ditched the aircraft but drowned outside the aircraft.

Site investigation in Greenland—cooperation in difficult climate

In Greenland, aviation accident investigation falls into the jurisdiction of the Accident Investigation Board of Denmark.

The investigator-in-charge (IIC) proceeded to Greenland to conduct the field investigation. On arrival in Narsarsuaq, he met up with the representative of the aircraft manufacturer, engine manufacturer, and the representative for the next of kin of the pilot.

The pilots of the remaining two aircraft had already been interviewed by the investigator-in-charge.

As both of these pilots had communicated with the aircraft in distress, and searched for and located the pilot and the aircraft, they became prime witnesses.

The two pilots stated they found their colleague floating about 70 meters from the aircraft. The aircraft itself was afloat with the tail broken (but still attached) protruding above the surface of the water. The sea had waves and swells (5-7 feet). Water temperature -1 to +1 C.

The alarm and mobilization of the local emergency response plan had also been initiated immediately, and the first helicopter (AS350) reached the area within about 10 minutes.

Shortly after, the first rescue helicopter was joined by a second one (Sikorsky S-61).

The S-61 retrieved the lifeless pilot and flew him to the Qaqortoq hospital (30 km), where he was pronounced dead.

The S-61 helicopter "froze" the location of the floating aircraft on GPS.

The next day it was reported that the aircraft had sunk.

The days following the arrival of the IIC were plagued by extremely cold, windy, and snowy weather conditions. Proceeding to the accident site was postponed by the IIC pending safe flying weather for the AS350 helicopter.

The two remaining aircraft were hangared in the only hangar in Narsarsuaq, in nice and cozy 20 degrees C. Going to the hangar from the hotel was a different story. High winds (100 km/h) and cold temperatures prevailed for days. The effects were, for example, reading glasses were blown off one of team members face, and promptly flew "straight and level" until later the next day they were found by a search party 50 meters downwind.

The two aircraft were checked for fuel level and balance, as well as service bulletin status.

Two service bulletins were of interest, "Oil Breather Tube Insulation" and "Engine Winterization Kit." They had not been incorporated for the flight.

Finally, on a Saturday, the sky cleared and the wind was calm. This was the time to fly to the site.

The intention by all was to see if the aircraft could be seen under water, if any debris could be spotted on the shores of nearby small rocky islands, and have the helicopter pilot comment on the location of the aircraft.

Equipped with three GPS units we set off. One of the GPS units was a Garmin 295 with maps for Greenland.

On the way, the pilot showed us some earlier crash sites—all well preserved, some dating back to the second World War.

The coastal islands were clearly visible on the maps of the GPSs, and we soon found the spot matching the coordinates taken at the site on the day of the rescue operation.

The site was open water, with some white chunks of glacier ice, fairly calm sea, at a distance of about 200 meters from the shore of an approximately 30 by 50 meters solid-rock island.

We thought it would be best to check the shore of the nearest island for any debris or other evidence of the aircraft.

Anxiously scanning the steep, rocky shore, we could not see a single shred of anything, but crystal clear water (would qualify as premium mineral soda water in any big city).

Suddenly one team member shouted, "I see it. I see it!" We all turned to his side of the helicopter, and indeed could see the shape of what looked like a white airplane. A minute later, big disappointment, on closer investigation it turned out to be a sand patch in about s meters of water.

We learned from that, as later, further a sea there were similar sightings.

Flying further out from the shore of the island, another "call for stop it."

This time it was clearly a paper page like a flight plan or chart, floating horizontally about a meter under the surface of the water. The location was about 300 meters further out to sea from were the aircraft had been ditching.

We searched for an amount of time, but could not find anything else, but we were getting a feel for the ditching and pilot rescue locations and its reference to the island.

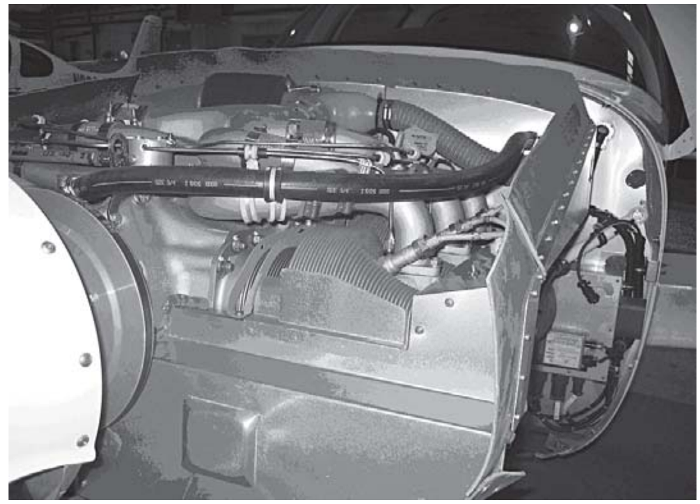
We returned to Narsarsuaq, somewhat disappointed, but appreciating what nature is like out there.

We realized boats with sonar and barges with cranes would be required for the next step to determine the depth of the seabed at the ditching location, then search for the aircraft and, if found, to lift it and bring it ashore in the nearest town (Qaqortoq).

But where in Greenland is it available and at what cost?

By speaking with local fishermen, they expressed the following concerns about the aircraft location and what could happen to the aircraft itself:

- Strong currents (north/south and tidal east/west).
- Icebergs in March to May to crush the aircraft on the seabed (icebergs can reach depths of 30 meters or more).
- Angle at which the aircraft sunk to the bottom of the seabed.
- Seabed surface could be anything from large rock boulders to sand or steep inclines or crevasses.



One of the two remaining aircraft—oil breather tube.

- The depth at the site. There are some recent charts that show general and sparsely measured depths further out (241 meters).

Aircraft search

The investigator-in-charge discussed the search for the aircraft by Greenland and Danish authorities. It became clear that the cost would be prohibitive.

The wife of the pilot asked her representative to the Investigation to explore a "low-cost solution" to find and raise the aircraft. She felt she needed to see the aircraft.

With the permission and cooperation of the IIC, the representative for the pilot began to contact the local police (Qaqortoq), which provided contacts to local owners of boats.

It became soon clear that the resources were limited.

The representative proceeded to Narsarsuaq, then to Qaqortoq to enquire and speak with local professionals in person.

The plan was to find someone who could scan the seabed at the site with an echo sounder, then if the aircraft was spotted try to lift it. How was not clear yet.

Speaking to crewmembers of the Danish Ice Patrol Unit based in Narsarsuaq brought forward good maps of the site area. They had checked the site from time to time by flying over it with their helicopter.

They also suggested contacting the only diver in the area as he has lots of experience finding things under water. The also suggested contacting the two Danish Navy ships, which were on a mission to chart the southern Greenland seabed out of Qaqortoq, where they have docked for the last few weeks. "How lucky can one get," I thought to myself.

It took a while to find the diver (Kaj), as he was held by bad weather in a remote location.

His wife, however, provided good information of his capabilities. Not only was he a diver, but he also owns two 10-meter boats well equipped with echo lots (as they are called locally).

In the meantime, wandering around the harbor in Qaqortoq and speaking with people also provided hope for finding the aircraft and lifting it.

No sight of Danish Navy ships. They had left in the morning, bound to be at sea for a few days.

Walking one evening on the pier, I saw a 20-meter trawler come in and moor. Looking at the net, it seemed massive with steel

Trawler with drag net.

The two ships surveying the seabed in the site area.

Danish Navy charting ship—SKA-12.

balls and huge grommet-like rubber rings.

"What can you do with this net?"

"What do you have in mind?" the captain/owner asked.

"Looking for an aircraft out in the Niaqornaq Island area."

"How big is the aircraft?" After he understood the situation and possible depths, he summarized: "We can find the aircraft as our drag net can trawl to 300 meters. Also at a depth of around 100 meters, we can snag it with the net and lift it and bring it right into this harbor."

He then showed and explained the gear and the measuring and navigation equipment—latest state of the art.

He suggested that I go with the diver and survey the seabed in the area around the GPS coordinates of the aircraft last seen to provide him a feel for the make up of the ground (level sand, boulders, or crevasses, etc.) as well as the exact depths a few hundred meters around the site.

The diver was available the next day, and with good planning we went off to the site.

On the way there, one of the Danish Navy ships, the SKA-12, appeared on the horizon. The captain contacted it by radio to ask about exact depths in the site area. In a cooperative tone of voice, the officer asked for the site coordinates. Ten minutes later we received depths in several locations.

We proceeded and found the exact site with the help of the GPS coordinates "frozen" last February.

Scanning the seabed with two ship echo lots, the seabed showed up as a level plateau bordered by the rock island on one side, by a rise in terrain (42 meters depth) on the north/east side, and a plateau of about 300 meters length, parallel to island (70 meters), then a shallow drop to the open sea.

Boat No. 2 was searching the south end of this plateau when he called on the radio, "I got something unusual here. I can not identify it, but there is something here."

We began to drag with the anchor for a while in the area, recording the tracks of the ships at the same time.

After about an hour of dragging with the anchor, we felt a net could do a better job and began the trip back to Qaqortoq (2.5 hrs).

We were satisfied with the work we had performed and information we were able to bring back.

The following is a list:

- Checked the shore of the island for evidence—nil found.
- Measured and recorded the depths and make up of the seabed in the greater site area.
- Confirmed witness statements by helicopter and two Cirrus aircraft pilots as to distance from the shore the aircraft and pilot were located.
- Checked performance of an immersion suit by wearing it while floating in the sea for a period of time.
- Marked the point of "interesting returns" by the echo lot.
- Had the good feeling of having been there.

The investigator-in-charge was briefed.

The next step should now be the dispatch of the trawler, fully staffed and accompanied by the diver and his staff.

The cost should be reasonable, as the trawler is expected to complete the search in 1 or 2 days.

Here is an example of cooperation of investigation team with accredited members, local authority (ice patrol, police, Danish Navy), local professionals, and general public to help the investigation (cause) and the pilot's family (closure). ◆

Standardizing International Taxonomies for Data-Driven Prevention

By Corey Stephens (MO3790), Olivier Ferrante (MO4749), Kyle Olsen, and Vivek Sood

Corey Stephens *is a senior staff engineer with the Air Line Pilots Association (ALPA)'s Engineering & Air Safety Department. He has assisted the International Federation of Air Line Pilots Associations (IFALPA) with technical expertise on international accidents. Corey Stephens is the industry co-chair to the CAST/ICAO Common Taxonomy Team (CICTT) and serves as an ALPA representative to the Commercial Aviation Safety Team (CAST)—Joint Implementation Monitoring Data Analysis Team (CAST—JIMDAT). Corey has also worked in the Safety Department of United Airlines and with the U.S. National Transportation Safety Board (NTSB). He has a master's degree in aviation safety from Central Missouri State University and a master's degree in space studies from the University of North Dakota.*

Olivier Ferrante *joined the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation civile (BEA) in 2000 and has been working with the Federal Aviation Administration (FAA) (Continued Operational Safety) since November 2005 under a BEA-FAA cooperation agreement. Before that, he has also worked with the Transportation Safety Board of Canada. Olivier holds a master's degree in aviation engineering from the French National Civil Aviation School (ENAC) and a post-graduate degree in human factors from Paris University.*

Kyle Olsen *joined the FAA Aircraft Engineering Division in 1970 and is now manager of Continued Operational Safety for the FAA Transport Airplane Directorate. He has been deeply involved with CAST since 1997. Kyle was the FAA certification project manager for the L-1011 and MD-11 and was aanager of the Propulsion Branch in the FAA Los Angeles Aircraft Certification Office. He has a bachelor's degree in aerospace engineering from the University of Southern California.*

Vivek Sood *is the manager of FAA's Aviation Safety (AVS) Aviation Safety Information Analysis and Sharing (ASIAS) center. He holds commercial, flight instructor, and dispatcher certificates. He has worked in the aviation sector for the last 18 years, particularly in the area of safety analysis. Vivek is a member of the CICTT and is the government co-chair of the Runway Confusion Study Group sponsored by CAST. He has a master's degree in aviation and aerospace operations and a bachelor's degree in aeronautical science from Embry-Riddle Aeronautical University.*

Introduction

The development of an industry-accepted taxonomy[1] plays an essential role in safety. It goes beyond just identifying occurrence categories. As more data sources and systems become available for use in reactive (post accident) and proactive safety programs, the importance of well-developed and agreed-upon standards becomes very apparent for data-driven safety initiatives. Industry-accepted standards aid in data sharing and analysis. Common taxonomies and definitions establish a standard industry language, thereby improving the quality of information and communication. With this common language, the aviation community's capacity to focus on common safety issues is greatly enhanced. The safety issues are commonly defined, which facilitates tracking the effectiveness of their mitigation solutions.

The investigation site can be the starting point for data collection. When data is collected and recorded using a standard taxonomy, it becomes even more valuable to investigators. Each investigator studying worldwide data is relying on these standardized definitions. In addition, the investigation results can be exchanged among organizations and with the International Civil Aviation Organization (ICAO). This standardized data also forms the core of the data in the ADREP reporting scheme (ICAO, 2001). This operational framework illustrates investigation cooperation, from the investigation site to ICAO.

This paper will emphasize how international cooperation in taxonomies can help in preventing accidents. We will present some CAST/ICAO Common Taxonomy Team (CICTT) taxonomies and give examples of their applications that have helped facilitate data collection and analysis for accident prevention. This paper will also discuss some work on new taxonomies to be standardized, especially for incident investigation. These new taxonomies will help answer the following questions: How do we know that our safety strategies prevented an accident from happening, and how often? Finally, the paper will address one last important question: How can taxonomies help safety investigators and vice-versa?

History of the CAST/ICAO Common Taxonomy Team

Commercial Aviation Safety Team

Comprised of industry and government safety experts, the Commercial Aviation Safety Team (CAST) came together in a unique industry-government partnership in 1997 and set a goal to reduce the U.S. commercial aviation fatal accident rate by 80 percent over the next 10 years.

Though CAST has focused primarily on the U.S. aviation system, throughout its history CAST has reached out internationally to help improve aviation safety around the world. A large number of international organizations are members and observers of CAST, including the European Aviation Safety Agency (EASA), Joint Aviation Authorities (JAA), and other ICAO member states. CAST's impact and leadership extends to regional safety alliances around the world, and its principles have been incorporated into the newly released ICAO global safety roadmap.

CAST has developed an integrated, data-driven strategy to reduce the commercial aviation fatality risk in the United States. To date, CAST has completed 40 of the 65 most promising safety enhancements identified to reduce the leading causes of fatal commercial aviation accidents in the United States. Adoption of these enhancements has been a major factor in the substantial reduction of the fatal accident rate over the past 10 years. CAST is redirecting its efforts to the analysis of incident data to identify emerging safety risks.

To continue to achieve reductions in the accident rate, it is necessary to expand into analysis of incident and normal operation data to unearth changing and emerging threats in a proactive manner. Access to the data is thus a vital component of this risk analysis. The use of CICTT taxonomies by all organizations will be critical to further advancements in aviation safety. The absence of a common taxonomy and the lack of industry data-sharing initiatives greatly diminishes the ability to recognize emerging risks and increasing threats before their manifestation in an accident or serious incident.

CAST/ICAO Common Taxonomy Team

Before the formation of the CICTT, there was no universal standard for safety data. A focus on safety worldwide at that time resulted in the startup of many disparate efforts. This in turn made the development of a common worldwide safety agenda extremely difficult. It was decided that an international industry and government standard must be developed, made up of common and "non-proprietary" standards. Non-proprietary standards were needed since proprietary or patented taxonomies had contributed to stove piping of data. ICAO and CAST jointly chartered the CICTT in 1999. The Team is charged with developing common taxonomies and definitions for aviation accident and incident reporting systems. CICTT includes experts from ICAO, several air carriers, airframe and engine manufacturers, pilot associations, regulatory authorities, transportation safety boards, and members from North America and Europe, and indirectly from more countries. CICTT is co-chaired

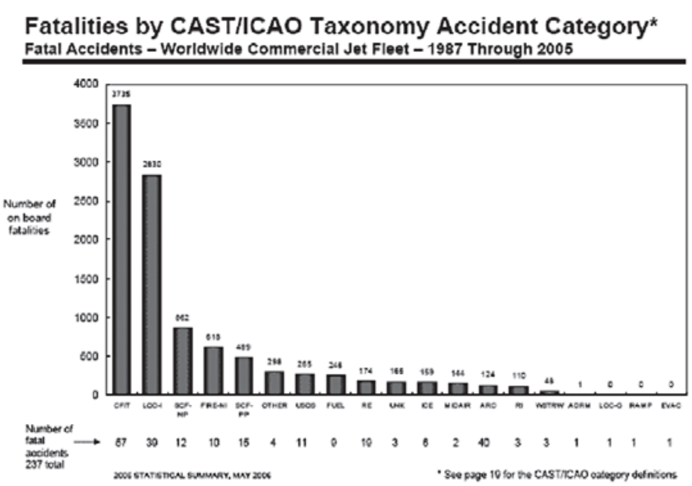


Figure 1. Boeing statistics based on CICTT Occurrence Categories.

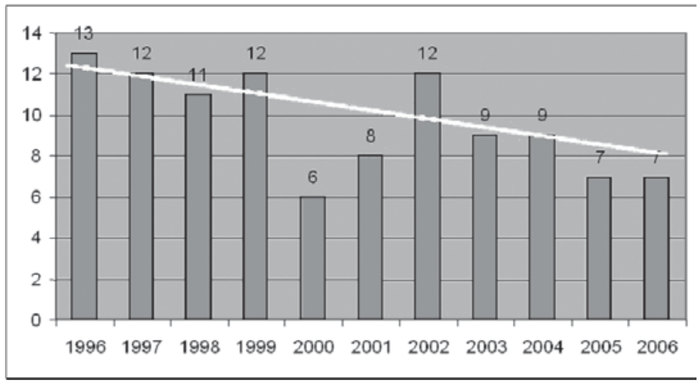


Figure 2. Worldwide evolution of CFIT accidents (source: ICAO SISG 2007).

by one representative from ICAO and one from CAST.

The original taxonomies established by the CICTT activity were Occurrence Categories, Phase of Flight, Aircraft Make/Model/Series, and Engine Make/Model. The Occurrence Categories and Phase of Flight definitions were completed in 2002. The Aircraft Make/Model/Series values were established in 2004, and the Engine Make/Model values activity started in 2006. Both the Aircraft and Engine taxonomies are updated quarterly. The establishment of these original taxonomies lays the foundation for

- worldwide sharing of common accident/incident data,
- focused, data-driven, coordinated safety agendas,
- common investigation, reporting, and post accident analysis, and
- shifting from reactive to proactive safety assessments.

Examples of CICTT product applications

Use of CICTT Occurrence Categories by industry

Industry has been gradually implementing CICTT products. Figure 1 shows how the Boeing Company adopted CICTT definitions for its annual statistical summary of accidents (Boeing, 2006).

The CICTT Occurrence Categories are also used by the Safety Indicator Study Group (SISG)—a group formed by ICAO after the 1999 Accident Investigation and Prevention Divisional Meeting (AIG 99). Since 2001, SISG has met annually to exchange, review, and jointly classify accident and incident data to produce consistent safety statistics.

Figure 2 illustrates the downward trend of controlled flight into terrain (CFIT) accidents. This example shows a "common taxonomy benefit" for CFIT prevention since a common understanding of this issue was needed before tackling it.

The efforts undertaken these past years to prevent CFIT accidents (the acronym CFIT was less known 20 years ago) introduced new safety nets to successfully address this accident category. The common categorization of a problem and its coding greatly helped in better identifying it and monitoring its trend. Above all, it contributed to gathering a global consensus. The different stakeholders (industry and government) could thus "talk" about the same issue and consequently act in a coordinate manner.

Example of ASIAS in the United States

The FAA promotes the open exchange of safety information to continuously improve aviation safety. To further this basic objective, the FAA established the ASIAS center.

A fundamental problem faced by ASIAS is the heterogeneous nature of the data systems that have been developed by the various organizations. The systems typically feature text blocks that are not governed by controlled vocabularies and contain data values that do not conform to any common standard (aircraft make/model codes). In addition, the systems store data in database structures that have little in common. As a result, safety analysts are faced with a mosaic of data that can only be viewed one piece at a time. ASIAS addressed these problems by implementing a data-management strategy known as the Advanced Data Architecture (ADA). The principal objective of the strategy was to enhance the analytical value of existing data sources by creating an operational environment that supports the rapid and cost-effective integration of data from multiple sources.

The development of ASIAS has allowed the FAA to standardize data-management practices and address data quality issues. Having developed and deployed a data-management framework, ASIAS is focusing its efforts on the development and adoption of common taxonomies and definitions, and analytical methodologies. ASIAS has made significant progress in developing analytical capabilities by establishing internal data standards and using CICTT taxonomies.

By focusing on standardizing key data elements initially, like the aircraft make and model, airport names, ,tate names, country names, and operator names, ASIAS is able to link databases and establish interoperability among multiple source systems. Through the ASIAS web-based portal (see Figure 3), users are able to query multiple systems in a single query.

The global query search can mine several databases by entering a unique aircraft model thanks to the CICTT Aircraft Make/Model/Series standard. Figure 4 depicts a single query for a Boeing 737-800 and its associated results.

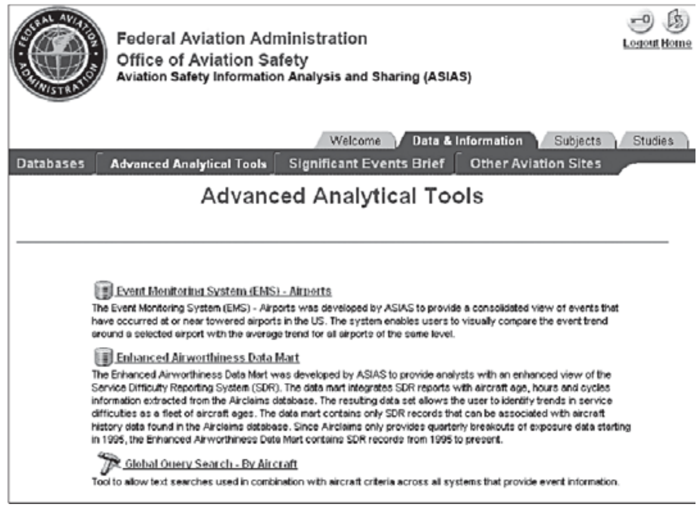


Figure 3. Access to global query search—by aircraft.

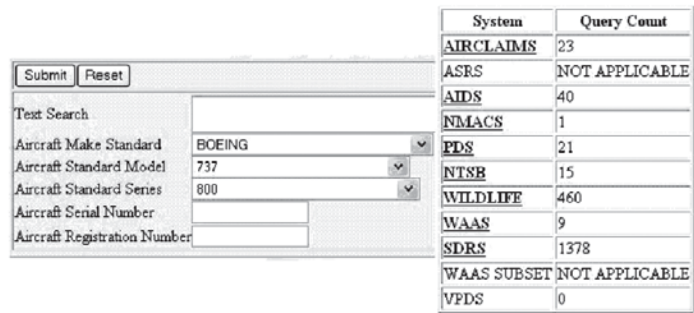


Figure 4. Global query and results for Boeing 737-800.

Example of ECCAIRS in Europe

The ASIAS "portal" approach and the European Co-ordination Centre for Aviation Incident Reporting Systems (ECCAIRS) share objectives. The European Commission provides a common tool for users across Europe to encode accidents and incidents into compatible repositories. ECCAIRS is based on the ICAO ADREP (Accident/Incident Data Reporting) 2000 taxonomy (Menzel, 2004). This common tool facilitates electronic exchanges and data integration among organizations from different countries (not necessarily from the European Union). Safety analyses can then be based on larger data sets.

The ADREP taxonomy has adopted CICTT products throughout the years. ADREP implemented the Occurrence Categories in 2004 and will adopt the CICTT Aircraft Make/Model/Series standard in its next release. Taxonomy changes take time as it generally requires changing the structure of existing systems. Such a migration has to be planned and coordinated among the various organizations involved.

The European Aviation Safety Agency, which operates ECCAIRS, directly implemented the CICTT Aircraft Make/Model/Series standard in its new airworthiness directive database. This new compatible database should facilitate investigations and enhance continued operational safety. For example, while working on a given occurrence, an investigator should easily be able to verify pending issues in the airworthiness directives system in relation with the Aircraft Make/Model/Series mentioned in the notification. This verification would be done electronically[2] with a high degree of confidence because of the common standard.

Interconnecting safety information systems

Common taxonomies are enabling tools that can accelerate the collection and consolidation of facts during an investigation. This can be done by interconnecting safety information systems (at national or international levels) or by making them interoperable like ASIAS. Studies have demonstrated the feasibility of interconnecting, for example, U.S. and European safety systems, by combining information technologies and common taxonomies.[2] The efforts undertaken by CICTT enable safety information systems to talk to one another (or to be cross-visible) and safety data to have the same meaning in respective systems.

Investigators soon will have easier and faster access to a growing number of data systems for their searches of similar incidents. The challenge is to avoid being buried by the exponential increase of electronic data. "Intelligent" classification schemes are needed more than ever.

Development of tools for incident analyses

During ISASI 2006, Dick Wood stressed that "an incident, properly defined, should be a precursor of a future accident." He also added that if we consult the current lists of incidents, none of them are precursors of accidents by themselves. They may be an initiating event or even a key factor in an accident, but there is always more to the accident than just a single event (Wood, 2006). The majority of these predefined lists of incidents (or taxonomies) deal with "visible" incidents. This means we already know what they are, their causal factors, and their solutions. Because they are generally isolated events caught by the redundant safety nets, they thankfully do not degenerate into accidents. There is a tendency to ignore them. The "real" precursor is a situation that is not "single error safe." Consequently, it becomes crucial to better understand the safety nets of the system and their effectiveness in preventing accidents.

"Hard" and "soft" safety nets

ECCAIRS allows investigators to record technical safety nets[3] as well as to keep track of the failure of the expected function of these "hard" barriers. On the other hand, when analyzing incidents and human defenses, it is not yet possible to keep track of those factors that saved the day, such as a successful third-party intervention or the application of the relevant procedure. These successful human interventions that prevented an incident from turning into an accident or minimized accident outcomes are not currently uniformly recorded in databases, probably because taxonomies illustrate the recent efforts in enhancing safety through the addition of technical safety nets like those available in the ADREP taxonomy. This is more in line with a reactive paradigm where a safety net (a new system or regulation) is added because of an accident, whereas the successful human interventions have not yet been recorded in a standardized way through a common positive taxonomy.

The aviation system has indeed achieved an impressive safety level across time by creating redundant systems and adding safety layers for prevention and mitigation. The "single error safe" system started with the airplane itself. Much of the airplane design criteria are meant to provide a redundancy wherein the failure of any system or part of a system does not lead to an accident (Wood, 2006). This concept has been extended to the other components of the aeronautical system. The Airborne Collision Avoidance System (ACAS), Minimum Safe Altitude Warning System (MSAW), Terrain Awareness and Warning System (TAWS), standard operating procedures (SOPs), and training are examples of "hard" and "soft" safety nets that prevent accidents. However, the effectiveness of these safety measures is difficult to assess. Our safety statistics are presently only using negative indicators, such as accident or fatality numbers.

We need to develop an easy-to-use target taxonomy that would enable "rough" trend analyses of some key safety nets (both "soft" and "hard") of the aviation system. Having better indications of the coverage of these safety nets should facilitate their monitoring and should contribute to reinforcing the resilience of the aeronautical system.

New CICTT "Positive Taxonomy" sub-team

CICTT has chartered a sub-team to develop a "Positive Taxonomy" that aims at better identifying the safety nets and assessing their effectiveness, with emphasis on the successful human interventions. Human factors have generally been considered in relation to accident causes or as performance limitations. The sub-team will—

- consider the human factor as a safety factor,
- record successful human interventions in databases, and
- capitalize on positive taxonomy to increase the resilience of the aeronautical system (Boudou et al, 2006).

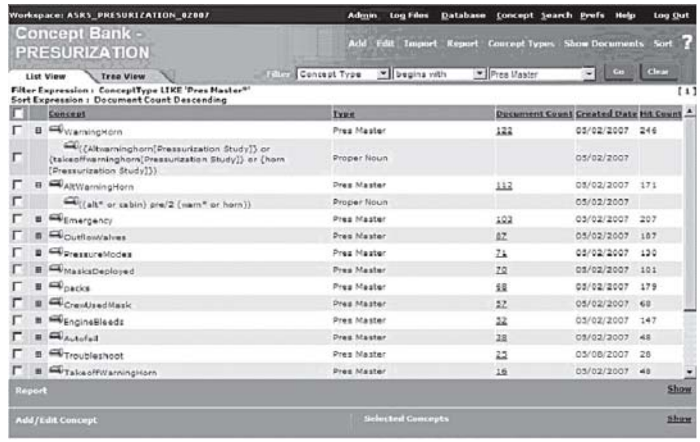


Figure 5. Examples of "concept banks" applied to various text-based data sources.

This shifting from a reactive to a proactive focus is not new. For example, it had been suggested in the following situations (Benner & Rimson, 1995):

- To redirect data acquisition concentration from accidents (which identify causes or operational failures) to incidents (which identify both operational failures and successful recoveries).
- To try to find answers to the question "What went right to prevent it?" instead of "What went wrong to cause it?"
- To acknowledge both the ubiquity of human error and the human capability to recover from errors. Redirect resources toward successful intervention processes that thwart accident progression, thereby focusing on adaptation to error rather than error perpetuation.
- To expand the focus of investigations to include positive factors.

The positive factors mentioned more than 10 years ago are included in the Terms of Reference of the "Positive Taxonomy" sub-team.

New CICTT "concept banks" sub-team

Another major challenge faced by aviation safety analysts is the extensive use of free text to capture important information related to accidents and incidents. Simple facts, such as date, time, operator, altitude, and location, are easily collected using structured data fields. Acquiring a thorough understanding of what happened, how, and why, however, requires a subject matter expert to interpret the narrative component of the report if there are no structured data fields. Accident narratives can be lengthy and complex. Depending on the nature of an analysis, subject matter experts may be required to read thousands of reports. As a result, a safety analysis can be a very time-consuming and expensive undertaking.

One approach to addressing the free-text issue is to develop text-mining concepts. A concept, simply stated, is a collection of words that have been related to a subject. Concepts can be combined to form complex concepts that include word strings and use text-mining techniques, such as stemming and word proximity rules, to assess the strengths of relationships among words.

In a recent study using the concepts for automation and confusion, analysts were quickly able to search 5.4 million records to identify 800 reports for further analysis. Figure 5 illustrates some concept banks in relation with another study on Boeing 737 pressurization events.

The objective of the CICTT Text-Mining Concepts Taxonomy is to develop a shareable collection of concepts (concept banks) and structure them within a taxonomy that will facilitate easy retrieval by the aviation community. The development of concept banks greatly helps in exploiting the current databases that do not operate a common safety language yet. A next step could be merging the concept banks within new structured fields for improved trend analyses.

Better defining of a "serious incident"

These sub-teams are part of a wider effort that has been trying to address the challenge presented by ISASI's president in his opening speech of ISASI 2006 ("Incidents to Accidents—Breaking the Chain"): "To do this right, we will need to sharpen traditional investigative and analytical skills to understand visible, high-risk incidents that come to our attention." (Del Gandio, 2006).

Braking the chain requires having tools to sift through the increasing number of reported occurrences in order to "find that needle in a haystack that might really be worth understanding...." (Del Gandio, 2006). These tools are needed because investigation organizations do not have the time or resources to investigate everything that might be reported under the current reporting rules. This brings up the "serious incidents" that should be the outcome of this sifting process.

As a result of the ICAO Accident Investigation and Prevention Divisional Meeting 1992 (AIG 92), the term "serious incident" was included in Annex 13 and defined as "an incident involving circumstances indicating that an accident nearly occurred." This paved the way for the investigation of serious incidents. How can reality be assessed 15 years after AIG 92? In some countries, serious incidents are treated like accidents by the investigation authority. Even the flight safety departments of many airlines investigate incidents and serious incidents. Nevertheless, not all incidents that should be defined as serious incidents are investigated. It is clear to anyone that the investigation of a serious incident can contribute as much to flight safety as the investigation of an accident with a fatal outcome. It is equally clear that it is nearly impossible to spend as much time and effort on this kind of investigation (Reuss, 2006).

Investigation authorities have stressed the need to bring more consistency to the interpretation of a serious incident. Resources would be well spent to identify serious incidents that avoided becoming accidents because of luck. These serious incidents should highlight the gaps and weaknesses of the system.

How taxonomies help safety investigators and impact Annex 13

The introduction of a "Positive Taxonomy" could help safety investigators in classifying incidents and Annex 13 serious incidents by putting more emphasis on causes rather than on consequences. Most incident lists describe known outcomes whose causal factors (and solutions) are also known. Considering "positive" factors should change the way occurrences are being considered and could help in addressing the challenge of finding new accident precursors. The following short checklist of questions (Boudou et al, 2006) could also be useful:

1. Why did this incident not turn into an accident?
2. Was there equipment, a decision, and/or a procedure that prevented an accident from occurring?
3. In the case of an accident, could it have been more serious?
4. What prevented the accident/incident from being more serious? For example, if a passenger is injured, is it worth considering that his environment (seat, seat belt, etc.) contributed to his survival?
5. Are the results of this occurrence only a matter of circumstances?
6. Was there any human (positive) factor that reduced the seriousness of the accident/incident?

The answer to the last question should be very helpful in classifying an occurrence as a serious incident. In other words, if the consequences appear to be merely a matter of circumstances, meaning that no human positive intervention was identified, then the occurrence could be considered a serious incident and investigated in depth. It could help identify causes that are more difficult to observe than effects.

The introduction of such a taxonomy, as well as the six questions previously mentioned, would help analysts and investigators classify, consider, investigate, and analyze occurrences. It would mean an alteration to the overall framework that should be discussed during the next ICAO Accident Investigation and Prevention Divisional Meeting (AIG 2008 tentatively scheduled in September 2008 in Montreal). Some proposals could include—

- for the short term, guidance material such as a checklist of questions.
- for the medium/long term, common fields in databases to better assess the resilience of the overall system.

If we want to be more proactive, we should collect data that would help in assessing the resilience of the existing safety nets. If for example the first elements of an investigation cannot highlight a safety net, that is, there was no damage nor injury thanks to luck, then the occurrence should be investigated in depth. Common taxonomies are tools that help in shifting focus from consequences to causes.

Weighing the pros and cons

The image of a balance leveraging production goals versus safety goals is commonly used by Safety Management System (SMS) programs. The positive taxonomy aims at completing this tool with a "safety balance" that would leverage the "new" positive factors versus the "usual" negative ones. This should help decision-makers in better assessing the pros and cons of a safety decision. For example, regarding the language issue for air traffic control, authorities in some countries may have to decide about implementing the systematic use of the English language for radio communications in areas with significant international traffic. In such cases, a risk analysis should also take into account the times when the use of the local language prevented a misunderstanding on a non-native speaker from turning into a hazardous situation. To have a more complete picture of the reality of operations, the reporting systems must flag and record the safety nets (that is, positive factors), such as the use of another language, which prevented accidents. If we generalize this example, we need to have a global and common approach to ultimately producing consistent data to give decision-makers a more complete picture of the aviation system.

Roles of safety investigators

Safety investigators are the end-users of data systems in one way or another: Either by entering data or by querying it for investigation or analytical purposes. They are instrumental as they collect and provide the facts on which the safety data is based.

When the Annex 13 tools and resources are applied on serious incidents, safety investigations can explore more in-depth the causal factors with clear cause and effects relationships, especially from a human factors standpoint, because all actors survived and can recollect the circumstances of the hazardous buildup. More investigations on serious incidents shared through the existing ADREP framework could provide quality data, ideally data also recording the strengths and weaknesses of the system.

The next step could be to combine incident, serious incident, and accident data to establish enhanced "reading grids" to better diagnose the risks. This can currently be done in hindsight. Foresight capabilities are on the horizon if we all apply the same approach on serious incidents. Safety investigators could thus mine more similar incidents (precursors?) and build up complete and convincing safety cases powered by more and better data. With more and more documents in electronic format and numerous reporting systems, there is a great potential for enhanced tools (based on common taxonomies) having foresight capabilities.

The safety investigators who provide the facts and data that will ultimately feed these analytical tools should be involved in these expanding new activities. Participation in the newly founded international working groups is more than welcome from both industry and government representatives. The challenge consists of jointly developing a universal set of simple tools, accepted and used by all for data-driven prevention. CICTT could ultimately have an impact on the investigation framework if supported by the various stakeholders, especially by ISASI and its members.

Conclusions

Taxonomies have evolved in line with the scope of investigations (technical failures in the 1950s/1960s, human failures in the 1970s/1980s, and organizational failures in the 1990s). Failures are tied to accidents. As we are moving toward incident investigations, why not have successes tied to incidents?

The rise of the Internet and powerful databases like Google have been under exploited for accident and incident investigations. The resources offer promising safety prospects if everybody shares the same safety language and if taxonomies are transcribed into user friendly tools. The efforts already undertaken by CICTT enable safety information systems to talk to one another and safety data to have the same meaning in respective systems. This common taxonomy is an indispensable tool to define common safety issues and complementary ways to globally enhance aviation safety.

Looking into the future, emerging information technologies will greatly improve our ability to collect data but, at the same time, make it even more difficult to conduct safety analyses. This is because the data management environment is simply not equipped to handle an exponential growth of data. For example, low-cost, sensor-equipped processors are starting to be deployed on everything from aircraft parts to produce in the grocery stores. These sensors can measure and regularly report various attributes such as locations, performance factors, or environmental conditions that are of interest to us over wireless networks. A single airliner equipped with thousands of these low-cost sensors could report various parameters every second. A fleet of these aircraft could generate terabytes of data per day and give new meaning to the expression information overload.

The technology to enable these capabilities is on the horizon. However, if it is difficult to manage aircraft accident/incident reports, how will the information systems adapt to the new technologies and their potential impact? How will value be derived from the new data? How will analyses be conducted and new safety hazards identified?

The CICTT is addressing standardization issues by developing an industrywide consensus as to what business rules and naming conventions should be applied for key aviation descriptors and data elements. The long-term goal of this effort is the development of a core universal aviation language that will maximize the industry's capability to analyze and share aviation safety data and information. The CICTT is nearing the completion of the first phase of the effort and will be moving on to subsequent phases. ◆

References

Benner, L., Rimson, I.J. (1995). Paradigm Shifts Toward Exploiting Successful Human Factors Intervention Strategies to Prevent Aircraft Accidents. In *Proceedings of the Workshop on Flight Crew Accident and Incident Human Factors*, June 21-23, 1995, McLean, VA. Office of System Safety. Washington, D.C.: U.S. Federal Aviation Administration.

Boeing Commercial Airplanes (2006). *Statistical Summary of Commercial Jet Airplane Accidents—Worldwide Operations 1959-2005*. Seattle, WA.

Boudou, B., Pouliquen, Y., Ferrante, O. (2006). Towards a Human Factor "Positive" Taxonomy for Occurrence Analysis. In, *Proceedings of the International Conference on Human-Computer Interaction in Aeronautics*, HCI-AERO, pp. 48-55, September 20-22, 2006, Seattle, WA. Toulouse, France: Editions Cépaduès.

Del Gandio, F. (2006). Welcome to ISASI and Cancun. *ISASI Forum*. Vol. 39, No. 4, p. 3, October 2006.

International Civil Aviation Organization. (2001). *Annex 13 to the Convention on International Civil Aviation—Aircraft Accident and Incident Investigation* (9th Ed.). Montreal, Quebec, Canada: Author.

Menzel, R. (2004). ICAO safety database strengthened by introduction of new software. *ICAO journal*, Vol. 59, No. 3, pp. 19-26, May 2004.

Reuss, J. (2006). Incident Investigation: A Diversion of a Boeing B-747 Resulting In a Serious Low-Fuel Situation. In, *Proceedings of the 37th Annual International Seminar "Incidents to Accidents-Breaking the Chain,"* pp. 66-69, Cancun, Mexico. Sterling, VA: ISASI.

Wood, R. (2006). Defining and Investigating Incidents. *ISASI Forum*. Vol. 39, No. 4, pp. 14-17, October 2006.

Related websites

ASIAS: http://www.asias.faa.gov

CAST: http://www.cast-safety.org

CICTT: http://www.intlaviationstandards.org

ECCAIRS: http://eccairs-www.jrc.it

Endnotes

[1] Throughout this document, "taxonomy" is defined as a classification scheme of keywords and definitions. It can also be considered the "safety language" of information systems.

[2] See the minutes of the Ninth ECCAIRS Steering Committee meeting (Pettenasco, Italy, October 19-20, 2006). http://eccairs-www.jrc.it/SteeringCommittee/1920October2006/Default.htm

[3] Dedicated fields are available in the ADREP 2000 taxonomy for the following:

—GPWS/TAWS (CFIT section in ECCAIRS): Ground Proximity Warning System/Terrain Awareness and Warning System

—STCA (ATM Unit section, attribute 380): Short Term Conflict Alert

—MSAW (ATM Unit section, attribute 370): Minimum Safe Altitude Warning System

—APWI (ATM Unit section, attribute 364): Area Proximity Warning Information

—A-SMGCS (ATM Unit section, attribute 367): Aerodrome Surface Movement Guidance Control System

—ACAS/TCAS alerts (Separation section, attribute 563): Airborne Collision Avoidance System / Traffic alert and Collision Avoidance System

Middle Air Collision Over Brazilian Skies—A Lesson to Be Learned

By Rufino Antonio da Silva Ferreira (Col.), CENIPA-BRA; José Mounir Bezerra Rahman (Col, Ret.), CENIPA-BRA; Carlos Eduardo Magalhães da Silveira Pellegrino (Col, Ret.), CENIPA-BRA; William English (Accredited Representative), U.S. NTSB; and Nick Stoss (Director of Air Investigations), Canadian TSB

Col. Rufino Antonio da Silva Ferreira *is the president of the Brazilian Aeronautical Accident Investigation Commission (CENIPA). e-mail: dipaa@cenipa.aer.mil.br*

José Mounir Bezerra Rahman. *e-mail: mounir@cenipa.aer.mil.br*

Carlos Eduardo Magalhães da Silveira Pellegrino. *e-mail: pellegrino@cenipa.aer.mil.br*

William English. *e-mail: bill.english@ntsb.gov*

Nick Stoss. *e-mail: Nick.Stoss@tsb.gc.ca*



Ferreira ***Pellegrino*** ***Stoss***

Introduction

This paper presents the history of the cooperation between Brazil, the United States of America, and Canada, including its preliminary findings and recommendations, during the major mid-air accident that occurred in Brazil on Sept. 29, 2006.

History

On Sept. 29, 2006, at 19:56.54 UTC, a recently purchased Boeing 737-800, PR-GTD, operated by GOL Airlines of Brazil, and an Embraer Legacy 600 business jet, N600XL, owned and operated by Excelaire of Long Island, N.Y., in its delivery flight to the U.S., collided in flight over the Amazon rain forest approximately 100 miles southeast of Cachimbo Air Force Base in Brazil.

The Boeing 737 was destroyed by inflight breakup and impact forces; all 154 occupants were fatally injured. The Legacy N600XL experienced damage to the left wing and left horizontal stabilizer and performed an emergency landing at Cachimbo Air Force Base. The two crewmembers and five passengers on board the Legacy aircraft were not injured.

Just after the accident occurred, the Brazilian Air Force search and rescue system was put into action. There was a communication search for the GOL, and by the end of the second day the aircraft wreckage was discovered in a dense jungle area.

In accordance with international rules and Brazilian procedure, the Accident Investigation Commission was created on the same day of the accident, and Col. Rufino Antonio da Silva Ferreira was appointed as the investigator-in-charge. In accordance with Annex 13, the first contact with American authorities, as state of manufacture and state of registry was made, and the National Transportation Safety Board (NTSB) team arrived at Rio de Janeiro on October 2 led by William English.

The coordination of CVR and DFDR readout was arranged with the Canadian Transportation Safety Board (TSB). The N600XL CVR and DFDR were the first boxes sent for readout at the TSB laboratory. During the following days, an effort to find the CVR and DFDR of the PR-GTD was made. The team of Brazilian Army mine searchers went into action to find the very last piece of the CVR. By the middle of November they found it.

The investigators of the Commission were able to visit all ATC facilities, Embraer, and Cachimbo Air Force Base, where N600XL still remains. They were exposed to the fact that there were many contributing factors to the accident. In the same way, the investigators were invited to visit the FAA New York ARTCC and the Air Traffic Control System Command Center located in Virginia. The Commission met only once in 2006 to define the main course of investigation. The next meeting of the Commission will take place in July 2007. Since that time, recommendations have been issued to involved parties.

Brazilian structure of investigation process

The Brazilian Safety System is called SIPAER—Sistema de Investigação e Prevenção de Acidentes Aeronáuticos (Prevention and Investigation of Aeronautical Accidents System), and it is responsible for managing both civil and military aviation occurrences in accordance with ICAO Annex 13 and supported Brazilian laws.

It was created in 1951 in order to replace the old military system that was based in Inquires to appoint culpability and responsibilities. It was improved by document Number 57055 from Oct. 11, 1965, when the structure was modified in order to change the main goal to strive for safety and accident prevention. As it evolved, the focus of investigations evolved from an attempt to place blame into an effort toward accident prevention through safety recommendations.

The Center of Aeronautical Accident Investigation and Prevention (CENIPA) is the system's central decision-making body where standards, instructions, and the training are directed. It is the FAR 121 company supervisor for safety. It has seven regional offices to support FAR 135 companies and FAR 91 owners. Having a safety mentality in mind, the Brazilian safety system is now looking for contributing factors instead of causes. The search is called factors and it's divided into three main areas: operational factor, material factor, and human factor. The last one is also divided into human factor physiological aspects and human factor psychological aspects.

We consider that all accidents and incidents are not caused by one main cause but by many situations linked together, so that one by one these links will contribute to an irreversible point of the occurrence. There is no measure or comparison between the contributing factors. All factors should be fully covered with a deep evaluation in order to find solutions to reduce or remove the level of risk, preparing defenses for expected and unexpected human errors and to identify and correct potential or latent organizational problems and material failures.

From another angle, the use of contributing factors reports makes more difficult the use if applied to other purposes rather than safety since there is no appointed main problem. The criminal process normally looks for a main cause or reason that will enable the authorities to find one person or a group to blame.

NTSB structure to support the commission

The National Transportation Safety Board is an independent federal agency charged by the U.S. Congress with investigating every civil aviation accident in the United States (and significant accidents in other modes of transportation), issuing safety recommendations aimed at preventing future accidents, and discharging the accident investigation responsibilities of the United States in accordance with ICAO Annex 13 for accidents that occur outside U.S. territory. As the U.S. is the state of manufacture of the Boeing aircraft and Honeywell/ACSS avionics equipment, and the state of registry of the Legacy, the NTSB named an accredited representative and technical advisors. The accredited representative, per normal NTSB procedure, is an investigator-in-charge from the Major Investigations Division, and coincidentally had extensive ATC experience, including serving as a technical advisor on the Ueberlingen, Germany, midair collision in 2002. Advisors from the NTSB who traveled to Brazil initially included investigators specializing in operational factors (airman activity, training, and certification) and airworthiness (aircraft systems).

Technical advisors from other parties—the Federal Aviation Administration (FAA, regulatory authority) and Boeing—also accompanied the accredited representative. Additional technical advisors assisted the accredited representative on subsequent meetings in Brazil and during activities in the U.S. NTSB investigators in human factors, air traffic control, CVR, FDR, and aircraft performance assisted the accredited representative and appropriate CENIPA group chairmen. Additionally, advisors from Honeywell (manufacturer of transponder, radios, and associated control equipment), ACSS (manufacturer of TCAS), and Excelaire (aircraft operator) participated. Further assistance was provided by the FAA Air Traffic Organization, providing familiarization briefings and visits at U.S. ATC facilities for the CENIPA investigators.

TSB structure to support the commission

The Transportation Safety Board of Canada (TSB) is an independent agency created to advance transportation safety through the investigation of occurrences in marine, pipeline, rail, and air modes of transportation. The Air Branch of the TSB, in part, is responsible for the investigation of all aviation occurrences in Canada, for representing Canadian safety interests in foreign investigations involving Canadian-certified aviation operators and products, and for providing investigation support to foreign investigations when requested to do so. Specific to this investigation, the TSB provided advice on major investigation management and investigation methodology, TSB Engineering support in the areas of CVR and FDR readout and analysis, as well as flight operations and air traffic services operational and investigation expertise. In accordance with ICAO Annex 13, Section 5.23, the TSB appointed an accredited representative and assigned another 11 technical advisors (investigators) to this investigation.

The accident history

Events related to the accident started to build up some days prior. The Excelaire crew arrived at São José dos Campos on September 25 to perform the acceptance flights on the brand-new Embraer Legacy. The crew flew three flights, and a number of items had to be corrected by Embraer. By the end of Thursday, Sept. 28, 2006, Embraer had corrected all discrepancies, and Excelaire agreed to accept the airplane.

September 29 started with a celebration at the Embraer plant—it was the formal delivery party. The flight to the United States was to depart just after the event. Because the flight from Brazil to the United States required one, enroute stop, the crew decided to stop at Manaus. One Embraer employee was flying with them to be the tour guide. To expedite the process, Excelaire asked Embraer for support to file and send the flight plan from SBSJ (São José dos Campos) to SBEG (Eduardo Gomes, Manaus). This flight was performed under RBHA 91 (very close to FAR Part 91). The proposed flight plan called for a route from Poços de Caldas, FL370, until Brasilia VOR, then a flight level change to 360 until Teres interception, then a flight level change to 380 until SBEG. This was because the airway from Brasilia VOR, UZ6, is bi-directional.

At the same time, at SBEG, the GOL 1907 crew was preparing the flight to Brasilia. By the filed company flight plan, the crew was supposed to fly at Flight Level 410. During the preflight checks, the second-in-command (SIC) contacted Manaus Clearance Delivery and asked to fly at 370. It was accepted. This flight was performed under RBHA 121 (very close to FAR Part 121).

The N600XL crew initiated the refueling of the aircraft and performed initial checks but no flight plan was provided to them. At the very last minute, it arrived just in time for the SIC to insert the data into the FMS.

At 1751Z, the N600XL took off from SBSJ to SBEG. The ATC clearance presented to the crew was understood as FL370 direct to Eduardo Gomes (SBEG), without following ATC rules in providing clearance limits. They performed the Oren SID with several intermediate restricted flight levels. At 1833Z, the N600XL reached FL370, which was maintained until the collision, proceeding north-northwest along airway UZ6.

At Eduardo Gomes, the 1907 took off at 1835Z and reached Flight Level 370 at 1858Z, proceeding south-southeast also on the UZ6 airway. Inside the Brasilia area control center (ACC-BS, also known as CINDACTA[1]), sectors 7, 8, and 9, on the north of the FIR were grouped together at ATCO console Number 8 because there was little traffic at that period of the day. There was only one controller at the console, and the number of ATCOs available in the facility at that time did not support more than one.

The last bi-directional radio contact between the N600XL crew and the Brazilian ACC was established at 1851Z. The crewmembers were cleared to maintain FL370 and advised that they were under radar contact. The aircraft was 4 minutes south of Brasilia VOR. No further instructions from ATC were issued to N600XL.

As N600XL passed Brasilia, the ATCO on console Number 8 had only five aircraft to control. The radio frequency assigned to N600XL was the one normally used for sector 9, and the transceiver site was located near Brasilia.

At 1902Z, the N600XL transponder was no longer received by ATC radar, although the airplane was well within the coverage area of many radar sites, and all other aircraft in the area displayed normal transponder returns. The aircraft label on the screen associated with N600XL no longer displayed a mode C altitude, but instead showed the Radar 3D altitude. The ATCO did not take any action.

At 1915Z, a change of ATCO occurred, still working the combined sector 7, 8, and 9. The new ATCO changed the assigned flight level of N600XL to FL360. The ATC software provides, as a feature, an automatic label change. It is the requested flight plan altitude that changes automatically at the right side of the label. Since the ATCO described the N600XL as FL360, the new ATCO change the cleared flight level to reflect that for the entire route.

The relieving ATCO started to call N600XL at 1926z, when the airplane was about 220 miles north of Brasilia. The controller made seven calls, but no replies were recorded.

At 1948z, the pilot of N600XL attempted to call Brasilia ACC. Following the Jeppesen chart, the crew tried twice for each frequency listed. The ATC recorder captured the pilot's tentative calls on two frequencies; however, no response was broadcast.

Three minutes prior to the accident the crew of N600XL heard the Brasilia ACC call in the blind. The controller asked the crew to contact the Amazonic Center at some frequency he could not understand completely. After that, N600XL tried seven more times to contact Brasilia ACC without success.

The Brasilia ATCO contacted the Amazonic ATCO to pass control information on the N600XL traffic. No information about the lack of radio communication was provided.

At 1956:54Z the accident occurred.

At 1959Z the Amazonic Center started to receive the N600XL transponder transmission on the originally assigned code. The code changed to 7700 at 2002Z. N600XL landed safely at Cachimbo Air Force base.

Management of judicial process requests

Each time that an aeronautic accident occurs, two questions immediately come forward. First, what was the cause? Second, who is responsible?

All people involved have different relations and interests related to the tragic event, but all of them have a right to expect a correct answer. So there are two different groups of experts that have different missions but with the same obligation to use their knowledge to find the right answers.

In Brazilian law, two processes are simultaneously opened in the event of an accident: one for criminal purposes and another one for safety prevention. In most cases, the investigators have been successfully dealing with judicial authorities in order to protect the records from the investigation process.

All personnel involved in the aviation safety business understand how important it is for air safety investigations not to be affected by the criminal process. This is particularly difficult when 154 direct losses are involved and hundreds of people's lives are affected forever.

Section 5.12 of ICAO Annex 13 covers the real possibility of the appropriate authority for the administration of justice of the state conducting the investigation and determining the disclosure of the records. It is important to note this is not necessarily unique to Brazil. The great social and political pressures to determine specific criminal liability could be the same in a large number of countries around the world.

Brazilian accident investigators have not been in a comfortable situation as they don't have any kind of protection or right to refuse the judicial determination specified by the document OF/GABJU number 240/2006 from November 13 signed by a federal judge. The judge required that, within 48 hours, the accident investigation commission release to the president of the police inquiry all material under guard of CENIPA, including DECEA (Brazilian ATC Department) material in custody, preliminary reports from both organizations, transcriptions from both the CVR (cockpit voice recorder) and FDR (flight data recorder). The only thing to do was to accomplish the request. However the Brazilian Accident Investigation Commission strictly followed Annex 13, 5.12, in that parts of the records not relevant to the analysis were not disclosed.

The Brazilian authorities with a background in safety investigation have long considered that we might need to change some of our practices. But the challenge that we have encountered is how to change in the middle of reality where the pilots and ATCOs involved refuse to cooperate with a safety authority in order to avoid taking on the risk of the threat of prosecution.

The release of a great deal of information normally controlled by the accident investigators, such as radar data, CVR transcripts, and training records, made public in the course of the criminal investigation as you have already seen is a fact.

This accident has brought all the theoretical discussion to reality; we have seen the chilling effect of threatened criminal prosecution directly influence the ability to conduct a thorough and unbiased safety investigation.

The events over the past year in Brazil, and others around the world, such as the recent trials in Europe stemming from the Ueberlingen collision, lets us know, in no uncertain terms, that accident investigators will be working toward our goals in parallel with organizations responsible for determining potential criminal liability.

We may need to change some of our practices, and we must acknowledge the challenge that we have encountered firsthand that the criminal threat will prevent some people involved in the accident from cooperating with a safety authority or at the very least will taint their information. Unfortunately, there is no easy answer for this. We found a great deal of difficulty when working in the U.S. on this case because of the threat of prosecution.

Additionally, the appearance of documents made by parties to the accident investigation but used for legal defense purposes blurs the line between the two efforts and confuses the public and the aviation industry. Such documents or other information releases that may bear a resemblance to accident files, findings, or reports, and include some technical information typically associated with air safety investigations may in reality only include those facts supportive of a particular side in a legal case, or be grossly misunderstood and misinterpreted by non-technical persons.

Criminalization directly affected the information gathering efforts of the investigators. For example, the flight crew of the Legacy had not been interviewed by trained aviation accident investigators since the early days after the accident. As the team developed more information, it was important to have a thorough discussion with the crew and the operator. Both the pilots and the operator expressed a great desire to cooperate with safety investigators yet at the same time had a very realistic fear that their words would be used against them in court. Because the accident occurred outside the U.S., the NTSB had no authority to issue subpoenas and compel the crew and company to cooperate. Months after the accident, after the crew had returned to the U.S., NTSB investigators and legal staff spent many long hours working with Excelaire and its legal representatives to come to a workable solution to have thorough crew interviews, and an examination of the operators facility, records, and practices. In this case, the Excelaire legal team decided that the risks of having Brazilian government personnel involved firsthand were too great and asked that only U.S. government personnel conduct the interviews.

This, of course, made it difficult for the Brazilian Investigators, as questions prepared in writing are never as desirable as a firsthand discussion. In a similar vein, proposed interviews and data gathering activity at the main training vendor, Flight Safety International, were also prevented due to fear of prosecution. At first, FSI was open to the investigative activities, but later refused to cooperate with either Brazilian or U.S. investigators to provide interviews with relevant instructors, or documentation of the Legacy crew's training. It is an interesting aside that the requested flight crew training documents did turn up in court papers filed later on.

We also must understand that our attitude about what is important for safety may be different from what a prosecutor may be looking for. In May of 2007, the NTSB released a recommendation about cockpit warnings for loss of TCAS or transponder function. To readers with an air safety mindset, we reason that a message that is not easily seen or responded to is an avenue for a safety improvement. Prior to this accident, the loss of TCAS functionality was not considered a flight-critical item; but with the knowledge gained in the investigation, we recommend that the operating status is important enough to warrant a more robust warning. However, the very same information from a point of view that requires finding a responsible party could imply that the responsible person was not diligent or missed something he shouldn't have. We are seeing the same types of differing opinions on how ATC issues are involved in the accident. At the time of this writing, the criminal and congressional inquiries in Brazil are pointing toward ATC lapses and focusing also on identifying a responsible person or persons, rather than evaluating safety issues.

National commotion during hard transition times

The accident was a nationwide event. A total of 154 lives were lost in the middle of the Brazilian rain forest. The first days started with the hope that survivors could be found. The Brazilian SAR aircraft were continually in flight over the jungle to discover any sign of life.

By the middle of the following week, the full impact of the disaster came over the nation. It was hard to measure the sadness.

The airline and the civil aviation authority put the family support plan into action. A hotel at Brasilia was selected to be the headquarters of the support. Health, psychological, and religious support were given to the families.

At the crash site, an Air Force command and control center was created. Several aircraft were used to support the operation. It took a month to find the CVR and the DFDR of the 1907.

In the mean time, there was the election of the president of Brazil. The media used the accident history to change the poll output. It tried to show the budget reduction on the ATC was due to restrictions of the current president.

The families of the accident victims were flown to the crash site. For them it was the last goodbye.

For the recently created civil aviation authority (ANAC), the accident was the worst-case scenario. There was a great deal of miscommunication with the media.

Currently the ANAC has a plan to be activated on these events. It is based on ICAO Annex 17 and covers all aspects of an accident.

The pressure of the nation wide commotion drove both the criminal and safety investigation.

U.S.-Brazil cooperation

Immediately after learning of the accident in Brazil, the NTSB realized that we would be involved via our Annex 13 responsibilities in a very complex manner. NTSB investigators participate very often as representatives of the state of manufacture, particularly with Boeing aircraft, and the large U.S. engine manufacturers. However, this accident investigation would quickly prove a more unique situation as it was the first time in many years that a major accident occurred outside the U.S. involving a U.S. operator. At the first word that the accident might have been a midair collision, and that the airplanes were both very new and technically advanced, we realized that there might be a question about collision avoidance equipment, so the U.S. was now also the state of manufacture of a major component of interest, namely the transponder and TCAS.

An investigation team was formed and traveled to Brazil during the next days. Three NTSB investigators, and representatives from the FAA and Boeing traveled immediately and representatives from Excelaire, Honeywell, and ACSS provided support from home. The U.S. and Brazil have a long history of working together in accident investigation, as of course both nations are home to major airframe manufacturers. However, quite early on it was recognized that this accident was going to be very different. By the time the U.S. team had arrived in Brazil, the criminal inquiry had opened, and the U.S. pilots had been prevented from leaving the country.

As previously mentioned, it was difficult to conduct a safety investigation during an ongoing criminal investigation, and the effects began to be noted right away.

The first complication was with access to the flight crew of the Legacy. As U.S.-certificated airmen, it was imperative that the U.S. team gather all possible information on the crew, including background experience, training, and operational knowledge of international flying. However, due to the high level of attention and controversy from the judicial proceedings, officials from both governments, and the pilots' legal defense team, decided that it would be inadvisable for the team to interview the crew while they were in Brazil. Effective interviews of surviving crewmembers must be timely and detailed, but in this case, the judicial activities had already intervened and potentially influenced the crew.

An additional complication, and one still persisting, involves the operating environment, mainly ATC, and the way that the flight crew relates to ATC procedures. Early on in the course of the judicial investigation, many statements that dealt with ATC and flight procedures were made by people in positions of authority and were widely reported in the media.

Pilots in the U.S. and elsewhere were confused by many statements, and knowing nothing other than what was reported in the media, began to wonder if there were some differences of procedure or of expectation in the ATC system of Brazil that they should be aware of. One specific example had to do with the expectation of crew actions when they had filed for an enroute change of altitude in the ICAO flight plan.

Initial statements implied that flight crews should, under normal conditions, change cruising altitude regardless of ATC instruction. This is of course not the case, but it clearly illustrates how the complex interrelations of ATC procedures and rules of the air can be easily misinterpreted by laymen and creates confusion. While there are numerous differences between ATC procedures in the U.S., and those described in ICAO Annexes 2, 11, and in the ICAO 4444, (Brazilian ATC procedures have fewer differences from ICAO guidance) basic ATC clearances and concepts must be quickly understood by flight crews. It is imperative that both sides of the microphone have the same understanding of what is expected of themselves and the other side. This is a clear example of one role of the safety investigation—by exposing facts of the accident in their proper context, questions can be cleared up in the minds of the industry, or conversely, if a safety issue is uncovered it can be quickly acted upon.

As we have seen, no aspect of an accident exists alone—it is also important to note the low level of situational awareness displayed by the N600XL crew during the flight. According to the CVR data, they demonstrated more than once a lack of familiarization with ICAO rules as they never discussed previously together the flight plan due to an inefficient sharing of tasks during the preflight checks. [Note—The lack of awareness of the extreme length of time with no communication is also an indicator.]

Clearly, ATC issues are one important and relevant point to understanding how this accident took place. Early in the investigation process, the investigative team was able to review some ATC information, and further team visits to CINDACTAs 1 and 4 further clarified the events that occurred within the ATC system. Brazilian, U.S., and Canadian ATC experts cooperated in revealing many safety issues that are still being examined. For example, numerous features of the ATC software may have come together with just the wrong timing to reinforce some erroneous controller assumptions about the flight.

Automatic updating of cleared altitude in the data blocks, display of search radar 3-D feature when transponder mode C is lost, methods of handing off data blocks and coordinating ATC information may have had the unintended consequence of reinforcing assumptions about what the crew of the Legacy was supposed to do. It is imperative that investigators not only understand the technology behind a safety issue, but also to understand how well the users understand it.

When an anomaly occurs, such as the loss of the Legacy's transponder, do the users—that is, the ATCOs—truly understand how the technology will react? Are the procedures for dealing with anomalies robust, clear, and widely understood? Technology is not the only part of the ATC story either. There has been much speculation about so-called "black holes" in the Brazilian airspace. This is a great misunderstanding of how ATC operates. Since air traffic control began, limitations in radio communications, navigation, and later radar have been part and parcel of the procedures and training used by ATC. To imagine that there should be perfect coverage of radio-based equipment is unrealistic—but the system must use established concepts for dealing with known limitations in the technology. For example, loss of a transponder or radar return is simply dealt with by use of non-radar ATC procedures, such as obtaining position and altitude reports, time estimates, and suspension of RVSM. Gaps in direct radio communication coverage can be accounted for by appropriate allocation of transceiver sites, issuance of clearances including such items as crossing restrictions downstream or use of relays through other outlets. None of these concepts requires great outlays in expenditure; they only require a robust set of procedures and training.

In supporting the effort to determine just what features of ATC technology, training, and procedures were applicable to the accident, the team also examined U.S. ATC facilities. Thanks to the FAA, Brazilian, U.S., and Canadian investigators were able to examine real-time operations, and obtain detailed briefings at the New York Air Route Traffic Control Center, the ATC System Command Center, and at FAA headquarters with an eye toward the issues that occurred in the CINDACTAs—lost communication procedures, loss of transponder or radar contact, and handoff and coordination procedures between ATC sectors. At the time of writing this draft, the ATC investigators working on this issue have collaborated on more than 12 draft recommendations regarding ATC.

Further coordination and cooperation between the Brazilian and U.S. investigative teams regarded the examination of the critical avionics equipment from the Legacy airplane. Radio and transponder units, control heads (called RMU, or radio management units), and TCAS were extensively tested. Test plans developed among Embraer, Honeywell, ACSS, and CENIPA and NTSB investigators were used for testing "on wing" in the airplane while at Cachimbo, and the pertinent components were removed for more detailed bench testing later on. Further detailed and exhaustive test plans were developed to examine two levels of function—first, the avionics components were run through a full battery of tests to confirm the actual electronic and mechanical function was as designed. Separate plans were developed, based on the outside evidence, such as ATC radar records and communication recordings, and internal evidence, such as fault and maintenance logs recorded within the units, and correlated with CVR and FDR data, to determine what scenarios for possible inadvertent entries might lead to the observed results. It is important to note how deeply the test plans were designed and executed—Honeywell and ACSS worked together for months to construct an integrated bench test. Investigators from CENIPA, the NTSB, the FAA, Embraer, Excelaire, and the avionics companies all had extensive input to ensure the test plans were as complete and accurate as humanly possible. In order to develop meaningful and relevant safety information, test plans for such complicated systems as modern "glass cockpit" avionics must include all of the available evidence—it is not sufficient to simply get in a cockpit and push buttons! False results leading to inappropriate responses could lead to dangerous, unintended consequences. In our case, the results of months of planning and testing found no mechanical, electrical, or software problems with the avionics components. An NTSB cockpit voice recorder group created an English language content transcript of the Legacy CVR, then careful correlation of the CVR and ATC background audio revealed no failures or inadvertent entries in the VHF communication systems. By comparing the ATC-pilot communications with a chart of the radio frequency coverage in the area, it was clear that the Legacy pilots did not change frequency inadvertently and stayed on the last assigned frequency until they had flown beyond the range of the transceiver site. All equipment was working properly—within its expected limitations. Thorough testing of entries into the RMU and other inputs revealed no undesired results from entry combinations—no "bugs" or undocumented "features." After that, we were left with nothing but the possibility of an inadvertent, physical selection of an undesired mode that was not seen by the crew until after the collision.

Early on in the investigation, based on cues in the CVR, investigators began to look at how the audible alerts (master caution etc.) worked in the Legacy. Initial auditions of the CVR revealed a tone, similar to a MCAU, just a few minutes before the collision. The pilots revealed that a passenger had opened a rear door of the cabin to access a baggage compartment, which activates the MCAU due to breaking the fire protection.

On the ground in Cachimbo, investigators confirmed this was true and contrasted this with the fact that switching the transponder to "Stand by," which causes the returns to vanish from ATC and other aircraft TCAS displays, and disables the own-aircraft TCAS, makes no audible alert, and causes only a status indicator of "STBY" on the RMU display and "TCAS Off" on PFD/MFD displays (depending on configuration). These status messages are static, in non-warning colors (green and white, respectively), do not correlate with any audible message, and do not require acknowledgement by the crew. This hypothesis was thoroughly examined during our test protocols; and while these features were completely within certification standards, and very common in any avionics suite, the circumstances of the accident led investigators to conclude that this was not desirable in today's environment. Therefore, this past spring, the NTSB issued Safety Recommendations A-07-035 through –37, which urged "that the airborne loss of collision avoidance system functionality, for any reason, provide an enhanced aural and visual warning requiring pilot acknowledgment." While not concluding that the loss of transponder was causal to the accident, the safety issue is an important result of our international cooperation, and potential improvements in safety even prior to the conclusion of the accident investigation.

Canada-Brazil cooperation

TSB investigation support planning

From the perspective of the Transportation Safety Board of Canada (TSB), the first indication about our possible involvement with this investigation came to the TSB as a rumor through the media. TSB's initial reactions were to confirm the rumor by contacting the DIPAA directly and through the NTSB, and to determine whether TSB had the required technical equipment to read out the recorders on board both aircraft, and if we had the capacity to take on the addition workload.

TSB planning also considered the fact that if the TSB was requested to read out the recorders, Canada, under the provisions of Annex 13 Section 5.23, would be entitled to accredited representative status in this Brazilian investigation. Of greatest importance was the fact that the TSB would be able to properly protect all investigation information to which it was given access, in particular the CVR, DFDR, air traffic recordings, and witness testimony.

Also, the most important principle for the TSB was that this was an investigation being conducted by the DIPAA, that all our work would be conducted under the direction of the DIPAA IIC, of course respecting Canadian laws, as well as TSB legislation, policies, and investigation principles.

TSB reaction to CENIPA request for support

This preplanning was very valuable because, when the TSB received the official request for support from DIPAA (the investigation commission), it was able to quickly ascertain that DIPAA was requesting support in the readout and preliminary analysis of the CVRs and DFDRs from both aircraft, and able to confirm that the TSB could do the investigative work requested in a timely manner. Also, when DIPAA granted accredited representative status to the TSB, this action facilitated our involvement in the investigation and our ability to conduct our work under ICAO Annex 13 standards and recommended practices, including the protection of investigation information.

To support the DIPAA investigation, the TSB appointed an accredited representative and technical advisors in the areas of flight operations, flight recorder readout and analysis, air traffic services, and investigation management. The TSB also provided the IIC with advice and support on media relations while he was in Canada. During our preliminary discussions with the IIC, we were also able to determine who would be participating in the investigation work being done in Canada. In essence, in addition to the TSB accredited representative and seven TSB investigators, and the DIPAA and two investigators, the investigation team in Canada would include representatives from CENIPA, Embraer, GOL Airlines, the NTSB, and Boeing.

TSB's next action was to contact the Canadian Department of Foreign Affairs and the Canadian Air Transport Security Agency to establish procedures necessary to ensure that problems would not interfere with the transportation of the DIPAA investigators and recorders while they were in Canada.

Readout and preliminary analysis of recorder information

The flight data recorder and cockpit voice recorder from the Legacy aircraft were hand carried to the TSB on the afternoon of Oct. 10, 2006. Because the Legacy recorders were undamaged, the downloading of these recorders commenced immediately on receipt. The next morning a CVR audition group listened to the entire 2 hour CVR recording. Subsequently, it was decided that only a partial transcript would be required. In parallel, the FDR data analysis was started.

The Boeing FDR and CVR were hand carried to the Engineering Branch on Oct. 11, 2006. However, the crash survivable memory unit (CSMU) was missing from the CVR chassis. It was later found and brought to the Engineering Branch on October 30 for download. Both flight recorders from the Boeing aircraft, due to their damage, required the use of bench units to download the data. In both cases, the memory was installed on a bench unit and successfully downloaded.

The FDR data for the Boeing and Legacy aircraft were validated and time synchronized based on the time of impact. In addition, the Boeing CVR data were time synchronized and audio clips were selected for inclusion in a flight data animation. A preliminary flight animation was produced to assist in the analysis of the data. The preliminary flight animation was provided to the DIPAA and other accredited members for their review and comment.

Prior to departing Canada, the IIC was provided with the FDR data plots, FDR data files, CVR audio files, CVR transcripts, and the flight animation. The refinement of FDR data analysis and the flight animation continued, and all results were shared with the members of the investigation.

Investigation management support

While in Canada, the IIC requested and was provided with TSB advice on investigation planning, investigation methodologies, potential safety issues, and other areas of investigation interest. It was during this process that the IIC made a specific request for air traffic control investigation expertise for the investigation.

Air traffic services investigation support

In response to this request, the TSB sent one of its senior investigator air traffic service specialist to Brazil for a period of 5 days.

The TSB investigator arrived in Rio de Janeiro late Monday afternoon, Nov. 6, 2006. The next day, on Tuesday, a team briefing was held, which included the Brazilian investigation team, NTSB representatives, and the TSB investigator. Areas covered during the meeting were the flight's background information, as well as the sequence of events known to date, including the safety-significant events and current status of the investigation. The follow-on investigation plan, in particular the work of the Air Traffic Services Group, was the product of this meeting. The data collection plan included, in part, all voice and radar data recording, inter-unit letters of agreement/procedures, coordination/handoff procedures of the ACC to ACC, controller to controller sector handover procedures, training, use of checklists, communication/radar coverage, radar holes, blind spots, radar display contents and formats, procedures for the events of communication and radar information/display problems, controller workload, on duty and rest times, and fatigue factors. In-country travel for the investigation team was coordinated and provided by the Brazilian military.

That evening, a small team, including the IIC, five Brazilian investigators, the NTSB representatives, and the TSB investigator departed for Brasilia.

The next morning, November 8, the group visited the Brasilia area control center (CINDACTA I). After a briefing on the operations, the group viewed the operations area and then viewed a replay of ATC radar and voice recordings. There was no opportunity to proceed to the operations floor or to interact with controllers directly. The group then departed for Manaus for a visit of the Manaus ATC area control center (CINDACTA IV), again via Brazilian military conveyance. A tour of the facility and replay of radar information followed directly after our arrival. Although time was short, some interaction with the duty control staff was possible.

The group returned to Rio de Janeiro the next day, Thursday, and spent some time preparing for a closing meeting planned for Friday. The entire investigation team was present for that meeting and provided an update on the activities undertaken in the last few days.

Prior to departing Brazil, the TSB investigator, with the concurrence of the NTSB representatives, provided a list of potential safety issues and further areas of investigation for the benefit of the IIC and his team.

TSB continuing support

The TSB has continued to support the investigation by responding to DIPAA requests for additional data analysis and investigation advice and participation in the investigation Recorders Group and Air Traffic Services Group.

Lessons learned

The lessons taught by this tragic accident are not finished yet. On the surface, this accident appears very complex—there are tight links and interrelations between the ATC and flight operations areas, understanding of the typically arcane ATC rules and technology, determining how two airplanes with state-of-the-art collision avoidance technology can collide. But all those subjects can be understood; there was no real ground-breaking technical investigation that needed to be done to find our answers.

Some of the work was not easy. We may never know why certain actions were not taken in the ACC. We never know why the transponder went off in the Legacy, but we have plausible scenarios—the "probable" cause concept. More than that, we have solutions—recommendations already made, and soon to come, should help prevent a recurrence. So the lessons we learn are not of the technical nature; those were easily enough broken down, but they are of the human nature.

It is not possible to properly investigate an accident by looking piecemeal at individual subject areas. ATC procedures are meaningless without understanding the flightcrew reactions and expectations. The flightcrew interface with the avionics is as important as understanding the technical status of the systems (which circle back to their own interface with the ATC radar and radio systems). During the course of this investigation, the criminal investigation was always overshadowing any of these interface areas of investigation, causing the different parties varying levels of distrust about motives. For example, although all parties participated in the avionics testing in the U.S., there were lingering questions about what non-safety-related people may have done in the Legacy airplane at Cachimbo, and various theories were put forth in court, which used selected portions of information gathered in the testing.

Similar concepts have been seen in the ATC area as well. Although the safety investigation has been blocked from much interaction with the ATCO due to the criminal process, the public pronouncements by different entities involved with ATC were contradictory and confusing to airmen around the world. Of course, such things have gone on throughout the history of aviation accident investigation, but in this case, the overwhelming presence of the criminal case has drowned out the voice of the safety investigation.

On January of this year, the commission released eight preliminary safety recommendations:

a. Review the Brazilian AIP, in order to update it, with emphasis on the inclusion of rules and procedures of the Brazilian Air Traffic Control.

b. Train the ATCO in the correct procedure accomplishment in the Air traffic control clearances, as defined in items 8.4.8, 8.4.9 and 8.4.10 of ICA 100-12 Air Rules and Air Traffic Control Services.

c. Assure the level of English proficiency for all ATCO of the Brazilian Air Traffic Control System, as well as provide the necessary means to fulfill the ICAO Annex I SARP and Doc. 9835.

d. Ensure the adherence of all ATCO to follow all the handover procedures for sectors or adjacent centers.

e. Ensure that written procedures for lost communication are completely followed by all ATC units.

f. Ensure that all ATCO attend specific ATC rules and procedure training classes, considering the recommendations on letters b), c), d), and e) of this document.

g. Standardize and operationalize the use of the OFF SET feature in the lack of communication and or radar coverage regions.

h. Implement a new presentation (effective alert system) of loss of transponder mode "C" in the ATC software in use, in order to increase the ATCO situational awareness. ◆

Conclusion

The midair collision accident of GOL 1907 and the Legacy N600XL was a nationwide event. It created a need to find not only new defenses for the aviation systems but also a criminal responsibility.

These parallel needs created difficulty for the safety investigation in both Brazil and the U.S.. People do not want to be interviewed; and if they agree, their information is colored by the fear that their words will be handed to the police by court request.

To avoid part of this problem the cooperation among Brazil, the U.S., and Canada created an excellent atmosphere of work sharing—with their findings always toward the idea of prevention.

References

ICAO. Annex 13 to the Convention on the International Civil Aviation Convention—Aircraft Accident and Incident Investigation—Ninth Edition. Canada.

Brazil. Air Force Command. CENIPA. NSCA 3-6 Investigação de acidente aeronáutico, incidente aeronáutico e ocorrência de solo. Brasília. 2003.

Endnote

[1]Brazil. Air Force Command. CENIPA. NSCA 3-6. Investigação de acidente aeronáutico, incidente aeronáutico e ocorrência de solo. Brasília. 2003.

Convair 580 Accident Investigation: A Study in Synergy

By Ian McClelland, Transport Accident Investigation Commission (New Zealand)

Ian McClelland *spent 22 years with the Royal New Zealand Air Force flying both helicopters and heavy transport aircraft. He completed postings in Antarctica, Southeast Asia, and the Middle East, and flew extensively around the Pacific, and to a lesser extent Europe and North America. As the commanding officer of the central flying school, McClelland was responsible for RNZAF instructor training and standards and led the formation aerobatic team for three years. On graduating from the senior staff college, he assumed responsibility for managing the Air Force safety office and all aircrew training and standards. He joined TAIC in 1998 and has led more than 30 investigations. He holds ATPL airplane and CPL helicopter licenses and was an A-category fixed-wing and rotary-wing instructor.*

Introduction

On Friday, Oct. 3, 2003, Convair 580 ZK-KFU was on a scheduled freight flight from Christchurch to Palmerston North. At 2126 hours, shortly after passing Paraparaumu (north of Wellington) in descent, the aircraft was observed on radar to enter a left turn and disappear. No radio calls were made, and attempts to contact the aircraft were unsuccessful. A search for the aircraft and its two pilots was commenced immediately. The Transport Accident Investigation Commission (TAIC) was notified soon after, and at 2305 I was appointed the investigator-in-charge.

I will shortly review the major milestones in the investigation, and demonstrate that only by working in conjunction with other organizations were we able to identify all the contributory factors and determine the probable cause of the accident. While this principle can be applied to any investigation, it is especially crucial for smaller agencies like ourselves, where we rely heavily on our fellow organizations to help provide those additional pieces of the jigsaw.

ZK-KFU

That is why events like this seminar are essential in ensuring we keep pace with those omnipresent developments in our aviation-orientated world, and continue to foster contacts and good lines of communication between our organizations to promote aviation safety. Only through this process can we hope to achieve our joint aim of identifying as many of the contributing factors as possible in an accident and thereby prevent a reoccurrence.

Convair 580 ZK-KFU

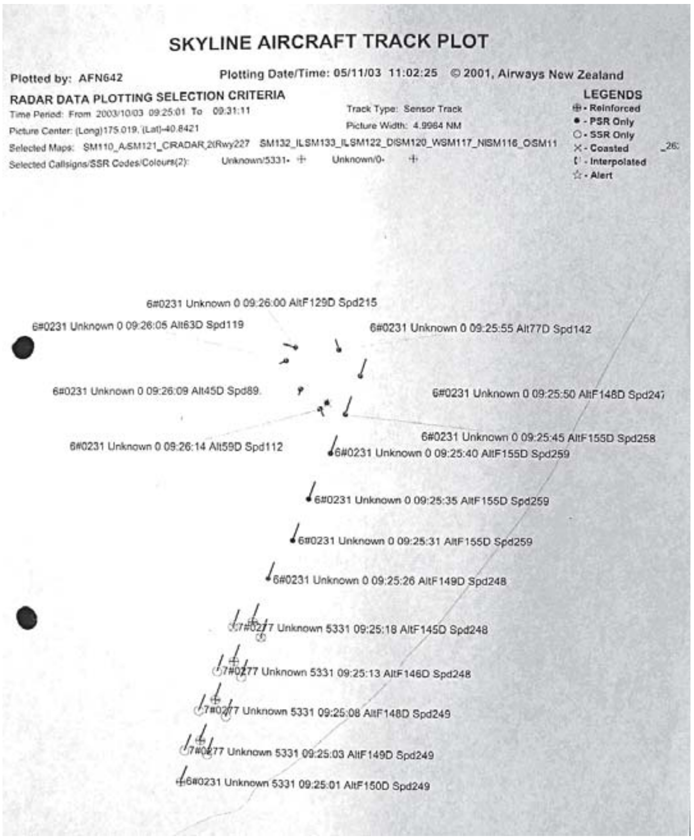
ZK-KFU was a dedicated freighter that primarily carried mail and courier packs. The aircraft was powered by two Allison 501 turboprop engines and had a maximum all-up weight of 26 450 kg. The aircraft departed Christchurch at 2032 and proceeded uneventfully north at Flight Level 210. At 2113, ATC cleared the aircraft to descend initially to 13,000 ft. At 2125, after a further descent clearance, ZK-KFU was instructed to change frequency to Ohakea Control.

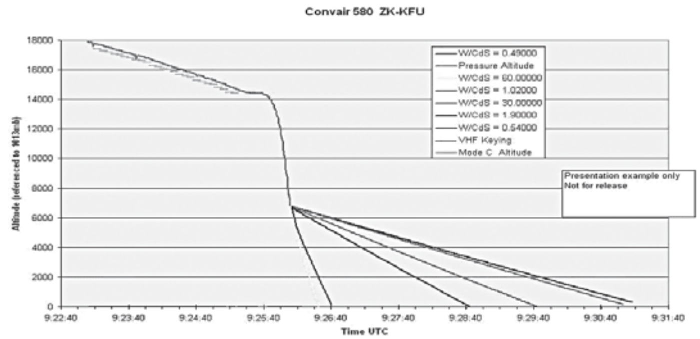
Ohakea cleared ZK-KFU to descend to 7,000 ft and passed on the ATIS information and joining instructing for Palmerston North. The copilot correctly repeated back the clearance but omitted the amended QNH. The controller asked for confirmation of the QNH, but there was no response.

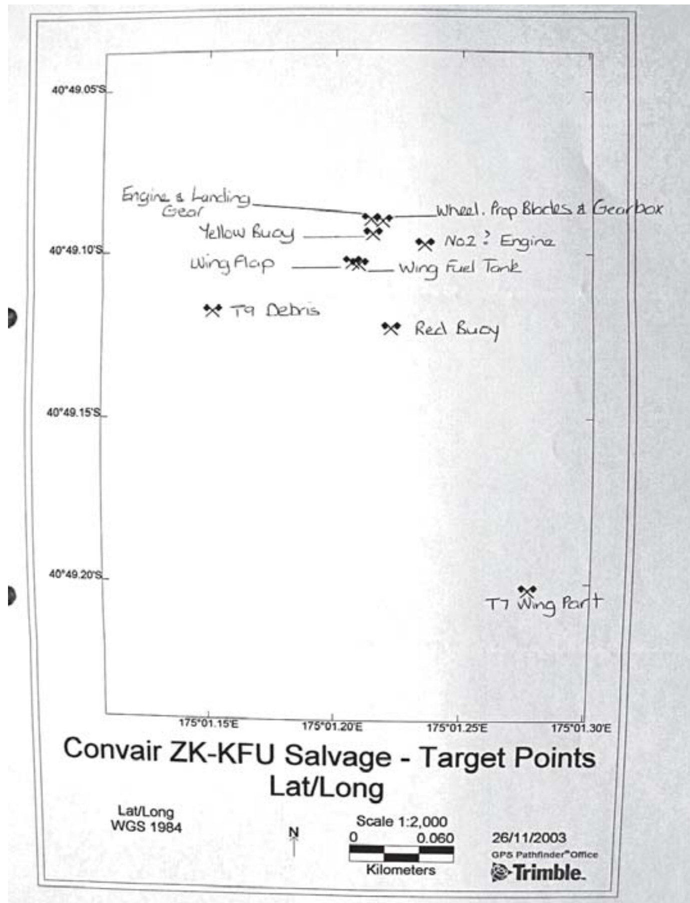
Shortly after, the controller observed ZK-KFU on radar enter a tightening left turn and disappear from the screen. About an hour later, debris identified as coming from the aircraft was found washed up along the shoreline. An aerial search by Air Force helicopter using night vision devices located further wreckage offshore, but no survivors.

This was an experienced crew, with the captain having flown nearly 17,000 hours, including 3,300 hours on type. The copilot was less experienced on type with 194 hours, but had more than 20,000 hours total experience. Both were in good health.

More than 1,000 Convairs in a range of variants were produced. Some 170 of these were later converted to 580 status; and with more than 80 still in service around the world, including 10 in New Zealand, it was important that we recover the aircraft and determine the cause of the sudden departure from controlled flight.







The investigation

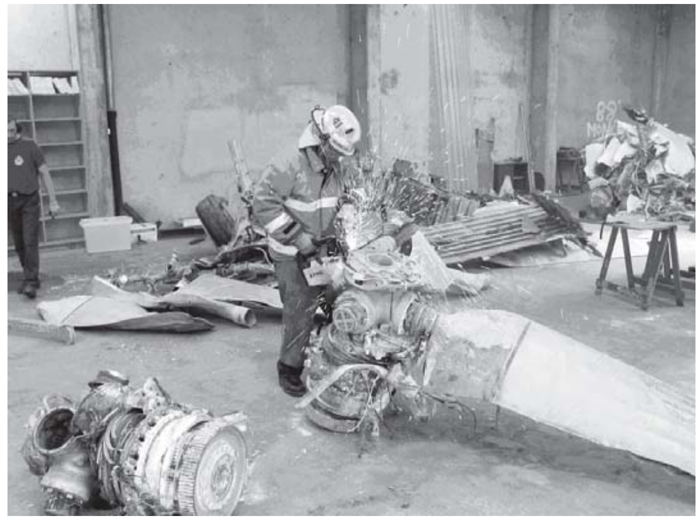
The first challenge was to locate and recover the aircraft. A marine salvage company and the Navy were given the task, and using side-scanning sonar located a possible wreckage field in 110 ft of water about 4 km offshore. The area was subject to strong tides with divers often working in visibility of less than a meter. However, after 12 days both pilots were located and the recovery of wreckage commenced.

A plot of the wreckage identified that the aircraft had likely broken up in flight, but the close proximity of the engines, propellers, and undercarriage raised questions about the height of the break-up. To add to the conundrum, light paper articles littered the beach areas, and four pieces of aircraft paneling were found spread in a line up to 3 km in land. With the assistance of the NTSB, the characteristics of the paneling, location found, and known wind were analyzed and a possible trajectory determined. This was combined with the radar track and mode C information to identify a break-up point.

In all, about 70% of the aircraft by weight and 15% of the cargo was recovered for examination. No dangerous goods were reported being carried or found. The Commission received assistance from Rolls-Royce (Allison), who sent out an investigator to review the inspection of the two engines. Both engines were found to producing power at the time of impacting the water.

The propeller hubs were sent to Pac Prop in the States and under NTSB supervision were examined. They were found to be operating normally at time of impact. With the assistance of TSB Canada, aircraft and performance information was sourced from the type certificate holder Kelowna Flightcraft, Transport Canada, and the National Research Council. The FAA also provided valuable supporting information.

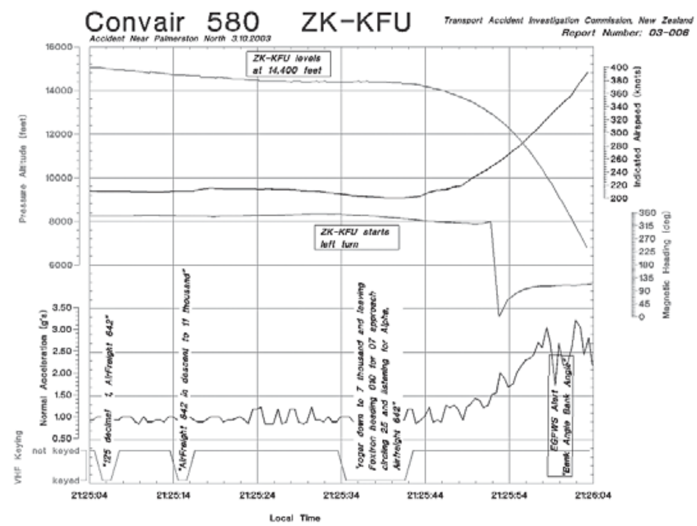
Across the ditch, the Australian Transport Safety Bureau (ATSB) worked on the DFDR and CVR. Unfortunately the CVR, although

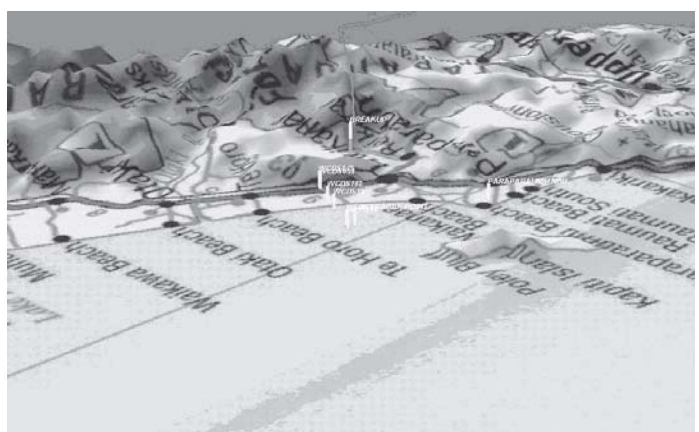


testing satisfactorily, only recorded VHF radio transmissions and no cockpit voice. This was a huge setback to the investigation, but we were able to extract engine noise, indicating that at the time of the last transmission both engines were operating normally.

Fortunately the DFDR provided good quality data and held a record of the full flight until descending rapidly through 6,800 ft. This matched the trajectory of those pieces of paneling found over land. The ATSB and NTSB were together able to determine that after leveling at 14,400 ft, the aircraft rapidly went to a 60° to 70° nose-down attitude, with a descent angle of about -70° increasing to -86° approaching 6,800 ft—at which stage the aircraft was doing 392 kts and pulling about 3.25 G.

Back in New Zealand, the MetService provided the weather information surrounding the event. Given the timing and routing of the flight, the meteorologists were able to determine that ZK-KFU descended through the trailing edge of a very active front. The conditions were conducive to turbulence and severe icing. For unknown reasons, possibly turbulence, the aircraft was leveled and slowed in this band of icing before suddenly departing controlled flight.





Finding

The investigation determined that ZK-KFU had descended through an area of severe icing and stalled after flying level for a short time. The crew was unable to recover from the ensuing spiral dive and the aircraft broke up as it descended through about 7,000 ft.

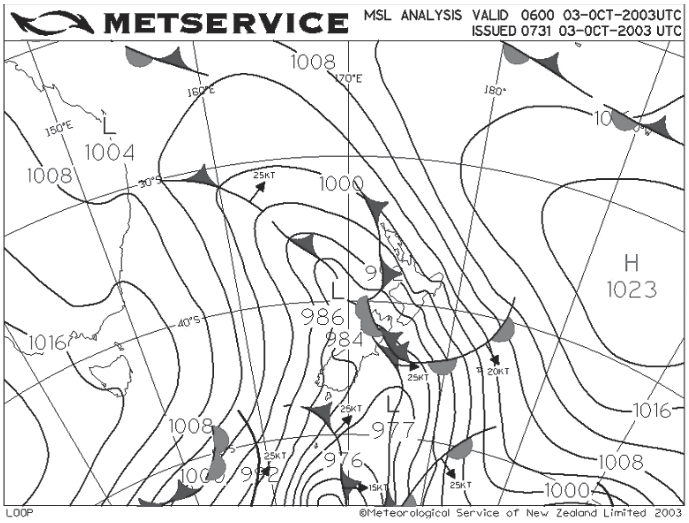
Coordination

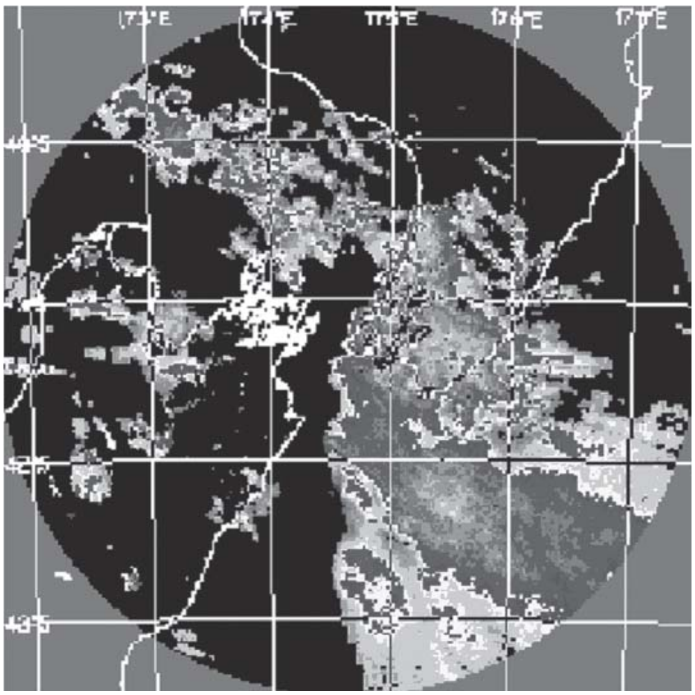
In all, 19 agencies provided direct support for the investigation, including 9 overseas organizations. In each of these cases, the relevant independent investigation agency (the ATSB, NTSB, and TSB) provided a central point of contact and joined the investigation as interested parties under ICAO Annex 13. The utility of this document can not be understated. For as the saying goes, we were all dancing to the same tune.

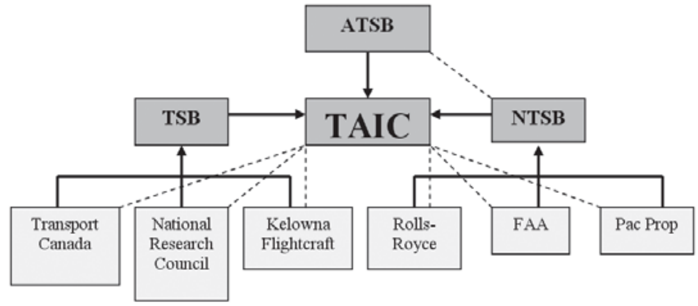
Where expert advice was required, either from within another investigative organization, for example the DFDR analysis in ATSB, or from an external agency, for example icing research data collected by the NRC, the national point of contact would facilitate direct access to these people. This was important, for while the IPs were kept informed of investigation progress, I needed to be able to talk directly to the experts to ensure that I got the required information and that the investigation remained focused. This way energy and resources were not wasted. In nearly all cases, this took the form of an exchange of e-mails providing contact details and smoothing the path.

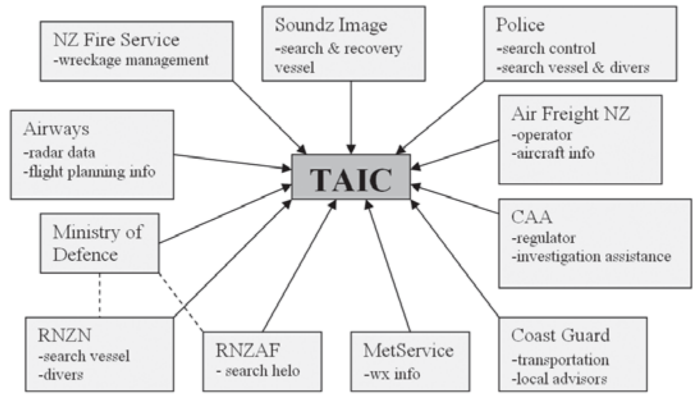
Memorandums of understanding

For the ATSB, the prior setting up of an MoU ensured full cooperation. It also provided comfort knowing that the CVR and DFDR would be afforded the same level of protection as under New









Zealand legislation. On the national front, an MoU with the police ensured a smooth transition from police control of the initial search, where we supported, to taking over after the recovery of the two pilots. A similar agreement with the CAA allowed a CAA safety investigator to be seconded to the investigation, providing a valuable interface and good training. A participants' agreement ensured that sensitive information remained confidential and avoided any potential conflicts of interest.

Organizational structure

Flexibility is a requirement for any organization. TAIC policy is for the IIC to manage the investigation through to and including the public release of the report. This allows for continuity of command and communications. However, with only three air investigators and the need to manage other investigations, we also need to be flexible in releasing staff during a protracted investigation. For ZK-KFU, the report was released to the public within 11 months—an easily manageable timeframe.

Another challenge for a small organization is the expertise of the staff available. We had only just recruited a new investigator when this accident occurred. A very steep learning curve ensued. However, the retiring investigator was at the opposite end of the scale, with nearly 25 years in the job, including investigating a previous Convair 580 accident in July 1989. Neverthe-

less, as Genghis Khan once said, "There comes a time when numbers count." So we pressed into service our marine and rail investigators where suitable—especially in the early days. For example, the marine investigators were used on the search and recovery vessels—a tummy-rumbling experience for these big ship captains. We also had a CAA safety investigator with engineering and large aircraft experience attached to the team for the duration of the investigation. However, to ensure credibility, interviews and the handling of the recorders remained solely our domain.

Conclusion

The accident and subsequent investigation, although not large by aviation standards, did pose some significant challenges—primarily wreckage location and recovery, combined with the lack of CVR information. This lead to a typical two-pronged approach for the investigation—what caused the accident and what didn't. TAIC's small size, with its limited manpower and material resources, dictates that we are adaptable and ardent in our investigations. We must also be able to have access to the wider safety community, to use the wealth of expertise available. For ZK-KFU, only through the cooperation of the agencies mentioned in this presentation were we able to determine the probable cause of the accident—a finding that the investigating coroner was able to accept without further inquiries. In short, the investigation and unchallenged report were made possible by

- an established investigation framework (ICAO Annex 13),
- direct and unhindered communications,
- flexibility,
- good team work,
- networking, both before and after accident (e.g., seminars, regional workshops), and
- established working relationships and agreements (e.g., MoUs).

Acknowledgements

The Commission again wishes to thank those agencies identified in this report for their unending support in the furtherance of aviation safety. Also to ISASI, for the opportunity to "spread the word." ◆

Information

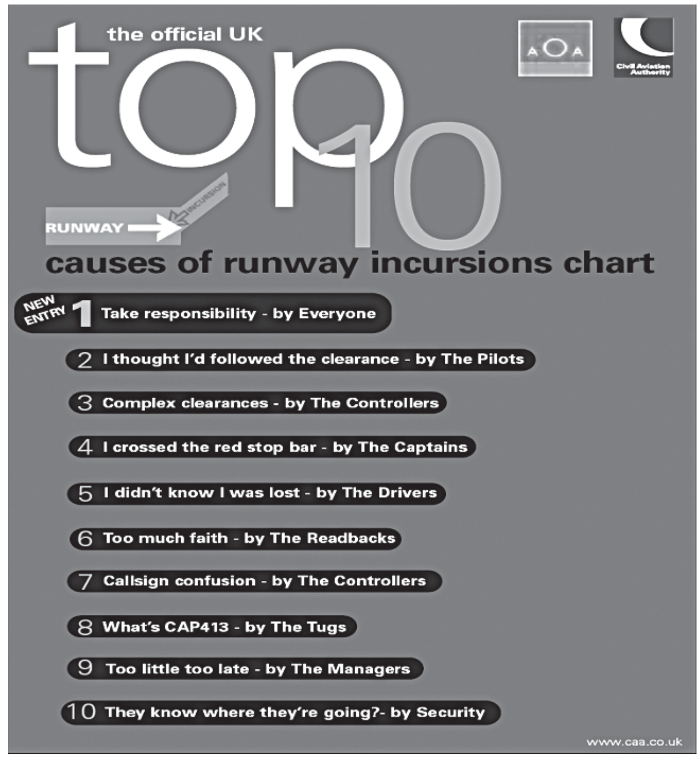
For more information: www.taic.org.nz
Report 03-006
Convair 580, ZK-KFU, loss of control and inflight break-up
Kapiti Coast, NZ, Oct. 3, 2003

Tenerife to Today: What Have We Done in Thirty Years To Prevent Recurrence?

By Ladislav Mika, Ministry of Transport, Czech Republic, and John Guselli (MO3675), JCG Aviation Services Australia

__Ladislav Mika__ is the head of the Flight and Operations Division in the Ministry of Transport of the Czech Republic.

__John Guselli__ is a director of JCG Aviation Services, an Australian company that specializes in the development of transport safety systems, safety management, investigative analysis and the delivery of specialist aviation training. Licensed as an air traffic controller in 1974, he has served in a wide variety of senior operational and strategic safety management roles at the national level. He has completed an Aircraft Accident Investigation Course at Cranfield University (U.K.) and has managed and assisted in civilian and military system evaluations, safety audits, incident investigations, and international airline liaison in Australia, New Zealand, Indonesia, China, and the U.K. He holds audit qualifications and diplomas in adult education and aviation. He has facilitated international safety management and investigation training in conjunction with operational management for the Singapore Aviation Academy, Eurocontrol, Airservices Australia, the Australian Transport Safety Bureau, the Southern California Safety Institute, Airways New Zealand, and the Civil Aviation Safety Authority of Australia. John is chairman of the ISASI Air Traffic Services Working Group. Tel: +61 2 9872 3722. Fax: +61 2 9872 9565. E-mail: jguselli@bigpond.net.au.



1.0 Introduction

The aviation industry is a composite of many diverse but interdependent systems.

Air safety investigators quickly learn that no matter how many ways they attempt to collate the contributory factors of an occurrence they usually come up with key issues related to

- people,
- equipment,
- procedures,
- environment, and
- organization.

Runway safety is one issue that has maintained a critical position at the top of the safety watch list.

Safety risk is a product of likelihood and consequence. Most runway collisions will continue to have a catastrophic consequence to the well-being of aircrew and their passengers as it is unlikely that we will ever, cost effectively, produce airframes capable of surviving high-energy impact.

It follows then that the most effective focus of our safety prevention effort lies within a reduction or removal of the likelihood of these events. At this point, a simple and logical equation begins to run out of steam. It does so because of incompatible goals generated by the obligation to balance safety with expedition.

As the global privatization process marches ever onward there is the increasing expectation of a return on investment by shareholders. This return will often be influenced by accommodating (or stimulating) an increased demand for runway capacity.

Airport real estate for operational activity is usually finite. This means that as the volume of traffic increases, capacity enhancement measures are developed. These measures will often involve an increase in procedural complexity or physical redevelopment of airport layouts. Some would argue that this is simply a logical evolution within the aviation industry, but they neglect the significance of people and their organizational structures.

Air safety investigators appreciate the significance of the human factor as it typically provides up to 80% of the causal factors associated with air safety occurrences.

People are associated with planning, documentation, training, and an assurance of the effectiveness of these measures. They are represented in the process by air traffic controllers, pilots, and plant vehicle operators.

Organizations are associated with the provision of the people as well as the resources for them to deliver the service.

2.0 What is a runway incursion?

ICAO defines a runway incursion[1] as "*Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft.*"

This simple enough statement is easily absorbed and captures the essence of the problem. It does not prevent anything on its own though.

Consider the tragedy at Tenerife.

In the Canary Islands, on March 27, 1977, a collision between two Boeing 747 aircraft, on a foggy runway, led to the deaths of 583 people. This single tragic occurrence polarized a growing awareness in the aviation industry to the diversity of simple and complex hazards associated with runway safety.

Terrorist activity had closed the Las Palmas Airport and, subsequently, arrivals were diverted to the smaller airport of Los Rodeos on Tenerife. This regional airport, though capable, was extremely taxed by the arrival of five large aircraft.

After ground-based delays and significant refueling activity, a KLM aircraft commenced to taxi along the runway to the departure threshold. The crew quickly noted a thickening fog rolling into Los Rodeos.

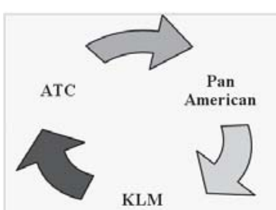
At the same time, a Pan American aircraft was taxiing along the same runway with a requirement to vacate it prior to the threshold. This ATC strategy would permit the KLM aircraft to depart, followed by Pan American. Tragically, this simple strategy failed.

The investigation ultimately revealed a combination of contributory factors related to

- people,
- equipment,
- procedures,
- environment, and
- organization.

Principal deficient elements among these factors were

- communication,
- complacency,
- phraseology,
- assumption,
- training,
- awareness,
- resource management, and
- violation.



In isolation and in combination, each of these conspired to deliver the tragic outcome. Thirty years later, we still regularly experience the phenomenon of the runway incursion. These events are not confined to any specific geographic location or to a particular type of aircraft.

3.0 Who are the stakeholders?

At a cursory level, the determination of stakeholders presents little difficulty. The frontline strategies will come from the following groupings (as they will usually bear accountability somehow):

- ANS providers,
- air operators,
- airport operators,
- aircraft manufacturers, and
- aviation regulators.

It is only when peak industry bodies, representing individuals through IFALPA and IFATCA, that measurable progress can be made.

4.0 What have they been doing?

Subsequent to Tenerife, many states have worked together (and in isolation) toward a reduction in runway incursions.

The following summary of recent initiatives by ANS service providers indicates the continuing focus on this phenomenon around the world. The work of these providers is highlighted on the basis that the most lasting and effective solutions may come from within their organizations.

4.1 Canada

In 2005, NAV CANADA invited stakeholders to form an independent working group to oversee runway incursion prevention activities in Canada. This was as a result of the dissolution of a previous group known as IPAT (Incursion Prevention Action Team) co-chaired by Transport Canada and NAV CANADA.

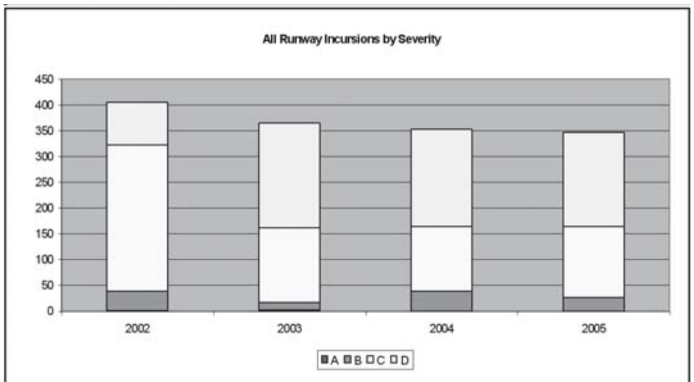
IPAT in the course of its life was tasked with implementing recommendations contained in reports on runway incursions produced by both Transport Canada and NAV CANADA. Following the successful adoption of these recommendations, it was decided not to extend IPAT beyond its April 2005 expiry date. NAV CANADA identified a need to continue oversight of runway incursion-prevention activities and this resulted in the formation of RSIPP (Runway Safety and Incursion Prevention Panel).

Membership in this multidisciplinary group will remain open but is normally composed of one primary and one back-up representative from NAV CANADA, the Canadian Airports Council (CAC), the Canadian Owners and Pilot's Association (COPA), the Air Line Pilots Association (ALPA), the Canadian Air Traffic Control Association (CATCA), the Air Traffic Specialists Association of Canada (ATSAC), the Air Transportation Association of Canada (ATAC), as well as other aviation stakeholders identified by the panel and observers with a direct interest in runway safety, such as the Transport Canada Aerodrome and Air Navigation Branch, the Transportation Safety Board of Canada, or technical specialists from stakeholder organizations.

The Panel's mandate is to provide a forum for the exchange of safety-related information pertaining to the movement of aircraft and vehicles in the vicinity of the runway, with the aim of promoting runway safety and with a primary focus on the reduction in the risk of runway incursions.

Canadian runway incursion statistics

Canadian runway incursions are classified as to the severity of the risk. Category A events are ones of extreme risk with instantaneous action required to avoid a collision. Very few runway incursions are Category A.



Severity	2002	2003	2004	2005
A	1	2	0	0
B	37	15	38	26
C	284	144	126	138
D	83	204	188	182
Total	405	365	352	346

Chart 1

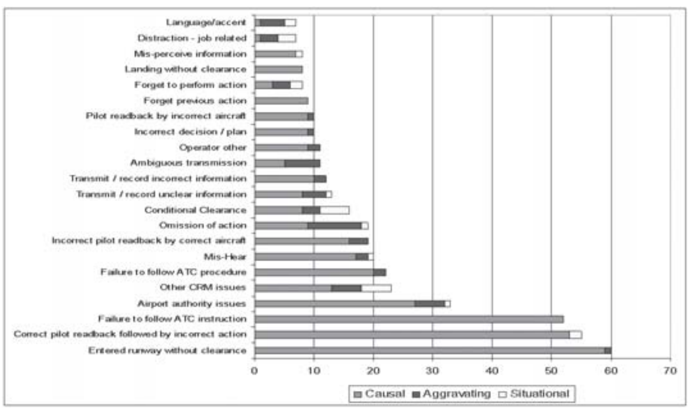


Chart 2

Factors such as weather, speed of the involved aircraft, and time to take action are considered in a matrix in order to determine the risk. Chart 1 shows runway incursions in terms of the severity of the risk.

4.2 United Kingdom

The National Air Traffic Services provides air traffic control services at 15 of the U.K.'s biggest airports and "enroute" air traffic services for aircraft flying through U.K. airspace. This year it expects to handle more than two million flights carrying more than 220 million passengers.

For more than 2 years now, the Runway Safety Focal Group has been in action supporting NATS runway safety activities. Representatives from the 15 U.K. airports meet on a regular basis. This group's activities have supported a significant amount of progress.

All airports now have a Local Runway Safety Team that is actively managing runway safety issues at the airports. Airports have identified their key runway safety risks and are in action to resolve or mitigate the issues.

Aerodrome Resource Management Training (effectively TRM in the airport environment) has been delivered at U.K. and European airports with positive results.

The use of conditional clearances has been challenged, and trials continue to enable NATS to understand how it might use them in the future.

Phraseology has been changed for aircraft and vehicles entering the runway.

A significant amount of data is collected post incursion through the use of pilot and controller feedback forms. This feedback has enabled NATS to understand how and why errors occur and continues to steer its runway safety strategy.

NATS participates in both the U.K. and European runway safety steering groups.

Statistics compiled by NATS and displayed below so far reveal three significant target areas for safety enhancement. They indicate that

1. an aircraft has entered a runway without clearance.
2. a correct pilot readback can be followed by an incorrect pilot action.
3. failures in following ATC instructions.

4.3 Europe

European runway incursion analyses received a fillip following a serious runway incursion occurrence on Dec. 10, 1998, at Schiphol, Amsterdam Airport[2]. After an investigation lasting more than 2 years the following conclusions were published:

a. Low visibility and a low cloud base at the airport made visual control from the control tower impossible. Low visibility procedures were effective for air and ground traffic.

b. There are no indications that prior coordination of the tow movement between apron control and tower, as required under low visibility conditions, took place.

c. Exit 2 of Runway 06/24 was not equipped with traffic lights.

d. The crossing clearance request was inadequate as it did not mention position and intended movement.

e. No further information was asked by the assistant controller to clarify the runway crossing request. This caused a misinterpretation resulting in a false hypothesis with regard to the position of the tow.

f. As a consequence, the wrong position of the tow was passed to the tower controller, which eventually led him to misinterpret the ground radar picture.

g. The working position of the assistant controller was not equipped with a radar screen. She was, therefore, not able to positively monitor the tow movement.

h. The tower controller based his decision to clear Delta Air Lines Flight 039 for takeoff on his interpretation of the ground radar picture and the indication of the stop bar control panel. He did not verify with the assistant controller to positively confirm that the tow was clear of the runway.

i. The alertness of the cockpit crew of Delta Air Lines Flight 39 prevented the occurrence of a catastrophic accident.

j. Design and position of the control panels for stop bars and traffic lights are not unambiguous and, therefore, prone to human error.

k. The non-use of checklists during the change over from inbound- to outbound mode resulted in an initially wrong set up for the stop bar control panel in relation to the controller duties. This reinforced their doubt about the correct functioning of the system instead of realizing their misunderstanding in the position and movement of the tow.

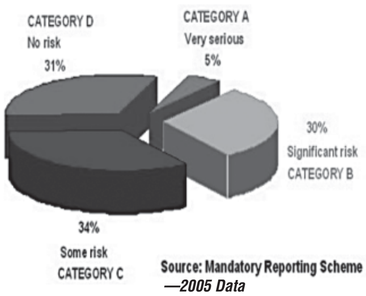
l. The supervisor/coach failed to adequately supervise the tower operations in general and did not timely intervene to prevent the incident.

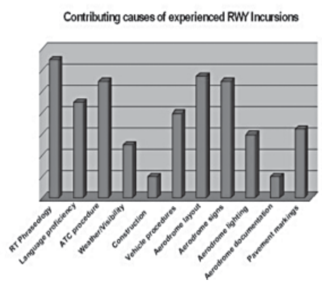
m. The staff on duty was not working as a team.

The conclusions to this investigation revealed different fac-

#	RECOMMENDATION	ACTION	COMPLETION DATE
4.1.1	At individual aerodromes, as designated by the National Aviation Safety Authorities, a Runway Safety Team should be established and maintained to lead action on local runway safety issues.	Aerodrome Operators ANSP Aircraft operators	As soon as possible
4.1.2	A local runway safety awareness campaign should be initiated at each aerodrome for Air Traffic Controllers, Pilots and Drivers and other personnel who operate on or near the runway. The awareness campaign should be periodically refreshed to maintain interest and operational awareness.	Local Runway Safety Team	On-going
4.1.3	Confirm that all infrastructure, practices and procedures relating to runway operations are in compliance with ICAO provisions.	Aerodrome Operators ANSPs	Jun. 2005
4.1.4	Where practicable, ensure that specific joint training and familiarisation in the prevention of runway incursion is provided, to the pilots, air traffic controllers and vehicle drivers, to increase understanding of the roles and difficulties of personnel working in other areas. This may include visits to the manoeuvering area to increase awareness of signage and layout where this is considered necessary.	Local Runway Safety Team	Jun. 2006

Chart 3





ets of contributory elements.

In 2002, the Eurocontrol agency hosted an international workshop where action was taken to consolidate past recommendations. The workshop offered a unique opportunity for participants to debate many different issues associated with runway safety, including communications, human factors, procedures, and situational awareness. Action to formalize the resulting recommendations for the prevention of runway incursions was supported.

The workshop concluded with agreement on the general principles in Chart 3.

To its credit, in 2005 Eurocontrol conceded that three main issues hindered Europe in reducing the rate of runway incursions across the region. They were

- the potential lack of data and reluctance to share safety information.
- the absence of a harmonized and consistent approach for analyzing runway incursions.
- the difficulty to understand causal and contributory factors.

It has actioned plans to reduce these difficulties as associated with the submission of occurrence reports. In 2007, 14 different European definitions have been superseded by the ICAO definition. In addition, a global taxonomy now assists the analysts.

A snapshot of the 2005 data (see above) revealed that 600 runway incursions were reported. Further analysis revealed that there was a serious incursion every 14 days.

By comparison, the number of reported runway incursions increased by 11% in 2005 compared to 2004. This does not necessarily indicate a lower safety performance, but possibly improved visibility of actual incidents.

The European Action Plan and supporting materials are produced by a joint working group comprising

- Eurocontrol,
- Safety Regulation Commission,
- Joint Airworthiness Authorities,
- Group of Aerodrome Safety Regulators (GASR),
- Airlines,
- Air Navigation Service Providers,
- IATA,
- IFATCA,
- IFALPA,
- IAOPA, and
- ICAO.

4.4 Australia

Airservices Australia was an early adopter in activities designed to mitigate the risk of runway incursions.

A group was established to take a national perspective on runway incursions and to facilitate greater awareness among operators and end users. The Airservices Runway Incursion Group (RIG) is comprised of representatives from safety management and air traffic control, and it operates under the terms of reference provided by the Airservices Safety Panel.

Besides maintaining a constant review of runway incursion incident data, the group has implemented a confidential human-factors-based survey that is issued to pilots and airside ground staff involved in a runway incursion.

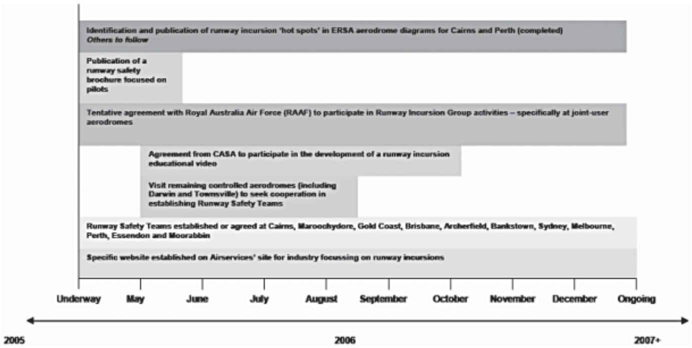
Another important activity has been the promotion of *Runway Safety Teams* at controlled airports. The local Runway Safety Team assists in enhancing runway safety by

- reviewing investigation reports to establish local hot-spot or problem areas at the aerodrome.
- working as a combined team to better understand the operating difficulties of those working in other areas and suggest items for improvement.
- coordinating with the organizations or teams they represent, the implementation of the recommendations that have been assigned to the local teams in the Runway Safety Document.
- identifying any local problem areas and making any suggestions for improvement that are considered necessary.
- running a local Runway Safety Awareness Campaign that focuses on local issues, for example by producing and distributing local hot-spot maps or other guidance material as considered necessary.
- confirming that communications between ATC and aircrew/drivers are satisfactory, or if any improvements could be suggested. For example, although standard ICAO phraseology may be utilized, some messages from ATC may be overlong or complex, which may have the potential to confuse drivers or aircrew.
- driving on the airfield regularly to ensure that signage is understandable and that no ambiguity exists.

Other activities being undertaken by the RIG include

- development of hot-spot posters for display in airline briefing centers and at aero clubs and other organizations.
- coordination of hot-pot aerodrome diagrams for inclusion in ERSA.
- development of runway safety posters.
- development of a runway safety brochure to be distributed to all pilots.
- production of a video, in conjunction with CASA, detailing runway safety issues from a pilots perspective.

The ongoing time line of joint civil and military initiatives, commenced in 2005 for this program, is displayed below.



4.5 United States

The FAA 2002–2004 Blueprint for Runway Safety[3] stated that its purpose was to

1. define and prioritize many of the coordinated efforts between the FAA and the aviation community to reduce runway incursions, and
2. to create engagement and alignment between FAA headquarters/regional staffs and the aviation community, which is essential to achieve success.

In doing so, it identified a number of elements critical to the success of the program. It stated:

Recognition of the following key points is fundamental to formulating and implementing solutions to improve runway safety for the nation:

1. Operational performance in the airport movement area must be further improved to reduce runway incursions. The NAS involves enormously complex interactions among air traffic controllers in the tower and people who operate on the airport surface, including pilots, mechanics, maintenance technicians, and airport employees. Improved awareness efforts and compliance are required to reduce runway incursions. A frequent reason runway incursions occur is loss of situational awareness. The major breakdowns in operational performance that result in runway incursions at towered airports are

Pilots who

a) enter a runway or cross the hold short line after acknowledging hold short instructions,
b) take off without a clearance after acknowledging "taxi into position and hold" instructions.

Air traffic controllers who

a) lose required arrival/departure separation on the same or intersecting runways,
b) make runway crossing separation errors.

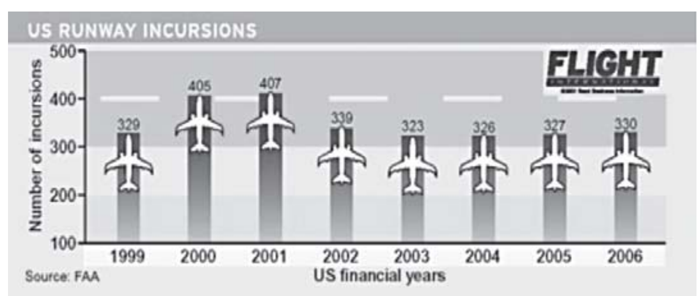
Vehicles drivers and pedestrians who

a) cross a runway without any communication or authorization,
b) enter a runway after acknowledging "hold short" instructions.

2. Runway incursions are systemic, recurring events that are unintentional by-products of NAS operations. Runway incursions are systemic because they are related to existing aviation procedures, airport geometry, training, operations, communications, and NAS infrastructure components. Improvements to the NAS will be required to reduce risk and improve safety performance.
3. Operations must be standardized to reduce risk at a time when growth is challenging runway and infrastructure expansion. Aviation in the United States is a mass transportation system with thousands of unique components. There are more than 480 towered airports (and thousands of non-towered airports), over 15,000 air traffic controllers, in excess of 650,000 pilots, and greater than 240,000 aircraft, all conducting millions of operations around the clock. Improvements that standardize operations and reduce risk on the airport surface will be essential to foster improved performance and safe growth.
4. Collision-avoidance safeguards need to be developed for the high-energy segment of runways. Fatalities are most likely to occur in the first two-thirds of the runway (typically called the high-energy segment) where aircraft are accelerating for takeoff or decelerating after landing. Approximately 65 million takeoffs and landings, plus millions of crossings, occur annually in this segment of the runway. Improvements to airport geometry, airport and aircraft technology, operating procedures, and airport usage patterns that address incursion risk on this runway segment will be required to reduce collision risk in the future.
5. Human factors are the common denominator in every runway incursion. A systematic attack on this aspect of the problem will require detailed analyses of the causes of these errors and the design of approaches to mitigate them.

These five conclusions, drawn from the ongoing analyses of runway incursion reports, will direct our systematic search for solutions. Given the constraints of time and resources, however, it is necessary to assign priorities. The guidance is to first invest our assets to resolve the problem of collision avoidance on the high-energy areas of runways—potentially the most lethal of the risks.

The effectiveness of this blueprint can be quantified by the following comparison of U.S. runway incursions (1999 to 2006)[4]. It is clear that despite significant recent traffic growth, the rate of incursions is reducing.



This relative success has not emerged without differing opinions.

NATCA testified in March 2007 at the NTSB Runway Safety Forum[5]. The main points, brought forward on behalf of their control tower perspective by NATCA, were—

Technology

Equipment needs to work in inclement weather. ASDE/AMASS operates in the limited mode with any kind of precipitation present (rain/snow). While operating in limited mode, the "safety logic" is not functioning, and, therefore, cannot warn of impending conflicts. ASDE-X is much better with the potential for multilateration support.

Procedures

FAR 91.129 (i) is in need of review. Additionally, an insistence on an individual clearance to cross any runway is needed.

The current "taxi to" runway assignment clearance has caused many runway incursions. Also, the *Aeronautical Information Manual* requires amendment if the FAR is changed. IFATCA agrees with this position.

Staffing

The FAA is losing three controllers a day to retirement. The FAA is not hiring replacements fast enough to keep up, plus it takes 3 years to get a controller fully certified. This staffing shortage leads to working shorthanded and combining positions. This leads to less eyes on the runways (to catch pilot transgressions), less ears on the frequencies (to catch missed read-backs), and an overall workload increase.

Fatigue

Based on the staffing dynamic, controllers are working longer and harder than they ever have before. This is causing fatigue. When controllers are fatigued, it affects reaction time, judgment, and decision-making.

The NTSB has cited controller fatigue as a contributing factor in runway safety events.

The FAA partly acknowledged this issue within the Blueprint at Objective 3.2 when it stated: *More than a third of the most serious runway incursions have been attributed to controller operational errors. These errors stem from items including memory lapses, a lack of controller teamwork, improper scanning, poor prioritization of duties, and ineffective on-the-job training being conducted. These errors could be mitigated with training and procedural interventions.*

The same Forum also noted the position of the Air Transport Association (ATA), which concluded that there was "*no silver bullet to prevent runway incursion.*"

ATA stressed the fact that "*many of the technologies are not mature; none are foolproof.*" It believes the measures to prevent runway incursions lie within

- moving maps,
- ASDE-X,
- runway status lights,
- FAROS[6],
- perimeter taxiways, and
- "low-cost" surface surveillance technology.

5.0 Developing initiatives

A tragic runway collision in Milan on Oct. 8, 2001, polarized the global aviation industry perspective of runway incursions and ground safety in general.

Scandinavian Airlines Flight SK686, an MD-87, collided on takeoff in reduced visibility with a Cessna Citation business jet. A total of 118 persons, including ground-based baggage handling personnel, were killed in the collision.

During the Eleventh Air Navigation Conference[7] (2003) a working paper was presented by the United States that sought to address the issue of runway incursions from a global perspective. This paper elegantly summarized the issue. It stated: *Demand for aviation to perform at increasing levels of safety excellence has never been higher. Integral to advancing safety performance is the reduction of collision risk associated with runway incursions. An international approach will lead to effective global solutions. Specifically, standardized runway incursion information is recommended as an essential step toward achieving global risk reduction and improving risk management of runway incursions.*

It produced the recommendation[8] that ICAO

a. develop a common definition of a runway incursion.
b. develop a common categorization taxonomy of runway incursion severity, error type and/or factors that contribute to incursions.
c. develop a common runway incursion database with a standardized set of data.

As a consequence of the working paper and an overall industry fragmentation, ICAO produced the *Manual for Preventing Runway Incursions* in 2006. The express purpose of this Manual was to address the topic of runway incursions generated through the interface of aircraft, air traffic control and vehicles on maneuvering areas. It provided the basis of standardization and simple classification across the industry in a meaningful way.

With regard to analysis of globally gathered data, the key element was contained in the severity classification. The primary objective was to assess each incursion with respect to its likelihood and consequence for recurrence.

As in any fundamental investigation, it was stressed that any assessment should be conducted as soon as reasonably practicable after a specific occurrence has taken place.

The following severity classification scheme was provided:

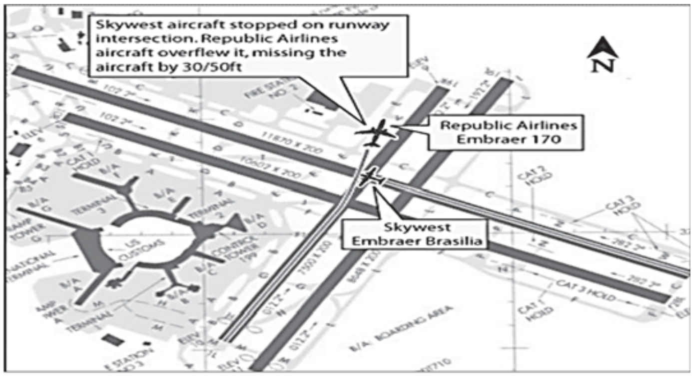
Accident	Description
A	A serious incident in which a collision was narrowly avoided.
B	An incident in which separation decreases and there is a significant potential for collision, which may result in a time-critical corrective/evasive response to avoid a collision
C	An incident characterized by ample time and/or distance to avoid a collision
D	Incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with no immediate safety consequences
E	*Insufficient information inconclusive or conflicting evidence precludes severity assessment*

Despite subsequent positive progress, many issues are still in need of resolution. Government agencies around the world have been galvanized by the statement of NTSB Chairman Mark Rosenker. Rosenker was quoted at the NTSB Forum as stating, *"We've been living on luck for too long."*

In addition, *USA Today*[9] provided the traveling public with a lead report on this issue stating that *"The National Transportation Safety Board (NTSB) says the risks of a crash on the ground represent the greatest threat in aviation, and the potential for a plane to strike one of the vehicles that crowd commercial airports is a significant part of the problem."*

This unfortunate prediction was nearly fulfilled on May 25 in San Francisco in an occurrence involving a Republic Airlines aircraft avoiding a collision with a SkyWest Airlines aircraft on the runway. A near collision at a runway intersection at San Francisco was categorized as Category A by the FAA. MediaNews reported it to be the most serious incident of its kind in at least a decade.

The investigative perspective becomes complex following an FAA statement shortly after the event, and reported by AeroNews—*"Every category A is a serious event, and it is a serious concern for us," said FAA spokesman Ian Gregor. "This wasn't a procedural issue; this was caused by a good controller with a lot of experience making* *a mistake." The controller, with about 20 years of experience, was required to be recertified for his job, Gregor said.*



6.0 Regulatory activity

Regulatory agencies have responded substantially to the hazards of runway incursions, and in particular, since the publication of ICAO Doc. 9870. Typical of many responses has been the provision of a watching brief and a formal oversight of organizational safety management system elements that defend against the likelihood and consequence of runway incursion.

Transport Canada cites the following key results in its oversight program, which has been active since 2000:

- Mitigation monitoring.
- Reduction of "extreme" occurrences reported.
- Awareness training resulted in a "leveling off" or stabilization of reported incursions.
- A shift from "awareness training" to more of a monitoring role.
- Incursion database maintenance.
- Analysis of contributing factors.
- Development of

—Awareness training.
—Safety presentations (all operations).
—Safety posters.
—Safety videos.

Similarly, the United Kingdom Civil Aviation Authority (UKCAA) has actively demonstrated an effective oversight of mitigation strategies for the runway incursion hazard.

Its first success was publicizing the issue with industry. A series of posters, leaflets, and other publicity material—all featuring specially designed runway incursion branding—made those involved much more aware of the issue and they then set about tackling these issues, as the increase in reporting showed. They also know that the educational impact of the material has helped as it specifically targeted certain sectors of the industry (i.e., airside drivers, pilots, and air traffic controllers).

The new reporting levels, of course, meant extra work for the data group; as well as collecting the data, they created a more precise picture on the more frequent causes of incidents, which could then be tackled more effectively (e.g., by identifying developing trends that were addressed by proactive measures before they became genuine risks to safety).

Moreover, this analysis of data showed that many incidents resulted from those involved failing to follow standard procedures. The group therefore targeted drivers, pilots, and air traffic controllers outlining the importance of following procedures accurately, emphasizing specifics such as *best practice while taxiing*; and a CAA requirement for aircrew to be assessed on *radio telephony standards* during recurrent training was introduced.

Most U.K. airports have now developed local runway safety teams (in line with a Eurocontrol initiative) to assess the safety risks, marking particular physical areas of concern as 'hot spots' and then take action to eliminate the risk. Recent statistics show that incidents appear to be on the rise at regional airports while they are reducing at the major international airports. They have, therefore, devised specific publicity aimed at general aviation pilots.

All work and findings have been shared with Eurocontrol to help feedback into the bigger picture. Work continues on a number of areas including a study into continuous 24-hour operation of runway stop bars and a pilot's organization proposal that aircraft switch on high-intensity lights when approaching or entering a runway.

Ultimately, as with all safety-related activities involving human beings, there will never be a total eradication of runway incursions. UKCAA continues to strive for the lowest level of incidents possible and targets the trends or observed serious incidents that pose the greatest risk to safety.

The steering group demonstrated a model example of how an effective regulator and the aviation sector can work together. This level of partnership is also vital on an international scale if it seeks to introduce common effective technological solutions and best-practice protocols and safety measures.

Much of the success associated with the UKCAA publicity related to an easily identifiable logo. This symbol focused the industry through regular association and has reinforced the project objectives.

RUNWAY INCURSION

This logo, in turn, became a focal point for a number of successful posters that presented a simplified message to aircrew of all levels. The following poster, in particular, highlighted the human performance limitations associated with routine airport operations.

7.0 The manufacturers

Robert Sumwalt of the NTSB believes that cockpit-based systems will eventually have the capacity to overlay an aircraft's "real time" position onto electronic airport maps, therefore, reducing the likelihood of runway incursions.

To Flight International, he stated that *"I can't yet point to a product that we can say, 'Put this on the aircraft,'" says Sumwalt. But new product development efforts in industry, spawned partly by new guidance on electronic flight bags (EFBs) and a groundswell of concern about runway incursions, could soon provide solutions to the problem[10]."*

Currently, Boeing offers an approved Class III fully integrated EFB with "own ship" position and moving maps for 200 airports around the world. This is a good start toward a solution however the significant unit cost precludes wide distribution. Allied to initial outlay are complex certification processes and maintenance.

It is anticipated that a progressive rollout of ADS-B functionality will hold the key to further advances in airborne based detection equipment.

Collaboration between competitors and industry stakeholders may deliver even greater progress as reported in Flight International (July 9, 2007):

"Honeywell and Sensis could come up with a more generic competing solution. The two companies are collaborating on a 'real-time runway incursion cockpit advisory capability' that will send automated advisories of potential collisions directly to the cockpit and simultaneously to air traffic controllers in the tower using Honeywell's onboard collision avoidance and airport information joined with Sensis' ground infrastructure.

"Sensis builds the ASDE-X system now installed at eight U.S. airports and slated by the FAA to be rolled out to 27 others. The system pinpoints the location of aircraft near or on the airport for tower controllers through a combination of radar, onboard transponder returns, and a multilateration system set up around the facility.

"That data, combined with Honeywell products that determine an aircraft's position in relation to runways, make it possible to compute potential conflicts. The companies are not saying whether the system will include a moving-map display or when a product might be available, but plan to demonstrate the package some time this year."

8.0 The way ahead

The hazards associated with runway incursions are proportional to traffic growth in our industry. There is no one practice or procedure that can currently inoculate us from the consequences in the short term.

It has become increasingly apparent that the solution lies within the utilization of all available resources. The following broad areas present the greatest safety benefit for the least expenditure of operational effort:

- **Communications**

All stakeholders need to understand, practice, and demonstrate the values of clear and unambiguous phraseology.

- **Airfield design**

Stakeholders need to validate practices whereby unnecessary runway crossings (under power or tow) are prevented or reduced to the minimum necessary to support safe operations.

- **Standardization of categorization and contributory factors**

Stakeholders should actively apply the standardized process collated and distributed by ICAO to further aid analysis of the phenomenon.

- **Occurrence reporting, investigation, and safety promotion**

Occurrence reporting and subsequent investigations are critical to the formulation of runway incursion mitigation strategies. Promulgation of derived data and contributory factors will raise industry awareness.

- **Flightdeck procedures**

Procedural operations on the flight deck require harmonization to ensure that identified precursors to incursions are highlighted in site specific airport briefing materials.

- **Control tower procedures**

Tower operating procedures must balance the competing needs of runway safety and traffic expedition.

- **Airside vehicle management**

The capacity of airside vehicles to access maneuvering areas must be reduced to the minimum extent necessary for safe and effective airport operations.

Acknowledgements

This document has been prepared as a product of the ISASI Air Traffic Services Working Group.

It represents contributions made by a dedicated group of air safety professionals with a global perspective on information sharing in order to enhance safety within their industry.

The following contributors are gratefully acknowledged:

Ladislav Mika—MoT Czech Republic
Monica Mullane—NAV CANADA
Darren Gaines—NATCA
Bert Ruitenberg—IFATCA
Ben Alcott—U.K. CAA
David Harvey—Airservices Australia
Mike Edwards—NATS
Mike Doiron—Transport Canada
Joe Beaudoin—U.S.
David Carbaugh—Boeing
Jim Burin—Flight Safety Foundation
Mitch Serber—ALPA ◆

Endnotes

1 Procedures for Air Navigation Services—Air Traffic Management (PANS-ATM, Doc 4444).
2 FINAL REPORT 98-85/S-14 N 193 DN, Boeing 767 Dec. 10, 1998, Amsterdam Airport.
3 http://www.faa.gov/runwaysafety/pdf/blueprint1.pdf.
4 Flight International, June 2007.
5 Runway Incursion Forum: Promoting Runway Safety, Arlington, Virginia: March 27, 2007.
6 Final Approach Runway Occupancy Signal.
7 Eleventh Air Navigation Conference, Montreal, September 22 to October 3, 2003, Doc. 9870. 2006.
8 Recommendation 2: Development of global runway incursion risk management information.
9 http://www.usatoday.com/news/nation/2007-04-05-runway-safety_N.htm.
10 http://www.flightglobal.com/articles/2007/07/09/215421/cockpit-techs-to-aid-runway-incursion-problem.html.

Flight Data—What Every Investigator Should Know

By Michael R. Poole, Managing Partner, Flightscape and Simon Lie, Associate Technical Fellow, Boeing Air Safety Investigation

***Mike Poole** is a professional engineer with a current pilot's license. He represented Canada as the national expert panel member to the International Civil Aviation Organization's Flight Recorder Panel. He's worked for more than 20 years with the Transportation Safety Board of Canada where he was the head of the Flight Recorder and Performance Laboratory and the Flight Recorder Group chairman on all major accidents, the most recent being Swissair 111. Mike is now one of the principals at Flightscape, a flight sciences company specializing in flight data analysis software.*

***Simon Lie** is an associate technical fellow and air safety investigator at Boeing Commercial Airplanes. He has an academic background in composite structures and aeroelasticity, and spent 10 years of his career at Boeing troubleshooting predelivery issues on the B-747, -767, and -777 aircraft. Simon led Boeing support of the numerous accident investigations including Singapore Airlines B-747 Taipei 2000, China Airlines B-747 Taiwan 2002, Flash Air B-737 Egypt 2004, and Mandala Airlines B-737 Indonesia 2005.*

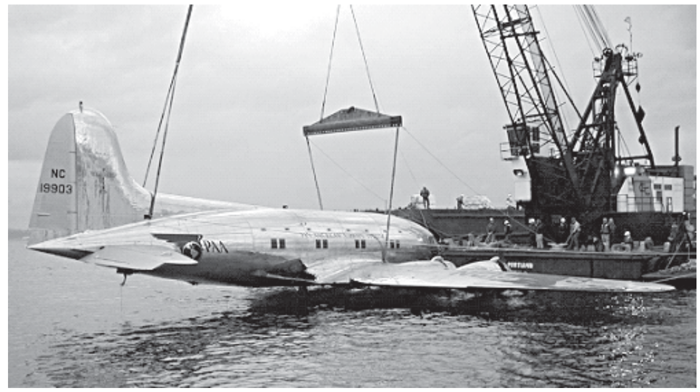


Figure 1. Recovery of the Boeing S-307 that ditched in Elliott Bay near Seattle, Wash., on March 28, 2002. The image below has been compressed to 1% of the file size of the original image above. The challenge of correctly interpreting the scene on the right is analogous to the challenge of interpreting recorded flight data, which are usually much less than 1% of the data available on board the aircraft.

Abstract

This paper summarizes issues that every investigator or airline Flight Operations Quality Assurance (FOQA) analyst should know about flight data and, in particular, how the information can be misleading if not fully understood. The process from recovery to final report is presented from a high-level perspective, citing actual examples from major international investigations where the data were initially misleading. The correct interpretation of flight data and/or audio data requires a full understanding of the entire signal path from measurement to recorder to investigator. Understanding the underlying principles of the process is paramount to successful interpretation. While not all investigators can have this level of expertise, it is important that they are aware of the types of problems that have been seen in the past but are generally little known outside of the flight recorder laboratory.

Major international investigations generate significant pressure to disseminate information both within the team and externally. Counteracting this pressure is the need to properly validate and understand the flight data. Balancing how much validation is sufficient before disseminating flight data is an important issue for the investigation team. This paper will also demonstrate an example of two flight animations of the same data with differing results and explain why.

Introduction

Flight data are becoming more readily accessible and are increasingly being used for investigation and airline safety programs. Modern aircraft record a huge amount of data compared to just a few years ago, but even in the most advanced aircraft recording systems, significantly less than 1% of the available data are actually recorded. The challenge of analyzing flight data is to recreate an accurate understanding of an event from that small percentage of the available data. To illustrate this challenge, the two photos shown in Figure 1 depict the same scene. The image on the right has been compressed to retain only 1% of the data.

It is not difficult to imagine that important details might be overlooked or misinterpreted if the image on the right is the only data available. However, given detailed a priori knowledge of the dimensions, weights, and capabilities of the airplane, crane, barge, and related operating procedures, the right-hand image

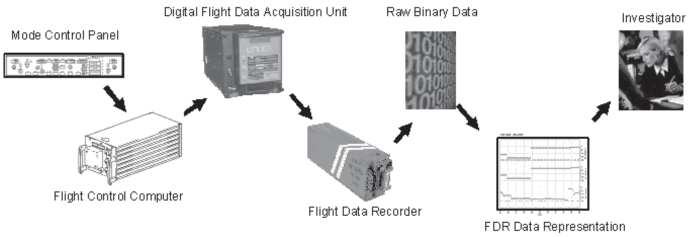


Figure 2. A graphical depiction of the provenance of the **selected heading** *parameter recorded on a B-737-300 FDR. The data originate in the mode control panel and passes through a number of distinct transformations before being utilized during an investigation.*

can provide an accurate picture of what happened. Similarly, the analysis of FDR data requires careful attention to detail to avoid misinterpretation, which is why most major investigative authorities consider flight data analysis as a specialty. It is important that investigators and airline FOQA analysts appreciate the "provenance" of the flight data, especially when drawing substantive conclusions. There is a proliferation of flight data analysis tools that are becoming progressively more automated, which in turn increases the potential to mislead. There are many examples where the correct interpretation of an FDR recording requires a full understanding of the provenance including the methods employed by the replay ground station.

The science of flight data

The scientific evaluation of data requires an understanding of the origin of the data and how the data were processed. No reputable scientific journal publishes research results unless the origin and history of the data has been reviewed and understood. The same principle applies to recorded flight data. Both of the authors have seen professional investigators reach mistaken conclusions when reviewing recorded flight data without fully understanding the origin and history. As parameters proliferate, even the naming of parameters can lead to confusion. Consider two different parameters that are recorded on certain B-737 aircraft: *Selected Fuel Flow* and *Selected Heading*. In the former, the "Selected" indicates that multiple fuel flow readings from different sensors are available and this particular value has been judged to be the most accurate and thus has been selected for display to the flight crew. In the latter, "Selected" means the target value of heading chosen by the flight crew via the autoflight mode control panel. As these two examples demonstrate, scientific rigor requires a full understanding of the origin of flight data and how it was processed.

Provenance

According to the *Oxford English Dictionary*, *provenance* is "a record of the ultimate derivation and passage of an item through its various owners." Adapted for the context of recorded flight data, the definition becomes "a record of a physical measurement or system state and the changes to that record as it passes through various system components until it is interpreted for an investigation." Consider the "Selected Heading" example above. The flight crew uses the heading window on the mode control panel (MCP) to choose a heading they wish to fly. The MCP transmits this value to the flight control computer (FCC). The FCC uses

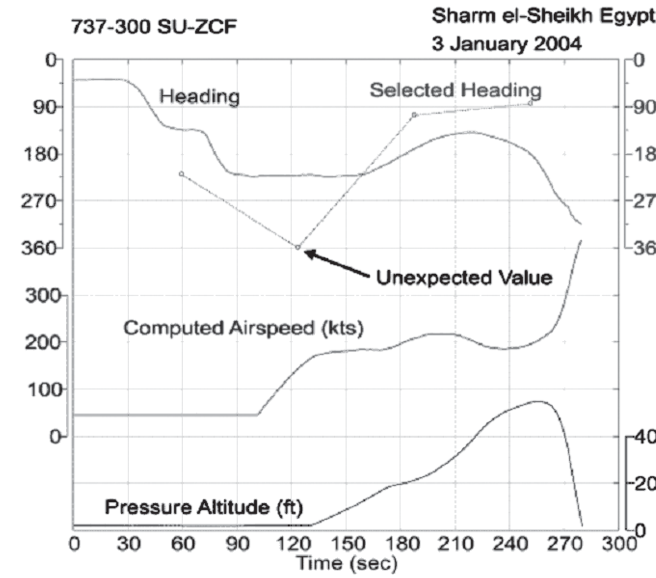


Figure 3. Altitude, airspeed, heading, and selected heading parameters during the accident flight. Selected heading is recorded once every 64 seconds. The other three parameters are recorded every second. The value at time 123 seconds is unusual as a value equal to the runway heading (220°) would be expected at this phase of flight. The unorthodox arrangement of the heading and selected heading scales (from higher values to lower values) is intentional. By convention, parameter values that result in or result from a right turn tend toward the bottom of the page. The FDR and CVR were subsequently recovered from a depth of more than 1,000 meters and provided data used during the investigation. The airplane began the left turn but then rolled out of the left turn and into a right bank that eventually reached 110° right bank. A recovery attempt was made but was not completed before the airplane descended into the Red Sea.

the value for computing the correct flight director and autopilot behavior. In addition, the FCC transmits the value to the digital flight data acquisition unit (DFDAU). Continuing to follow the signal chain, we find that the DFDAU stores the values it receives from the FCC until it is scheduled to be written to the FDR. The FDR writes the value to either magnetic tape or (we can hope) solid-state memory as a sequence of ones and zeros. The data are subsequently extracted and converted from raw binary format back into engineering units (i.e., degrees). The converted value is represented as a plot, table, animation, or possibly another format. Finally, the data representation is interpreted by the accident or incident investigator. Figure 2 shows the signal chain in pictorial format.

In theory, each parameter may have its own unique signal chain. In practice, parameters that have the same source often share the same chain—but not always. At each step of the chain, there is the potential for a change to the signal. Therefore, each step must be fully understood as both intended and unintended changes can affect the results.

B-737-700 example

On Jan. 3, 2004, about 02:45:06 UTC, 04:45:06 local time, Flash Airlines Flight FSH604, a Boeing 737-300, Egyptian registration SU-ZCF, crashed into the Red Sea shortly after takeoff from Sharm

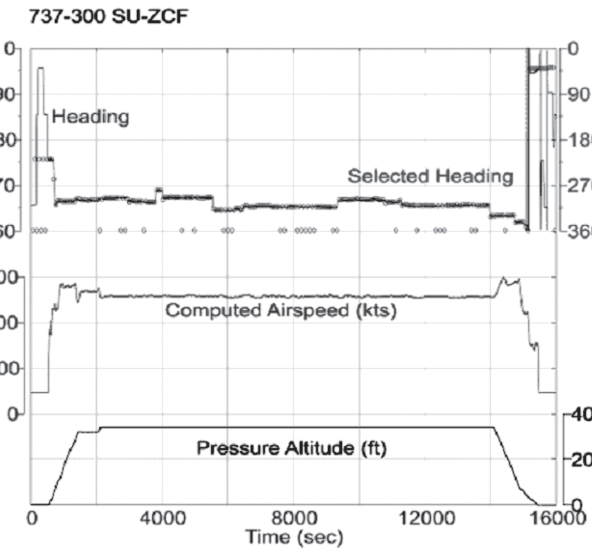


Figure 4. Altitude, airspeed, heading, and selected heading parameters during an earlier flight. Although selected heading generally follows actual heading as would be expected, there are repeated instances where unexpected values of 360° are recorded.

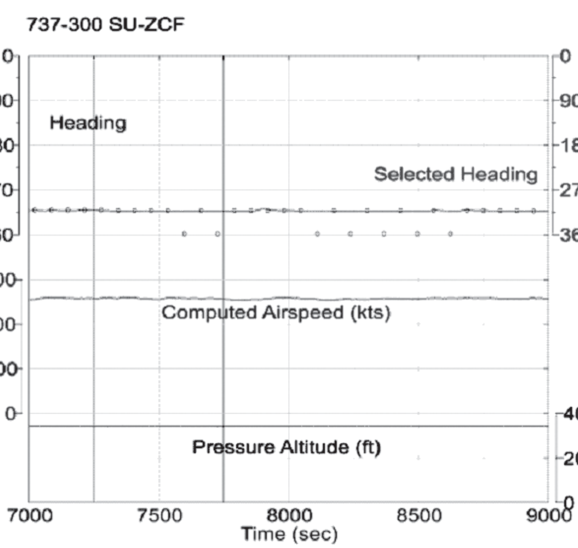


Figure 5. A portion of the same flight depicted in Figure 4 (note change in time scale). The unexpected 360° values of selected heading alternate with values coincident with the actual airplane heading (expected values).

el-Sheikh International Airport (SSH) in South Sinai, Egypt. The flight was a passenger charter flight to Charles de Gaulle Airport (CDG), France, with a stopover in Cairo International Airport (CAI) for refueling. Flight 604 departed from Sharm el-Sheikh airport with two pilots (captain and first officer), one observer, four cabin crew, six off-duty crew members, and 135 passengers on board. The airplane was destroyed due to impact forces with the Red Sea with no survivors.

The airplane had departed from Sharm el-Sheikh Runway 22R and was airborne at 02:42:33 UTC, approximately 2½ minutes prior to the crash, and had been cleared for a climbing left turn to intercept the 306 radial from Sharm el-Sheikh VOR station located just north of Runway 22R.[1]

The FDR and CVR were subsequently recovered from a depth of more than 1,000 meters and provided data used during the investigation. The airplane began the left turn but then rolled out of the left turn and into a right bank that eventually reached 110° right bank. A recovery attempt was made but was not completed before the airplane descended into the Red Sea.

The FDR recorded that the departure was flown with the use of the captain's and first officer's flight directors in heading select mode. In this mode, the flight director provides roll guidance to turn the airplane toward and hold a "selected heading" set by the flight crew on the mode control panel. Accordingly, investigative attention turned to the recorded values of selected heading on the FDR. Figure 3 depicts the airplane heading, selected heading, altitude, and airspeed during the accident flight. Heading, computed airspeed, and altitude are recorded each second. Selected heading is recorded once every 64 seconds. Standard practice calls for setting the selected heading equal to runway heading during take off. At time 59 seconds, before the airplane turns onto the runway, the recorded value of selected heading[2] was 220° (runway heading) as expected. At time 123 seconds, just prior to rotation, the recorded value was 360°. Later during the flight, the recorded values were to the left of the airplane heading, as would be expected during a left turn. The 360° value was unusual as the expected value would still be runway heading at this point of the takeoff roll. The recorded selected heading data could have indicated an unusual procedure by the flight crew, a malfunction of the mode control panel or flight control computer, or something else. Thus, one focus of the investigation was to understand the actual reason for the unusual reading.

When examining unexpected FDR data, a common practice is to use the entire 25-hour record to determine if the unusual behavior has been present on previous flights. Figure 4 depicts the same four parameters from an earlier flight recorded on the FDR. The recorded values of selected heading generally followed the actual heading (as expected), but there were repeated instances where the two differed and the selected heading was recorded as 360°. During some of the times that the 360° values were recorded, the airplane was flying on a heading of approximately 315° with the autopilot engaged in heading select mode. With the selected heading 45° to the right of the actual heading the airplane would have been expected to begin a right turn toward 360°. However, no such behavior was observed in the recorded data. Figure 5 depicts a portion of the same flight as shown in Figure 4 at a different time scale. The unexpected 360° degree values can be seen to alternate with values coincident with the actual airplane heading.

A common practice among DFDAU manufacturers is to use alternating patterns to indicate errors in the FDR data. For example, "stale data" occur when a source stops transmitting data to the DFDAU or the transmitted data are not received by the DFDAU. Consultation with the manufacturer of the DFDAU confirmed that the alternating pattern observed in the FDR data from the accident flight was an error code indicating "stale data," which originated in the DFDAU. The stale data error code is an alternating sequence of 4095_{10} counts (i.e., 111111111111_2) and the last value received[3]. For selected heading, 4095_{10} counts converts to 360°, therefore the stale data error code consists of re-

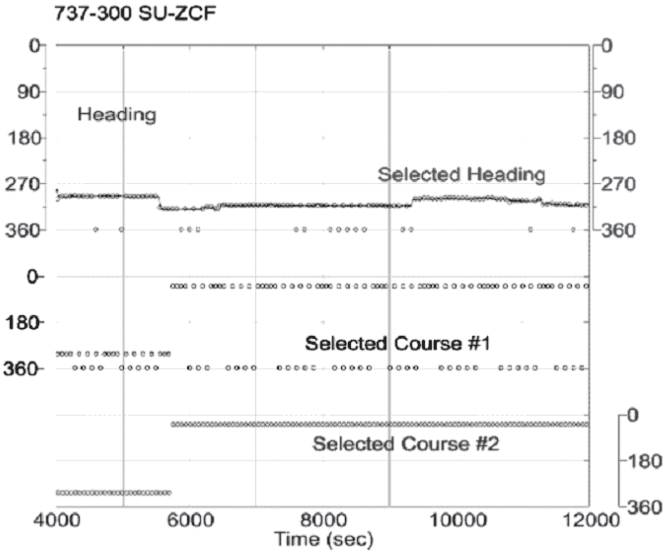


Figure 6. Similar to selected heading, unexpected values of 360° were also observed in the selected course #1 parameter but not in selected course #2. All three parameters are recorded once every 64 seconds. FDR data from the accidents airplane's sister ship exhibited the same unexpected values in the selected heading and selected course #1.

corded values of 360° alternating with the last value received. If the inquiry had ended here, one might conclude that the FCC had malfunctioned as evidenced by the apparent lack of selected heading transmission to the DFDAU. Such a conclusion would be incorrect.

In addition to the 25 hours of FDR data available from the accident airplane, the Egyptian MCA provided 25 hours of FDR data from the sister ship. An examination of that data confirmed the same behavior—selected heading occasionally alternated between an expected value and 360°. As shown in Figure 6, the same behavior was also discovered in the selected course #1 parameter[4] on both airplanes but not in the selected course #2 on either airplane. Based on these discoveries, the possibility arose that some sort of design characteristic was responsible for the observed data. Perhaps there was some difference in the way the selected heading and selected course #1 parameters were processed compared to the selected course #2 data that would explain the anomaly.

Accordingly, the inquiry focused on how the DFDAU detected stale data. According to the DFDAU manufacturer, stale data are detected as follows:

- The DFDAU uses an 8-bit counter to track the number of data samples it has received from the source (in this case the FCC).
- When scheduled to write a value to the FDR, the DFDAU compares the value of the counter to the value of the counter the last time a sample was sent to the FDR.
- If either the counter value or the data value is different, the DFDAU concludes the data are fresh. If both the counter value and the data value are the same, the DFDAU concludes the value is stale. After three consecutive stale samples, the DFDAU begins writing the stale data error code until either the counter value or data value change.

Consulting with the FCC manufacturer, it was determined that selected heading and selected course #1 were transmitted to the

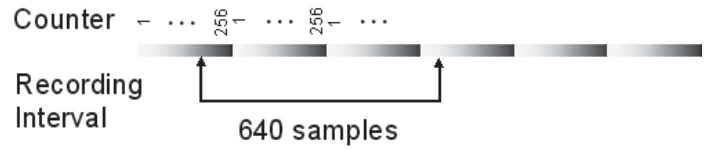


Figure 7. Behavior of an 8-bit counter when the receive-to-transmit interval is 640 to 1 as is the case for selected course #2. The capacity of an 8-bit counter is 256[5]. During normal operation, the counter will "roll over" twice (or possibly three times) between each transmission. Regardless of the value of the counter when a sample is transmitted, the counter will be at a different value (that differs by approximately 128 from the previous value) when the next sample is transmitted with the result that the DFDAU correctly detects that the data are fresh.

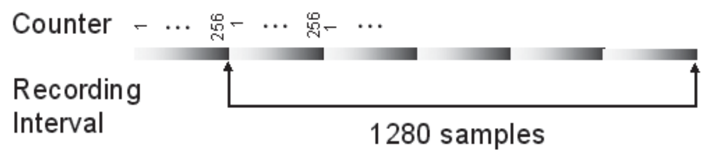


Figure 8. Behavior of an 8-bit counter when the receive-to-transmit interval is 1,280 to 1 as is the case for selected heading and selected course #1. The counter will roll over exactly five times between each transmission. The result is that the DFDAU incorrectly detects that the data are stale during normal operation.

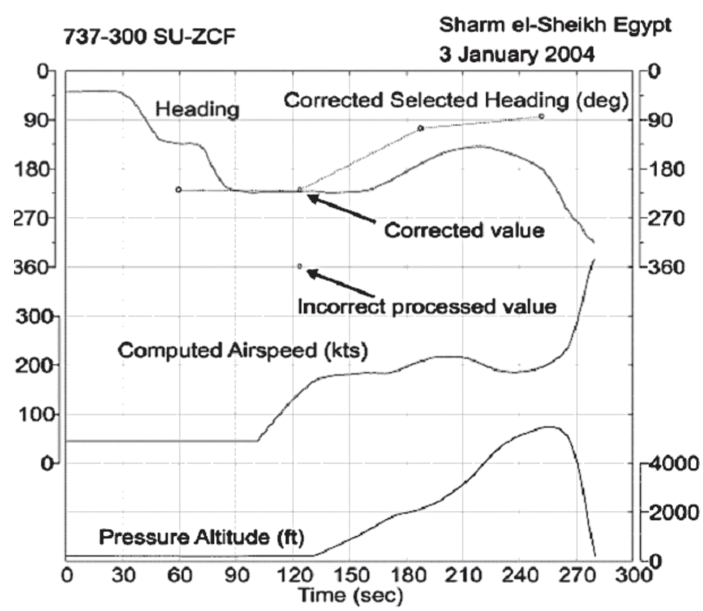


Figure 9. The same data as depicted in Figure 1 corrected to account for the anomaly discovered in the way the DFDAU processed the selected heading data. These were the data used for the analysis portion of the investigation.

DFDAU at a rate of 20 Hz. Thus, the DFDAU received selected heading data once every 50 ms and transmitted it once every 64 seconds—a ratio of 1,280 to 1. In contrast, selected course #2 was transmitted by the FCC (and received by the DFDAU) at a rate of 10 Hz for a ratio of 640 to 1.

Figure 7 depicts the behavior of the 8-bit counter when utilized for selected course #2 (receive to transmit ratio of 640 to 1). The capacity of an 8-bit counter is 0-255 or 256 distinct values.

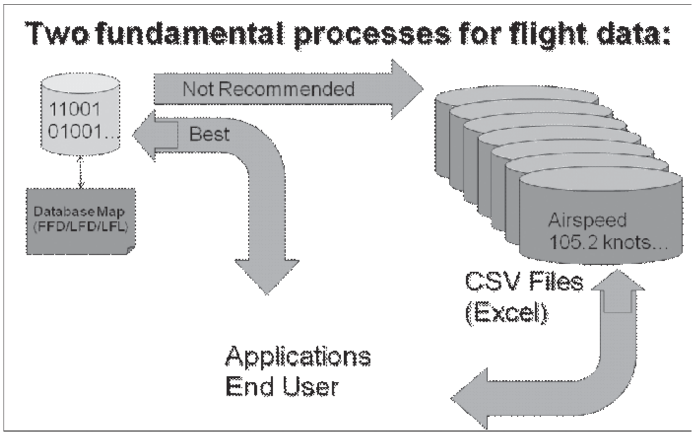


Figure 10. Flight data must be converted from raw binary format to engineering units for use in plotting and animations. The most common method is to perform the conversion one time and store the results as engineering units, often in CSV files. The conversion process itself can affect the relative timing and precision of data. Unfortunately, the conversion details are almost never provided—thus a portion of the provenance of the data is lost. A better method is to work interactively with the raw data performing explicit conversions only when needed.

During normal operation, the 8-bit counter will reach its maximum value and "roll over" back to zero at least twice and possibly three times as the 640 samples are received by the DFDAU between each sample transmitted to the FDR. Regardless of the value of the counter when a sample is transmitted, the counter will be at a different value (that differs by approximately 128 from the previous value) when the next sample is transmitted. The result is that the DFDAU can correctly determine if the data are fresh or stale.

Applying the same analysis to selected heading and selected course #1 yields a different result. Figure 8 depicts the situation when the ratio of receive-to-transmit interval is 1,280 to 1. In this case, the counter rolls over exactly five times between each transmittal to the FDR. Normal operation will result in the counter value being the same when successive samples are transmitted to the FDR. If the parameter value has not changed, the DFDAU will incorrectly detect that the data are stale, even though the correct number of samples (1,280) has been received.

The anomalies in the selected heading and selected course #1 parameters occurred frequently but not in every instance during which the above conditions are met. The last step in the inquiry determined that the exact receive-to-transmission ratio depended upon the relative timing between the FCC internal clock and the DFDAU internal clock, known as jitter[6]. Occasionally, the DFDAU would detect 1,279 or 1,281 samples instead of 1,280, in which case the data would be treated as fresh.

Once the behavior of the stale data detection algorithm was understood, it was a simple matter to correct the FDR data to accurately reflect the selected heading values transmitted by the FCC. The DFDAU will only detect stale data if the parameter value itself is unchanged. Therefore, it was possible to conclude that the selected heading transmitted by the FCC that resulted in the 360° value recorded on the FDR must have been the same as the previously recorded value—220, the runway heading. The investigation concluded that the anomaly in the stale data detection capability of the DFDAU was responsible for the unexpected value of selected heading recorded on the FDR and that the actual value of selected heading at this time was 220°. The corrected value shown in Figure 9 depicts the data used for the analysis portion of the investigation.

As often occurs, this investigation uncovered a finding not related to the accident itself—that the DFDAU did not correctly process data when the receive interval-to-transmit interval ratio was a multiple of 256[7]. A full understanding of the provenance of the FDR data allowed for the correct interpretation of that data for subsequent use in the analysis of the accident.

Flight data processing

As shown in Figure 10, flight data can be processed and used in two fundamentally different ways. One way is to convert the binary ones and zeros into engineering units data and produce CSV (comma separated variables) files, which are similar to what you would see in an Excel spreadsheet. The other, which is rare, is to interactively work with the binary data on a demand basis. The first method (CSV) is the most frequently used in the airline FOQA industry because the CSV format can be interchanged with nearly any computer system and software package. The second method (binary) requires software applications that have a built-in engineering unit conversion process that allows interaction with the actual raw flight data. The CSV method can introduce several problems that can, in some cases, make it unacceptable for an accident investigation owing to the inability to trace the provenance of the data and high potential to produce misleading results.

By way of example, Figure 11 depicts three CSV files generated with different options from the same source binary file. Each table lists the parameters across the top against time for each line of data. The table on the left discretizes time based on the highest sample rate of the data in the table (in this case the 8 Hz vertical acceleration parameter). This is the most compact and most frequently used method to convert flight data. It is also the most commonly used method to transmit converted data. The center table shows an expanded time base that includes the actual sample time for each entry in the table. This method makes the table larger in length but shows the relative timing between the parameters selected. The table on the right demonstrates what happens when the same principle is used to generate a table that includes parameters from each of the 64 words recorded each second[8].

From Figure 11 (next page), it can be seen that the length of the table is growing in size from the left to right. A first-generation FDR recording at 64 wps will record 5,760,000 words over 25 hours. The equivalent to the table on the right side of Figure 11 would, therefore, require 5,760,000 lines. To display the entire data set in Microsoft Excel would require 180 spreadsheets due to the 32,000 line limit in Excel, assuming you have enough columns to list all the parameters, which is not usually possible. A 512 wps QAR recording for 25 hours would require 1,440 Excel spreadsheets. Some QAR have up to a 400-hour capacity. Thus it is impractical to replicate the original binary file in a CSV format. As a result, most data processed and transmitted in the CSV format often compress the data such that each line of the file represents one second and includes only a subset of the actual recorded parameters.

UTC	Altitude (ft)	Air/ Ground	Pitch (deg)	Vert Accel (G)
01:38:45.00	196	GND	2.64	1.0778
		GND	2.81	0.9886
			3.34	0.9702
			3.87	1.0023
				0.9817
				0.9863
				0.9794
				0.9702
01:38:46.00	192	GND	4.22	1.0115
		GND	5.10	1.0069
			5.27	0.9931
			6.33	1.0389

1 second

UTC	Altitude (ft)	Air/ Ground	Pitch (deg)	Vert Accel (G)
01:38:45.00				
01:38:45.01				1.0778
01:38:45.04		GND		
01:38:45.07			2.64	
01:38:45.14				0.9886
01:38:45.26				0.9702
01:38:45.32			2.81	
01:38:45.39				1.0023
01:38:45.51				0.9817
01:38:45.54		GND		
01:38:[illegible]			3.34	
01:38:[illegible]				0.9863
01:38:45.76				0.9794
01:38:45.82			3.87	
01:38:45.89				0.9702
01:38:45.96	196			
01:38:46.00				
01:38:46.01				1.0115
01:38:46.04		GND		
01:38:46.07			4.22	
01:38:46.14				1.0069
01:38:46.26				0.9931
01:38:46.32			5.10	

1 second

UTC	Altitude (ft)	Air/ Ground	Pitch (deg)	Vert Accel (G)
01:38:45.01				1.0778
01:38:45.03				
01:38:45.04		GND		
01:38:45.06				
01:38:45.07			2.64	
01:38:45.09				
01:38:45.10				
01:38:45.12				
01:38:45.14				0.9886
01:38:45.15				
01:38:45.17				
01:38:45.18				
01:38:45.20				
01:38:45.21				
01:38:45.23				
01:38:45.25				
01:38:45.26				0.9702
01:38:45.28				
01:38:45.[illegible]				
01:38:45.[illegible]			2.81	
01:38:45.34				
01:38:45.35				
01:38:45.37				
01:38:45.39				1.0023
01:38:45.40				
01:38:45.42				
01:38:45.43				
01:38:45.46				
01:38:45.50				
01:38:45.51				0.9817
01:38:45.53				
01:38:45.54		GND		

1 second

Figure 11. Three methods of displaying the same flight data in tabular format. The table on the left lists discrete times based on the highest sample rate data in the displayed data (in this case 8 Hz vertical acceleration). It is the most compact format, but the relative timing between the different parameters is lost. The center table lists the actual sample time for each observation of the four parameters listed. The table on the right demonstrates how the length can expand as more parameter sample times are added.

The CSV method requires a number of compromises. The creator of a CSV file must decide which parameters are to be evaluated by the investigators and which are to be ignored. At best, the investigators are forced to request additional parameters once they begin their work and focus on a particular area (often resulting in a significant delay). At worst, the investigators may not realize that additional parameters were recorded and instead rely solely on the data in the original CSV file. Further, because the CSV file does not include the conversion algorithms themselves, it does not allow the provenance of the data to be checked and verified. For these reasons, Boeing does not accept CSV data from airlines requesting an evaluation of an event. Instead, Boeing requires the original raw binary data.

A320 example 1—CSV versus binary

The following example highlights the problems with accepting and using a processed engineering units CSV file instead of working interactively with the binary data. During the investigation of an A320 tail strike, it was determined that both pilots operated the side sticks simultaneously. When operated simultaneously, the A320 performs an algebraic sum of the two inputs to command the aircraft. (The algebraic-sum algorithm is used unless one pilot presses the priority button to eliminate the other side-stick position from the control algorithm. Neither priority button was used in this event.) Figure 12 shows the flight data for the four Hz side-stick inputs as CSV data (line) and the original binary data at their precise sample times (diamonds). As expected, the line is shifted slightly to the left by a fraction of a second since the CSV file is truncated to the nearest quarter second. Had this example been done with 1 Hz data, the time shift would be more pronounced. The difference between the two processing methods may seem very minor—surely nothing serious that would affect the analysis. A more-thorough analysis of the event reveals the problems introduced by the time shift in the CSV file.

A flight animation was developed using both the CSV data and the binary source data side-by-side to demonstrate the effect of the time shift. Figure 13 contains screenshots showing the recorded side-stick position at various points during the animation. The first officer is the pilot flying. The binary data are shown in the lower-left quadrant and the CSV data are shown in the lower-right quadrant of each image. The white diamond is the captain's input and the gray diamond is the first officer's input. When both are operated together, the white hollow diamond shows the algebraic sum. In Figure 13, the error between CSV and binary becomes dramatic. At key points in the animation, the behavior of the side sticks, and in particular the first officer's pitch inputs, is considerably different. While the binary data still have issues regarding resolution, accuracy, latency, and other provenance issues, they are considerably better than the CSV data, which have all those issues as well as the time shift resulting from the processing. It is not difficult to imagine that an analysis of the event based solely on the CSV data could result in erroneous conclusions.

A320 example 2—recovering data "dropouts"

The second A320 example highlights the need to work with the binary data to recover what is known as data "dropouts." These are frequent with magnetic tape-based recordings, which are susceptible to mechanical vibrations such as those that occur during tur-

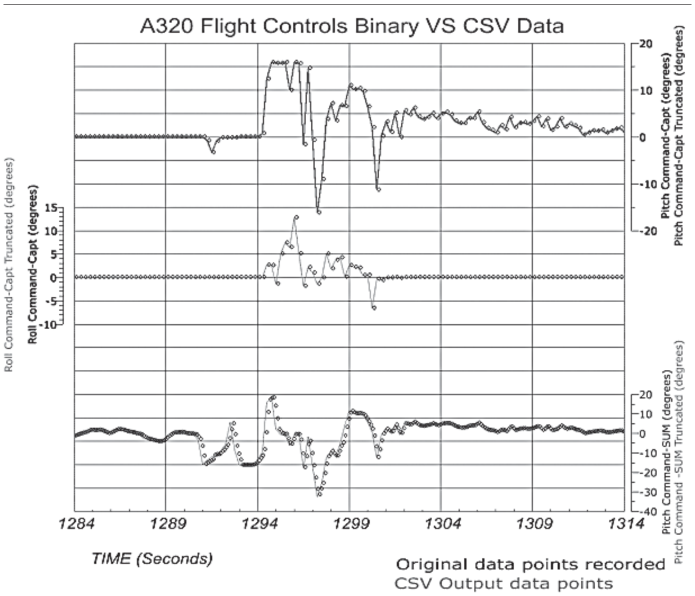


Figure 12. Comparison of A320 side-stick position data recorded at 4 Hz. The original binary data points are shown as diamonds. The same data processed by the CSV method is shown as lines. Note the time shift as the CSV method positions the 4 Hz data to the nearest ¼ second rather than at the actual time recorded.

bulence or a crash sequence. Data dropouts can also occur within solid-state recordings, primarily due to power interruptions.

On Feb. 14, 1990, an A320 crashed in Bangalore, India, with the loss of 92 lives. The investigation was conducted by the High Court of Karnataka, in accordance with Indian laws and regulations. The Court initially decided to have the recorders replayed at a local operator's readout facility, but the operator did not have A320s in its fleet at the time and it was unable to playback the FDR. The Court eventually decided to go to the Transportation Safety Board of Canada (TSB), where a request was made for a "readout" of the data only with no analysis. The TSB took the position that some analysis of the data was necessary in order to ensure that the data produced was correct. As discussed in this paper, the processing of flight data is fraught with the potential for error as well as choices in the manner in which it will be produced. The best way to ensure the data have been processed correctly is to examine and analyze the data. If the data appear unusual or unexpected, start by ensuring that the signal chain or provenance of the data is fully understood. It is important to understand that readouts using different systems or different settings on the same system can produce different results. As noted above, different results are possible depending on the options selected (for example, timing options on the generation of a CSV file).

The aircraft crashed short of the runway in daylight VFR conditions. At the moment of first impact, the initial playback "lost" one second of data due to vibration or jarring of the magnetic tape-based digital FDR. The initial investigation from the field concluded that a mild initial touchdown on the golf course was followed by a bounce and a second devastating impact. During the bounce, one engine spooled up and the other spooled down in response to the TOGA (take-off go-around) command. Early beliefs were that if both engines had spooled up, it may have been possible to avoid the accident. In fact, some newspapers reported that Canadian experts believed that the engine failed to respond and likely caused the accident (apparently because the readout had occurred in Canada).

The software system originally developed at the TSB is unique in that not only can it interactively work with binary data, but it also has an extensive "wave-bit editor"—which enables investigators to study the waveform recorded on the magnetic tape, which represents the digital ones and zeroes. Figure 14 is a sample screenshot[9] that shows how the bits are interpreted from the raw waveform recorded on the magnetic tape. The bits are recorded at a constant rate in bit cells of constant length. A zero is encoded as 180° of a sine wave within the allocated time while a one is encoded as 360° in the same interval. As shown on the third line of

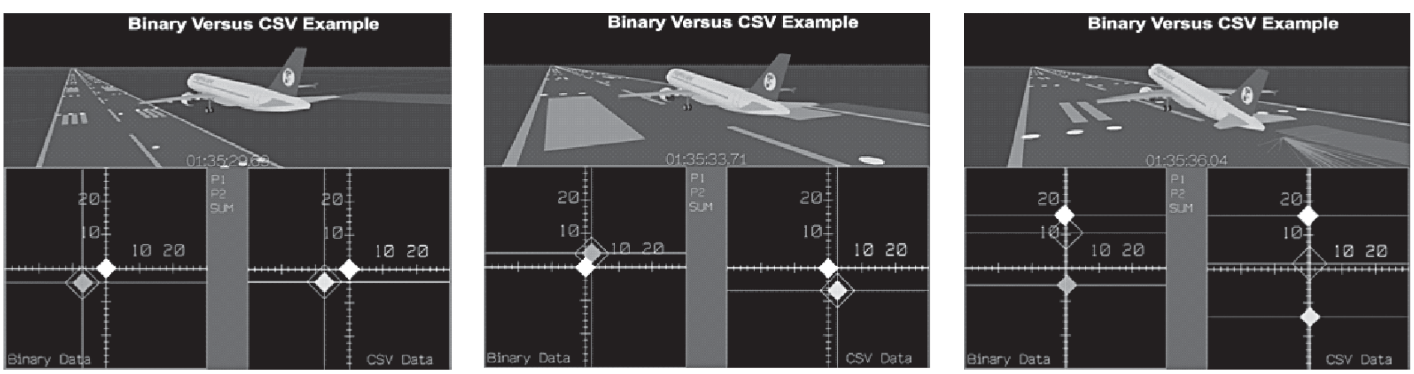


Figure 13. LEFT: Still frames taken from an animation of an A320 tail strike event during which both pilots operated their side-stick controllers simultaneously. The lower portion of each screen depicts the location of the side-stick controllers. Position based on the binary data are shown in the left quarter, and position based on CSV data are shown the in right quarter. The white diamond in the lower portion of each screen depicts the motion of the captain's controller, the gray diamond the first officer's, and the white hollow diamond the algebraic sum. The first image is taken approximately 6 seconds prior to the tail strike.
CENTER: Approximately 3 seconds later, the first officer's pitch input appears to be opposite directions in the binary and CSV data. In actuality, the apparent reversal is an artifact of the time shift of the CSV data and the frequency of the first officer's inputs.
RIGHT: At the time of the tail strike, differences can be seen in the first officer's pitch input and in the algebraic sum. A performance evaluation of the airplane's response based on the CSV data will not yield the same results as one based on the binary data.

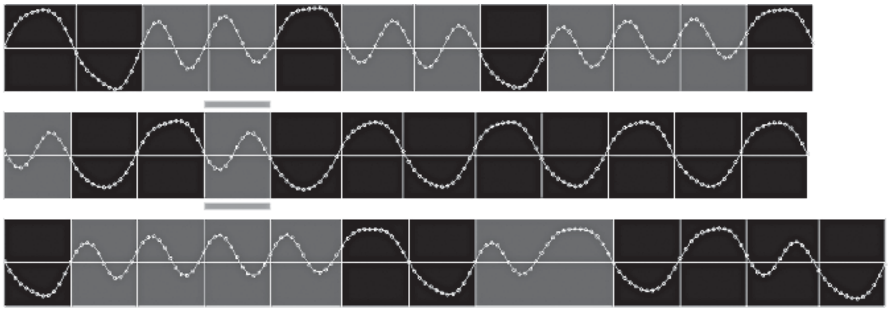


Figure 14. Digital FDR data recorded on magnetic tape consists of a sinusoidal waveform. A one or zero is encoded as either 360° or 180° of sine wave, respectively, within a fixed-length bit cell. The actual location of the cells is not known and must be deduced from the waveform by the readout software. The variation in bit cell length evident above is the result of tape stretch, variations in tape speed during either recording, or playback and other inconvenient realities inherent in mechanical devices. For ease of analysis, the readout system has drawn boxes around deduced location of each bit cell and color-coded the background as black or gray representing zero and one bits respectively. The gray highlight line indicates the position of the "cursor." On the third line of the Figure, the large gray block has been incorrectly interpreted as a single one bit rather than a one followed by a zero. When such errors occur, an entire second[10] worth of data is lost as all the subsequent bits are shifted.

Figure 13, a one followed by a zero was incorrectly interpreted as a single long one. The error is readily detectable by the FDR specialists and can be manually edited using the analysis software.

The FDR data from the Bangalore accident contained several similar problem areas in the waveform around the time of the first impact. Manual review and correction required a full day to correct the "lost" one second of data. However, once done, the corrected data revealed that the vertical acceleration peaked at over 6 G, the maximum range of the recording. This changed the initial conclusion that the engine may have *caused* the accident to the first contact *being* the accident. In fact, the first contact was so hard it was the "crash" and caused the engine to spool down due to damage to the electronic controls. Attention to the provenance of the data, specifically the reevaluation of the conversion from waveform to binary bitstream, redirected the entire focus of the investigation.

It should be noted that readout facilities used for FOQA or maintenance purposes typically do not have any ability to view the waveform and correct errors such as the ones that affected the data from the Bangalore accident. Had the Court gone to an operator for the readout or had the contribution of the TSB been limited to the readout without the necessary analysis to confirm the provenance of the data, it is likely the specific one second of data at the time of first impact would not have been recovered leading to erroneous conclusions[11].

Summary

Every investigator or analyst who uses flight data should know that the correct interpretation of flight data requires a full understanding of the provenance of the data. Each step in the signal chain from measurement to transmission, recording, decoding, conversion, and the final representation can introduce unintended changes and thus the potential for error. The examples discussed above demonstrate unintended changes introduced on board the accident aircraft and during the subsequent recovery and conversion processes. Determining the provenance of each parameter and understanding the capabilities and replay processes within the analysis software is a necessary step in the interpreting flight data. ◆

Endnotes

1 Flash Airlines Flight 604 Final Report, Egyptian Ministry of Civil Aviation 2006, page 2.

2 In this article, reported values of selected heading are rounded to the nearest whole degree. Although the resolution of the recording system for this parameter is 0.088°, only whole degrees are selectable on the mode control panel.

3 The subscript notation used in this article indicates the radix or base of the number. Thus binary numbers have the subscript 2 and decimal numbers have the subscript 10. By convention, the radix itself is expressed in base 10.

4 Selected course is the VOR radial selected by the flight crew on the mode control panel. In data originating from the left FCC, selected course #1 is the captain's course and selected course #2 is the first officer's course. In data originating from the right FCC, the two are swapped. The DFDAU can receive data from both FCC, but only records data from a single FCC. A different parameter on the FDR indicates which FCC is the source of the data on the FDR—demonstrating yet another reason to ensure the provenance of the data is well understood.

5 The actual values an 8-bit counter can encode are 0 through 255, a total of 256 distinct values. Software engineers may find fault with figures 7 and 8 because the values portrayed for the counter are 1-256 rather than 0-255. This choice was made for the benefit of that portion of society which starts counting at one rather than zero.

6 Another instance of jitter is often seen in the recording of UTC seconds. UTC seconds are typically recorded at an interval of four seconds (e.g., successive samples may be 3, 7, 11, 15, 19…). Occasionally, a recorded value will appear to be off by one second resulting in a pattern such as 3, 7, *10*, 15, 19….

7 As a result of this finding, the DFDAU manufacturer was notified of the anomaly so that necessary corrective actions could be taken.

8 First generation digital recorders use a recording rate of 64 twelve-bit words per second (wps). Later recorders use 128, 256, 512, and even 1024 wps recording rates. The length of the table on the left side of Figure 3 would grow accordingly.

9 The example data are not from the Bangalore accident which was an NRZ format recording.

10 Each second, a predefined synchronization code is written to the FDR. The readout system searches for and uses these "sync codes" to identify the beginning of each second of data thus limiting the effect of missing (or extraneous) bits in the data stream.

11 In part as a result of this accident, ICAO updated Annex 13, which now provides that states that conduct substantial analysis or provide substantial technical support (such as FDR readout) be permitted to appoint an accredited representative to the investigation. Annex 13, Appendix D, was updated to include guidelines for states without readout facilities that highlights the difference between an "airline" and "investigation" facility and the need to be able to work with and interactively edit FDR source data at the bit level.

Sound Identification and Speaker Recognition for Aircraft Cockpit Voice Recorder

By Yang Lin (AO5012), Center of Aviation Safety Technology (CAST) of CAAC, and Wu Anshan and Liu Enxiang, General Administration of Civil Aviation of China (CAAC), Air Safety Office

Yang Lin *(yanglin@mail.castc.org.cn) has more than 12 years of experience in the field of aviation safety and is a member of the International Society of Air Safety Investigators (ISASI). Currently she is an air safety investigator and senior engineer at the Civil Aviation Safety Technical Center (CASTC) of Civil Aviation of China (CAAC), where she has been working since 1994. While at CASTC, she analyzes and presents recorded data in support of accident/incident investigations and also conducts flight data recorder readouts on behalf of government authorities and airlines in China and other countries. She has helped to develop and apply CAAC regulatory policies for aviation recorders, FOQA, and other areas. Since 2005, she also worked for China Postal Airlines in Beijing. Her duties include incident investigation, flight crew safety awareness briefings, and flight data analysis program management.*

Wu Anshan *(as_wu@caac.gov.cn) is a senior air safety investigator with CAAC, and has been at the CAAC since 1970. His primary role has been to investigate the air traffic control and organizational aspects of aviation accidents and incidents. He has substantially contributed to more than 20 significant investigations and has been actively involved in developing investigation methodology at the CAAC.*

Liu Enxiang *(ex_liu@caac.gov.cn) is the deputy director at the CAAC's Office of Aviation Safety. He has been with the CAAC for more than 18 years. Liu has participated in several national aircraft accident investigations as an investigator-in-charge (IIC), as an expert in investigation of avionic equipment. He graduated from Nanjing University of Aeronautics and Astronautics with a degree in aeronautical engineering and has commercial aviation aircraft maintenance experience.*

As air transportation systems have expanded around the world in recent decades, aviation safety and accident/incident prevention have assumed greater importance to governments and airlines. Aircraft accident investigation has a key role to play when an aircraft has an accident or unexpected incident during flight operations. Traditionally the flight data recorder (FDR) has played the major role in establishing the causes of most accidents or incidents. However, information contained in the cockpit voice recorder (CVR) is also very useful during such investigations by providing a better understanding of the real situation. The CVR can act effectively as a latent signal transducer for both speech and non-speech audio information. Some typical techniques, such as sound identification, and voice recognition, appear to offer significant clues in the analysis and classification of speech and non-speech CVR signals.

The CVR records audio information on four channels. Non-speech information from the cockpit area microphone (CAM) is recorded on channel 1. CAM records thumps, clicks, and other sounds occurring in the cockpit other than speech. Channel 2 and 3 of the CVR record speech audio information from the captain and first officer's audio selector panels. Channel 4 records the audio information from the jump seat/observer's radio panel.

Background of cockpit sound identification

It may be hard to believe that non-speech sounds are highly important to the investigation of aircraft damage because the background cockpit sounds can reveal problem areas of the aircraft during the time leading up to the accident. Non-speech data from the CAM can be analyzed with sound spectrum analysis to detect whirl flutter, as well as possibly distinguish the sound of a bomb explosion from the sound of cabin decompression. Spectrum analysis can also be used to confirm that the clicks and thumps recorded by the CAM are simply generated by cockpit controls and the sound of the aircraft moving through the air.

Analysis background information recorded in aircraft CVRs has been proposed as a complement to the analysis of onboard FDRs in civil aircraft investigations. One reported case provides a good example of the analysis of CVR data playing a key part in an aircraft accident investigation. In 1992, a 19-seater commuter aircraft crashed during an evening training mission. At that time, the U.S. Federal Aviation Agency (FAA) did not require the installation of FDR on board all small commercial aircrafts, and the CVR on board the small jet that crashed was the only flight record available to provide clues to the causes of the accident. Fortunately, in this case, the CVR recording not only included the voice communication, but also structural acoustics as well as other sounds and noise sources. This allowed the accident investigation to focus on the non-speech sounds taken from the CVR tape. A close inspection of the time series from the CVR track revealed a periodic set of transient components occurring at a frequency of 0.86 Hz. Comparing this frequency with an independent dynamic analysis of the engine mount damage, the 0.86 Hz transient data were demonstrated by independent structural and flutter analyses to be quite close to the frequency experienced from a damaged engine mount. Moreover, there was a sudden, loud sound at the end of the tape. This 25-millisecond-long event was much louder than the sound in the cabin. Although this short length of the sound did not provide adequate audio listening time, there was enough signal time and ampli-

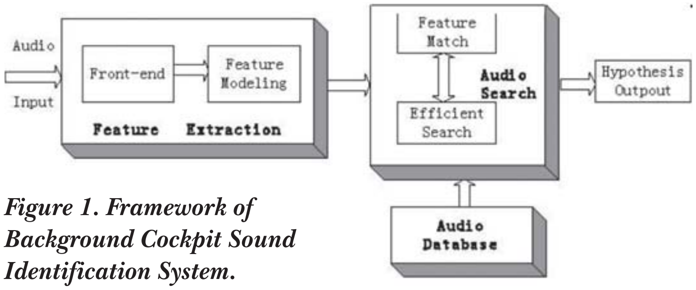


Figure 1. Framework of Background Cockpit Sound Identification System.

tude to perform wavelet and voice recognition analysis. The conclusion drawn after the investigation was that the engine on the starboard wing separated during the flight. Subsequently, the fallen engine struck the tail of the aircraft, damaging most of the horizontal surfaces. The loss of the engine also led to the separation of the right wing panel outboard of the engine. As a result, the aircraft pitched down, rolled to the right and crashed[1,2,3].

The results of the accident investigation described above, and that of Pan Am Flight 103, which disintegrated over Lockerbie, Scotland, in 1989 due to a bomb explosion, motivated us to explore the analysis of aircraft CVR sound sources for use in aircraft accident investigations.

In our system, background cockpit sound identification is used to find the audios identical to the given audio in the background cockpit sound database. The identical audios refer to the audios that are from the same source and maybe different in time and frequency domain just because of different codecs, bit rates, channels, noise, and so on. An audio ID is identified by audio fingerprint in acoustics. An audio fingerprint is composed of a series of audio features. Generally, audio feature design should obey the following guidelines[4].

- Discriminability: sensitive enough to distinguish the different audios.
- Robustness: stable enough to various codes, channels, and modest noise.
- Compactness: small enough for easy storage.
- Simplicity: inexpensive to compute and easy to implement.

There are many approaches available to extract audio features. Mel Frequency Cepstral Coefficients (MFCC) are used as audio features in "Robust Sound Modeling for Song Detection in Broadcast Audio,"[5] and in "Method and Article of Manufacture for Content-Based Analysis, Storage, Retrieval, and Segmentation of Audio Information."[6] "Content-Based Identification of Audio Material Using mpeg-7 Low-Level Description"[7] takes spectral flatness measure as feature parameters. Papaodysseus takes the choice of band representative vectors that is an ordered list of indexes of bands with significant energy[8]. In the approaches above, audio signal is segmented into frames first and a set of features are extracted frame by frame. Some approaches compute a block of features from a big segment of audio. Etantrum gets a 512-bit audio feature from as long as 30 seconds.[9]

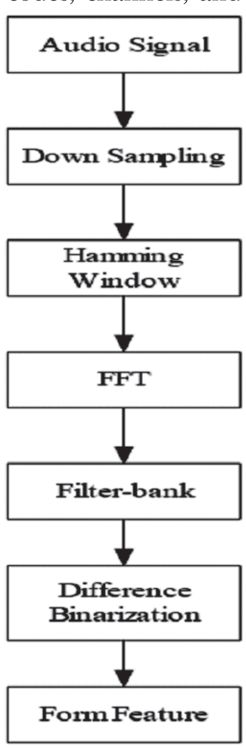


Figure 2. Feature extraction flow chart.

The background cockpit sound feature extraction approach proposed in this paper is based on "Robust Audio Hashing for Content Identification."[4] It takes into account that the sign of spectral band energy difference (both in time and frequency axis) is very robust to many kinds of processing. By analyzing this approach carefully, we proposed an improved approach, which enhances the robustness of audio feature significantly. When audio features are ready, the Background Cockpit Sound Identification System will be able to search identical audios in the database quickly and effectively.

Haitsma presented a method that locates the potential identical audios by a hash table[4]. It is quite efficient. But it needs about four times or more space to save data compared to other methods, and it slows down the process dramatically when audios are in bad quality.

Kimura adopted a two-pass search strategy.[10] He generated the vector codebook of audio features first and obtained the distribution of vector code within a period of audio. This distribution is then compared to that of a given audio. This comparison is regarded as the first rough search. The audios with similar distribution will continue to go in for the next fine match. Since the distribution comparison is processed by a block of frames instead of frame by frame, it can search audios quickly. The beam-based search approach cuts off branches whose cumulative match scores are higher than the beam width from the best score. Plenty of unpromising paths are pruned away during the search process. The search space is reduced dramatically and high efficiency is achieved.

1. Framework of Background Cockpit Sound Identification System

Figure 1 shows the framework of the system. It is composed of three modules: feature extraction, audio search, and audio database. When audio signals are fed into the System, it extracts audio features first. Audio features are compared to the features in audio database. Audio candidates are generated according to the result of the match process.

The feature extraction module does some preliminary processing, such as down sampling, and low band pass filtering. Then it computes the audio features using algorithm described in Section 2 below. The audio feature database stores the audio features computed in advance. The audio search module compares the features of possible identical audios and outputs the best candidates.

2. Audio feature extraction approach

Figure 2 shows the audio feature extraction flow chart adopted. Because human hearing is most sensitive to the frequencies below 2,000 Hz, high-frequency parts lose heavily when audios are encoded at very low bit rates. Accordingly, in this System audio signals are down sampled to 5,000 Hz first. Then signals are segmented into frames and weighted by a hamming window. Fourier transformation is performed, and spectrum power is obtained. A total of 33 overlapped frequency bands are used at an equal logarithm interval. A 32-bit audio feature is computed for each frame.

In order to make the audio feature stable, a frame length as long as 410 milliseconds is chosen. Frame shift is only 12.8 milliseconds. As a result, the frame boundaries of audio queries in the worst case are 6.4 milliseconds off from the boundaries used in the database that are precomputed.

3. Audio search approach

3.1 Audio feature similarity measurement

Each frame has one 32-bit audio feature. The similarity of two features is measured by the Hanning distance, which is the number of different bits. The smaller the Hanning distance, the more similar the two features are, vice versa.

Bit error rate (BER) defines the similarity of two audio feature serials with the same length. Let **X**, **Y** are two audio feature serials, $\mathbf{X}=\{x_1, x_2,\ldots, x_N\}$, $\mathbf{Y}=\{y_1, y_2,\ldots, y_N\}$. Where N is the frame number of the features. The BER between **X** and **Y** is

$$BER(X,Y) = \frac{\sum_{i=1}^{N} H(x_i, y_i)}{32N}$$

Where, ***H***(.) is the Hanning distance between **X** and **Y.** Obviously, 0d"BERd"1, the lower the BER is, the more similar the two feature serials are.

3.2 Beam-based search approach

When searching audio candidates in the audio database, it will be of very low efficiency if a whole match comparison is processed at every possible starting frame. A beam-based search strategy is presented in this System to avoid low efficiency. The main idea of this approach is that it takes the current best score as the base and prunes away all branches whose scores are higher than the base plus the empirical threshold (beam width).

4. Experimental results

First, we used the Chinese National Project Speech Database as test data. All silent parts at the beginning and the end of the speech files are cut off. Speech files are merged into 5-minute-long files. Totally 20 hours of speech are used as the audio database. Five hundred 3-second audio files are randomly picked out from the database. These 3-second audios are used as the audios to be identified. All these speech data are originally in PCM 16K sample rate format. They are encoded by various codecs at different bit rate and then decoded to the PCM 8K sample rate wave files that are used in our experiments.

4.1 Audio feature robustness test

The audio feature robustness test checks the degree of consistency between the features of original audios and the processed ones by various codecs. The robustness of audio features can be measured by a BER of features. Fifty-minute-long data are tested in our experiments. We compared the performance of our approach and that of Haitsma's approach. Figure 3 shows the test results. Where MP3@32K means MP3 encoded and decoded at 32K bit rate. BER1 are obtained by Haitsma's approach, and BER2 are from our approach. It shows that our approach enhances the robustness of the audio feature consistently at various codecs and bit rates. It reduces BER by 20.4% on average. Additionally, we tested the robustness for the non-speech audio data. The results show there is no difference between speech data and non-speech data for robustness in terms of statistics.

Codec	BER1	BER2	Reduction
MP3@64K	0.105	0.075	28.6%
MP3@32K	0.117	0.086	26.5%
WMA@16K	0.116	0.095	18.1%
Real@20K	0.105	0.082	21.9%
Real@5K	0.265	0.227	14.3%
Average	0.142	0.113	20.4%

Figure 3. Feature robustness comparison under various conditions.

AudioDB	Query	Precision Rate	Recall Rate	RTF
ORI	MP3@32K	98.0%	100%	$1.8*10^{-6}$
ORI	Real@5K	98.2%	100%	$2.0*10^{-6}$
Real@5K	Real@20K	97.7%	99.8%	$1.9*10^{-6}$
WMA@8K	Real@5K	98.6%	99.6%	$1.9*10^{-6}$
WMA@8K	MP3@32K	99.2%	99.8%	$1.9*10^{-6}$

Figure 4. System performances under various conditions.

4.2 Audio search performance test

Nearly 20-hour-long speech data are in the audio database. Five hundred 3-second audio segments are used as queries to be identified. Precision rate and recall rate are used as the performance indicator. Precision rate is the ratio of the number of correct candidates to the number of all candidates the system outputs. Recall rate is the ratio of the number of correct candidates to the number of all queries to be identified.

Figure 4 shows the performance of the system under different codecs and bit rates. AudioDB refers to the encoding and decoding method for the background cockpit sound database. Query refers to that for query audios. ORI refers to the original data not processed by any codecs. RTF refers to the real-time factor, which is the ratio of the average recognition time for one query to the total amount (time) of the audio database.

Figure 4 shows that the system works quite well for various cases, and the search speed is reasonably fast.

4.3 Real CVR audio search performance test

We performed two types of audio search tests in this study. First, the following three types of sounds generated in the cockpit were recorded as sound samples:

- Warning and alert signals such as GPWS, TCAS, engine fire, autopilot disengage, etc.
- Sounds generated by switches on central panel P2, glare shield P7, and forward overhead panel P5.
- Sounds generated by levers such as landing gear lever, thrust lever, speed-brake lever, and flap lever as well as stall warning signals generated by the levers.

Audio Sample	Sound Source	Time Begin	Time End	Score=1-100*BER
TOGA switch	Audio database	32:53.8	32:54.4	[94.9]
TOGA switch	SSCVR	02:07.4	02:08.0	[77.8]
TOGA switch	Tape CVR	20:30.8	20:31.3	[77.3]
IAS_MACH	SSCVR	09:57.5	09:58.1	[84.7]
IAS_MACH	Tape CVR	14:29.3	14:29.9	[79.4]
IAS_MACH	Audio database	03:31.6	03:32.3	[91.3]
Sink Rate	SSCVR	05:47.5	05:48.1	[75.3]
Sink Rate	Tape CVR	08:09.3	08:10.0	[77.8]
Sink Rate	Audio database	10:32.5	10:33.1	[89.1]
Flap Lever	Audio database	15:52.8	15:53.7	[93.4]
Flap Lever	SSCVR	10:48.3	15:49.2	[53.1]
Flap Lever	Tape CVR	20:10.1	20:11.0	[50.4]

Figure 5. Example of searching result.

Nearly 20 hours of audio data are saved in the audio database. Fifty audio segments that are less than 3 seconds long are used as queries to be identified.

The first type of audio search test uses the cockpit sound samples we recorded earlier to test against all prerecorded cockpit sound samples in the same database.

The second type of audio search test uses real sound recorded on tape CVR and solid-state CVR. The sound samples to search with are the same as in the first type of test. The result of these tests is shown in Figure 5. The higher the score is, the more similar the two feature series are.

From the test results, we can see that in the first type of audio search tests three types of sounds generated in the cockpit were recorded as sound samples have the higher score. While in second type of audio search test, warning, and alert signals and switch sounds have higher scores; the sounds generated by various levers have the lowest score.

Automatic speaker recognition

The speech information recorded by the CVR can be analyzed with spectrum analysis in order to match the recorded voices to the appropriate person.

Automatic speaker recognition automatically extracts information transmitted in the speech signal, which can be classified into identification and verification, and identifies a speaker based on his or her voice in the CVR recording. Speaker identification is the process of determining which registered speaker provides a given utterance. Speaker verification is the process of accepting or rejecting the identity claim of a speaker. Speaker recognition methods can also be divided into text-dependent and text-independent methods. The former requires the speaker to say key words or sentences having the same text for both training and recognition trials, whereas the latter does not rely on a specific text being spoken (Figure 6).

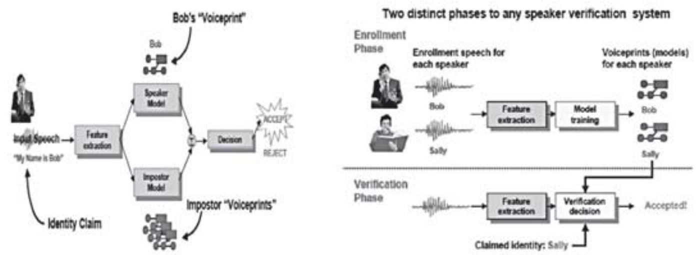


Figure 6. Speaker Identification and Speaker Verification System.

Current state-of-the-art systems for text-independent speaker recognition use features extracted from very short-time segments of speech and model spectral information using Gaussian Mixture Models (GMM).[11] Using a Universal Background Model (UBM)/GMM-based system is now compulsory to obtain good performance in evaluation campaigns such as the U.S. National Institute of Standards & Technology (NIST) Speaker Recognition Evaluation (SRE).[12,13] NIST has conducted an annual evaluation of speaker verification technology since 1995. This approach, while successful in matched acoustic conditions, suffers significant performance degradation in the presence of ambient noise. Some methods are proposed to compensate for channel variation and intra-speaker variation by normalization techniques such as the Cepstral Mean Subtraction (CMS), feature warping[14], feature mapping[15], and joint factor analysis.[16] Modeling of spectral information by GMM can be improved or complemented by the use of other modeling techniques like Support Vector Machines (SVMs)[17,18,19], or by transformations of the cepstral space.[20] However, short-term cepstral modeling fails to capture longer-range stylistic aspects of a person's speaking behavior, such as lexical, rhythmic, and intonational patterns. Recently, it has been shown that systems based on longer-range stylistic features provide significant complementary information to the conventional system.[21,22,23] Another important issue in the statistical approaches to speaker recognition is that of score normalization, which covers aspects such as the scaling of likelihood scores. [23,24]

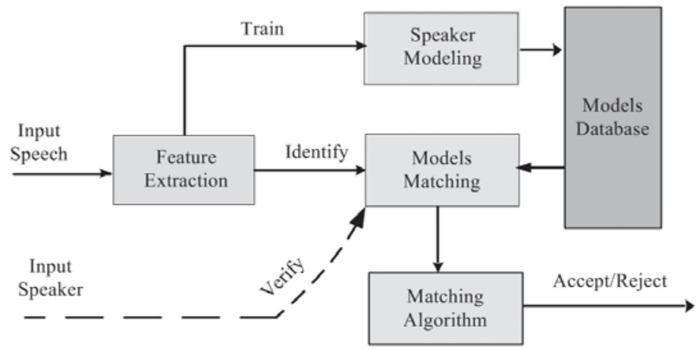


Figure 7. Framework of Automatic Speaker Recognition System.

1. Framework of Automatic Speaker Recognition System

Figure 7 shows the framework of the System. It is composed of three modules: feature extraction, speaker modeling, and speaker recognition. When audio signals are fed into the System, the speaker features are drawn from the input speech segments. Furthermore, the influence of channel and environment is restrained by robust techniques. During the speaker modeling process, input front-end features characterize the speaker. The GMM or SVM modeling approach is used to train the target speaker models, which compose the speaker model database.

2. Speaker feature extraction approach

The speech signal is smoothed in short time. For analyzing the speech signal, the usual frame concept is introduced by shortening the speech segment by 10 ms-30 ms. The shift length is the half length of one frame. To compensate for the attenuation of the high frequency, every frame of the speech signal uses preweighted processing.

There are two main aspects of speaker features. First, the physiologic structure is different for each individual, such as the track length and oral cavity structure, so the short-time spectral is differ-

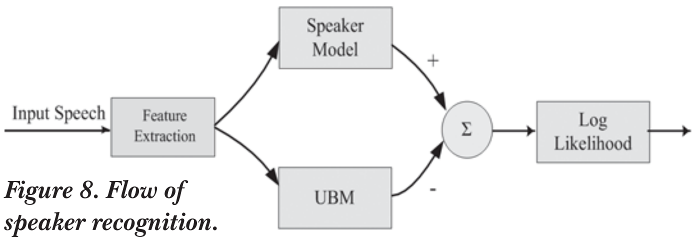


Figure 8. Flow of speaker recognition.

Training Condition		Test Segment Condition			
		10 sec 2-chan	**1 conv 2-chan**	**1 conv summed-chan**	**1 conv aux mic**
	10 seconds 2-channel	optional			
	1 conversation 2-channel	optional	required	optional	optional
	3 conversation 2-channel	optional	optional	optional	optional
	8 conversation 2-channel	optional	optional	optional	optional
	3 conversation summed-channel		optional	optional	

Figure 9. Matrix of training and test segment conditions.

ent. Second, the uttered habits are different, such as an accent. It can be described as prosody features. In the field of speech signal processing, the former is embodied on the structure of frequency. The classical features include cepstral and pitch. And the latter is embodied on the variability of the speech based on the spectral structure. The classical features include the delta cepstral and delta pitch.

In speaker recognition, the cepstral is used mostly and could achieve a good performance. Besides, it can be extracted more easily than other features. At present, the Mel Frequency Cepstral Coefficients are used successfully in speaker recognition, which is proven in applications. In feature extractors of speaker systems, all of the feature vectors are processed by CMS and the feature warping method.

Using the delta cepstral information based on a time domain proves that the performance of speaker recognition is enhanced mostly. In our system, speech data are parameterized every 25 ms with 15 ms overlap between contiguous frames. For each frame, a feature vector with 52 dimensions is calculated: 13 Mel Frequency Perceptual Linear Predictive (MFPLP) coefficients, 13 delta cepstral, 13 double delta cepstral, and 13 triple cepstral.

3. Two of the speaker models

3.1 Cepstral GMM system

The GMM system uses a 100-3800 Hz bandwidth front end consisting of 24 MEL filters to compute 13 cepstral coefficients (C1-C13) with cepstral mean subtraction, and their delta, double delta, and triple-delta coefficients, producing a 52-dimensional feature vector. The feature vectors are modeled by a 2,048-component GMM. The background GMM is trained using data from the NIST 1999 and 2001 speaker recognition evaluation. The features are mean and variance normalized over the utterance. For channel normalization, the feature mapping is applied using gender- and handset-dependent models that are adapted from the background model. Target GMMs are adapted from the background GMM using a Maximum a Posteriori (MAP) algorithm adaptation of the means of the Gaussian components. The resulting scores are T-normed.

3.2 Cepstral SVM system

The cepstral SVM system is based on the cepstral sequence kernel proposed by "The Contribution of Cepstral and Stylistic Features to SRI's 2005 NIST Speaker Recognition Evaluation System."[23] All of them use basic features, which are similar to the cepstral GMM system. The only difference is that MFCC features are appended with only delta and double delta features. This results in a 39-dimensional feature vector. This vector undergoes feature-transformation and mean-variance normalization using the same procedure as explained in the cepstral GMM system. Each normalized feature vector (39 dim) is concatenated with its second (39x39) and third (39x39x39) order polynomial coefficients. Mean and standard deviation of this vector are computed over the conversation side.

4. Speaker recognition approaches

As mentioned above, the speaker recognition includes speaker verification and speaker identification. The speaker verification is determined by whether the test speech segment is uttered from the given target speaker or not. The result of recognition is "YES" or "NO," and the comparison happens between one segment and one fixed speaker. The speaker identification is that given the test speech segment. The system needs to choose the true speaker from the speaker models database. The key function is calculating the log likelihood of the input test speech features and one target speaker model. Its calculated method is denoted as follows:

$$S(X) = \log p(X \mid \lambda_{hyp}) - \log p(X \mid \lambda_{UBM})$$

Where $S(X)$ is the final output score, $p(X \mid \lambda_{hyp})$ is the probability of the speech segment based on the hypothesis model; $p(X \mid \lambda_{UBM})$ is the probability of the speech segment based on UBM. The final output score $S(X)$ is according as the final answer "YES" or "NO" by comparing with the system threshold. The flow of speaker recognition is shown in Figure 8.

5. Evaluation and experimental results

5.1 NIST evaluation

We used NIST 06 SRE tasks and data as training and test data. The NIST speaker evaluation method is introduced in this section. The evaluation includes 15 different speaker detection tests defined by the duration and type of the training and test data. Each of these tests involves one of five training conditions and one of four test conditions. One of these tests (Figure 9) is designated as the core test. The task is to determine whether a specified speaker is speaking during a given segment of conversational speech.

The task of speaker detection includes single speaker verification and conversational speaker verification based on a telephone database. In the single speaker verification task, a training or testing speech segment is uttered from one speaker. Thus, the task determines whether a specified speaker is speaking during a given segment of conversational speech. Moreover, in the conversational speaker verification task, there is at least one conversational speech segment in the training database and testing database. The conversational speech segments are uttered from two speakers. In speaker verification task, the test data are segmented by speakers first and then processed by conventional verification.

There is a single, basic cost model for measuring speaker detection performance to be used for all speaker detection tests. For each test, a detection cost function will be computed over the sequence of trials provided. Each trial must be independently judged as "true" (the model speaker speaks in the test segment) or "false" (the model speaker does not speak in the test segment), and the correctness of these decisions will be tallied. This detection cost function is defined as a weighted sum of miss and false alarm error probabilities:

The parameters of this cost function are the relative costs of detection errors, C_{Miss} and $C_{\text{FalseAlarm}}$, and the *a priori* probability of the specified target speaker, P_{Target}. The parameter values are used as the primary evaluation of speaker recognition performance for all speaker detection tests, $C_{\text{Miss}} = 10$, $C_{\text{FalseAlarm}} = 1$, $P_{\text{Target}} = 0.01$. Besides, the equal error rate (EER) also describes the performance. EER is denoted as the point value when the miss rate is equal to the false alarm rate,

$$EER = P(\text{Miss} \mid \text{Target}) = P(\text{False} \mid \text{Non Target}) .$$

5.2 Experiments and results

The experiments are assigned based on the 2006 NIST speaker recognition evaluation database.

- The performance of the speaker identification system. The correct detection rate is more than 92%, in a case in which the speaker number of the closed database is no more than 50 and the number of candidate is 5.
- The performance of the speaker verification system. The EER is no more than 10%. It is similar to the best level compared with other systems.

5.3 Real CVR speaker recognition performance test

First, we created captain (CAP), first officer (FO), and observer (OBS) speech segments manually from four audio files from a 30-minute tape CVR (Figure 10). The segments were then saved as small wav files, which were used to train speaker models for CAP, FO, and OBS. Due to limited data availability, CAP and OBS speaker modeling used about 30 seconds of data, and FO speaker modeling used about 60 seconds of data.

Next, for each speaker we randomly chose four segments to test; for each testing segment, a score was calculated for each of the three speakers, and the speaker with the highest score was identified. Our testing results are shown in Table 5. The first column is the different testing segment. The second column shows whether speaker recognition was correct. The third, fourth, and fifth columns show that for the same testing segment, different scores were obtained against different speakers. Some of the fields are blank, which means an unusually low score, indicating that the speech segment and the speaker do not match. In most cases, speaker recognition was correct. Because we have limited pilot data available, we also see some mistakes.

The correct rate is usually used to evaluate the effectiveness. The correct rate C is defined as follows:

C = number of correctly recognized test utterances/total number of test utterances.

In this test, the correct rate is 10 out of 12, which is 83.3%. ◆

CVR Transcript	Results	CAP Score	FO Score	OBS Score
CH-2-OBS-Eighteen degrees three six left-I heard. wav	Correct		0.46	***0.94***
CH-2-OBS-ATIS gives us inches-hectopascals. wav	Correct		0.17	***0.19***
CH-2-OBS-What data were they given. wav	Correct	0.09	0.41	***0.5***
CH-2-OBS-Select altitude to two three zero .wav	Error	0.27		0.2
CH-3-FO-ILS frequency is one zero eight point five. wav	Correct	0.13	***1.51***	0.84
CH-3-FO-Look at that side taxiway. wav	Correct	0.13	***1.32***	0.97
CH-3-FO-No outer marker-no inner marker-VOR one one three point eight with DME. wav	Correct		***1.14***	0.39
CH-3-FO-Circle to land-cleared for ILS approach three six left-and then circle to land one eight right-report runway in sight. wav	Correct	0.22	***1.47***	0.78
CH-4-CAP-Wind direction is two two zero-but how much-more than ten knots. wav	Correct	***0.13***		
CH-4-CAP-Do we have to maintain this altitude. wav	Error	0.1	0.15	
CH-4-CAP-We won't enlarge the traffic pattern-the mountain is all over that side. wav	Correct	***0.48***		
CH-4-CAP-I feel it is seldom to be instructed to fly this traffic route-it is the first time. wav	Correct	***0.23***		

Figure 10. Example of training and test segment results for speaker recognition.

References

[1] Vogt, C., Coughlin, S., Lauber, J.K., Hart, C.A., and Hammer Schmidt, J., "Loss of Control Business Express-Beechcraft 1900C N811BE Near Block Island, Rhode Island." Aircraft Accident/Incident Summary Report, National Transportation Safety Board, Washington, D.C., April 1993.

[2] Stearman, R.O., Schulze, G.H., and Rohre, S.M., "Aircraft Damage Detection from Acoustic and Noise Impressed Signals Found by a Cockpit Voice Recorder." Conference Institute of Noise Control Engineering, 1997.

[3] Stearman, R.O., Schulze, G.H., Rohre, S.M., and Buschow, M.C., "Aircraft Damage Detection from Acoustic Signals Found by a Cockpit Voice Recorder," 133rd Meeting Lay Language, Acoustical Society of America, 1997.

[4] J. Haitsma, T. Kalker, "Robust Audio Hashing for Content Identification," in Proc. of the Content-Based Multimedia Indexing, Firenze, Italy, September 2001.

[5] P. Cano, E. Batlle, H. Mayer, and H. Neuschmied, "Robust Sound Modeling for Song Detection in Broadcast Audio," in Proc. AES 112th Int. Conv., Munich, Germany, May 2002.

[6] T. Blum, D. Keislar, J. Wheaton, and E. Wold, "Method and Article of Manufacture for Content-Based Analysis, Storage, Retrieval, And Segmentation of Audio Information," U.S. Patent 5,918,223, June 1999.

[7] E. Allamanche, J. Herre, O. Helmuth, B. Fröba, T. Kasten, and M. Cremer, "Content-Based Identification of Audio Material Using mpeg-7 Low-Level Description" in Proc. of the Int. Symp. Of Music Information Retrieval, Indiana, U.S.A., October 2002.

[8] C. Papaodysseus, G. Roussopoulos, D. Fragoulis, T. Panagopoulos, and C. Alexiou, "A New Approach to the Automatic Recognition of Musical Recordings," J. Audio Eng. Soc., Vol. 49, No. 1/2, pp. 23–35, 2001.

[9] Etantrum. [On line]. Available: http://www.freshmeat.net/projects/songprint.

[10] A. Kimura, K. Kashino, T. Kurozumi, and H. Murase, "Very Quick Audio Searching: Introducing Global Pruning to the Time-Series Active Search," in Proc. of Int. Conf. on Computational Intelligence and Multimedia Applications, Salt Lake City, Utah, May 2001.

[11] D. Reynolds, T. Quatieri, and R. Dunn, "Speaker Verification Using Adapted Mixture Models," Digital Signal Processing, vol. 10, pp. 181-202 (2000).

[12] G.R. Doddington, M.A. Przybocki, A.F. Martin, and D.A. Reynolds, "The NIST Speaker Recognition Evaluation—Overview, Methodology, Systems, Results, Perspective," Speech Communication, Vol. 31, pp. 225-254, 2000.

[13] [On line] The NIST Speaker Recognition Evaluation Home: http://www.nist.gov/speech/tests/spk/index.htm.

[14] Jason Pelecanos and Sridha Sridharan. Feature Warping for Robust Speaker Verification. Proc. Speaker Odyssey. Crete, Greece, 2001.

[15] D. Reynolds, "Channel Robust Speaker Verification Via Channel Mapping," Proc ICASSP, Hong Kong, pp. 53-56. 2003.
[16] C. Vair, D. Colibro, F. Castaldo, E. Dalmasso, P. Laface, Channel Factors Compensation in Model and Feature Domain for Speaker Recognition, Odyssey 2006 Workshop on Speaker and Language Recognition.
[17] W. Campbell, J. Campbell, D. Reynolds, D. Jones, and T. Leek, "High-Level Speaker Verification with Support Vector Machines," Proc. IEEE ICASSP, Montreal, 2004.
[18] S. Kajarekar, "Four Weightings and a Fusion: A Cepstral SVM System for Speaker Recognition," Proc. IEEE ASRU Workshop, Cancun, 2005.
[19] W.M. Campbell, J.P. Campbell, D.A. Reynolds, E. Singer, P.A. Torres-Carrasquillo, "Support Vector Machines for Speaker and Language Recognition," Computer Speech and Language, Vol. 20, pp. 210–229, 2006.
[20] A. Stolcke, L. Ferrer, S. Kajarekar, E. Shriberg, and A. Venkataraman, "MLLR Transforms as Features in Speaker Recognition," Proc. Eurospeech, Lisbon, pp. 2425-2428, 2005.
[21] W. Campbell, J. Campbell, D. Reynolds, D. Jones, and T. Leek, "High-Level Speaker Verification with Support Vector Machines," Proc. IEEE ICASSP, Montreal, 2004.
[22] E. Shriberg, L. Ferrer, S. Kajarekar, A. Venkataraman, and A. Stolcke, "Modeling Prosodic Feature Sequences for Speaker Recognition," Speech Communication, Vol. 46, pp. 455-472, 2005.
[23] L. Ferrer, E. Shriberg, S. Kajarekar, A. Stolcke, K. Sonmez, A. Venkataraman, and H. Bratt, "The Contribution of Cepstral and Stylistic Features to SRI's 2005 NIST Speaker Recognition Evaluation System," Proc. ICASSP, Toulouse, pp. 101-104, 2006.
[24] Reynolds, D., Comparison of Background Normalization Methods for Text-Independent Speaker Verification. Proc. Eurospeech, Rhodes, pp. 963–966, 1997.

International Cooperation and Challenges: Understanding Cross-Cultural Issues

By Dr. Wen-Chin Li, National Defense University; Dr. Hong-Tsu Young, Taiwan, ASC; Thomas Wang, ASC; and Dr. Don Harris, Cranfield University

Dr. Wen-Chin Li *is assistant professor in the National Defense University, Republic of China, and Visiting Fellow in the Department of Human Factors, Cranfield University, United Kingdom. He is an aviation human factors specialist in the European Association of Aviation Psychology and a registered member of the Ergonomics Society (MErgS). Contact e-mail: w.li.2002@cranfield.ac.uk.*

Dr. Hong-Tsu Young *is the managing director of the Executive Yuan, Aviation Safety Council, Republic of China. He was the coordinator of the National Taiwan University Commercial Pilot Training Program by the Civil Aviation Authority (CAA) and deputy chairman of the Department of Mechanical Engineering, National Taiwan University.*

Thomas Wang *is currently the director of the Flight Safety Division, Aviation Safety Council. He is a former China Airlines Airbus A300 pilot. He joined ASC as an aviation safety investigator in 2000. He was the investigator-in-charge of the China Airlines CI611 accident investigation and was the Singapore Airline SQ006 accident investigation Human Factors Group chairman.*

Dr. Don Harris *is the director of the Flight Deck Design and Aviation Safety Group in the Human Factors Department, Cranfield University. He was an aircraft accident investigator (specializing in human factors) on call to the British Army Division of Army Aviation. He sits on the editorial boards of the International Journal of Applied Aviation Studies (FAA) and Cognition, Technology, and Work (Springer-Verlag). He is also co-editor in chief (with Helen Muir) of the journal* Human Factors and Aerospace Safety *(published by Ashgate).*

Abstract

The idea that national cultural characteristics play a part in aviation safety had been suggested by Helmreich and Merritt (1998). This research involved around 45 aviation accident investigators from different cultural backgrounds and investigated attribution of causal factors in the Ueberlingen accident report through the application of the Human Factors Analysis and Classification System (Wiegmann and Shappell, 2003). Hofstede's (1991 and 2001) cultural dimensions draw a clear picture of the attributable patterns of human errors based on cultural differences. As a result, it is necessary to develop a better understanding of the differences in attribution of accident causes and contributory factors across cultures to promote both aviation safety and international cooperation for accident investigation to be achieved. Furthermore, when suggesting safety enhancements resulting from accident investigations it needs to be noted that the same remedy may not work in different cultures. Remedial actions must be "culturally congruent." This process starts with understanding the cultural factors at work in the accident investigation process itself.

Introduction

There has been a great deal of research regarding the relationship between national culture and aviation safety (e.g., Braithwaite, 2001; Helmreich and Merritt, 1998; Jing, Lu, and Peng, 2001; Lund and Aaro, 2004; Merritt and Maurino, 2004; Patankar, 2003; Rose, 2004). Culture is at the root of action; it underlies the manner by which people communicate and develop attitudes toward life. Accident investigation is supposed to be an objective exercise, but different cultures may produce different interpretations for human factors issues based upon different cultural preconceptions. In the aviation industry, pilots not only fly in foreign airspace transporting passengers around the world, but also in multicultural crews. Furthermore, according to ICAO Annex 13, the accident investigation team should include representatives from the state of the aircraft's design and manufacture, the state of the occurrence, the state of the operator, and the state in which the aircraft was registered. As a result, by its very nature, accident investigation is a multicountry, multicultural undertaking. International cooperation has always been a great challenge for accident investigation as a result of the many cultures often involved in an accident. It only requires a little imagination to demonstrate how culture may impact upon the accident investigation process. Take a hypothetical example, where an Airbus aircraft, operated by a Chinese airline, equipped with General Electric's engines crashes in Japan.

There are many definitions of culture. Kluckhohm (1951) proposed one well-known definition for culture—"culture consists in patterned ways of thinking, feeling, and reacting, acquired and transmitted mainly by symbols constituting the distinctive achievements of human groups, including their embodiments in artifacts; the essential core of culture consist of traditional ideas and especially their attached values." If the majority of people in a society have the same way of doing things, it becomes a constituent component of that culture (Jing, Lu, and Peng, 2001). A culture is formed by its environment and evolves in response to changes in that environment; therefore, culture and context are really inseparable (Merritt and Maurino, 2004).

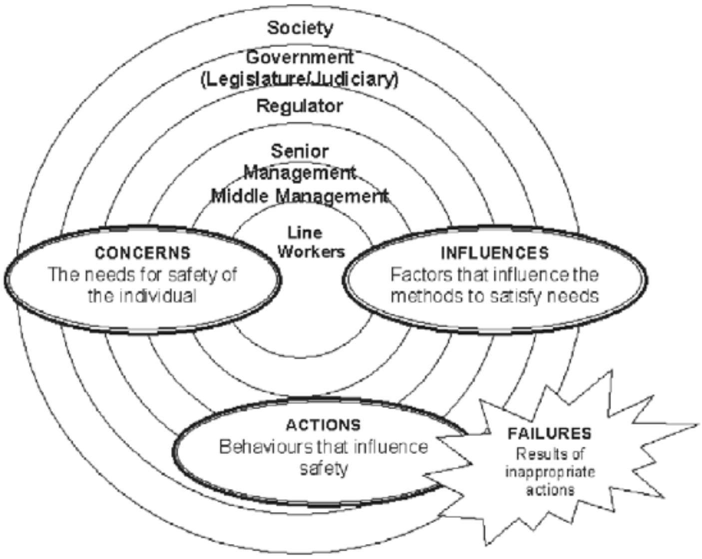


Figure 1. Layers of influence and categories comprising the Ripple Model of safety culture (Morley and Harris, 2006).

Cultures can be divided into different levels: families, organizations, professions, regions, and countries. The power of culture often goes unrecognized since it represents "the way we do things here." It is the natural and unquestioned mode of viewing the world as national cultural characteristics play a significant part in aviation safety (Helmreich and Merritt, 1998). Johnston (1993) suggested that regional differences have a major impact on CRM implementation and crew performance. There is a marked difference in how crew resource management (CRM) training is perceived outside the United States. In the United States, CRM is normally seen as the primary vehicle through which to address human factors issues. Other countries, notably those in Europe, see human factors and CRM as overlapping, viewing them as close but distinct relatives. Orasanu and Connolly (1993) have suggested that a great deal of decision-making occurs within an organizational context, and that the organization influences decisions directly (e.g., by stipulating standard operating procedures) and indirectly through the organization's norms and culture. Culture fashions a complex framework of national, organizational, and professional attitudes and values within which groups and individuals function.

To a certain degree, aviation human factors has been dominated by research into psychological and psycho-physiological attributes such as motor skills, visual perception, spatial abilities, and decision-making (Hawkins, 1993). This may crudely be classified as the "hardware" of human factors. However, for operating hardware, codes and instructions are required that may be referred to as the "software of the mind." This software of the mind may be considered to be an indication of culture because culture provides "a toolkit" of habits, skills, and styles from which people construct "strategies of action" (Hofstede, 1984). National cultures provide a functional blueprint for a group member's behavior, social roles, and cognitive process. Culture provides rules about safety, the basis for verbal and nonverbal communication, and guidelines for acceptable social behavior. Culture also provided cognitive tools for making sense out of the world. National culture was rooted in the physical and social ecology of the national groups (Klein, 2004).

Hofstede (1984, 1991, and 2001) proposed four dimensions of national culture:

• Power distance (PDI) focuses on the degree of equality, or inequality, between people in the country's society. In countries with a large power distance, subordinates are subordinate to their superiors. A relatively small power distance between superior and subordinate results in informal relationships and a great deal of information and discussion. If necessary, the subordinate will contradict his superior.
• Uncertainty avoidance (UAI) is the extent to which the members of a society perceive a threat in uncertain or unfamiliar situations, and the extent to which they subsequently try to avoid these situations by means of regulations and bureaucratic sanctions, among others actions. Uncertainty avoidance concerns the situations of unclearness events, preferred more predictable, and which risks are more clearly defined events.
• Individualism (IDV) focuses on the degree that society reinforces individual or collective achievement and interpersonal relationships. In a highly individualistic society, rights are paramount. Individuals in these societies may tend to form a larger number of moderately distant relationships. A society with low individualism is typical of a society of a collectivist nature with close ties between individuals.
• Masculinity (MAS) exemplifies the traditional masculine work role model of male achievement, control, and power. Expressions of this are an orientation toward competition and performance and the desire for recognition of one's performance. A highly masculine social order is one in which males dominate a significant portion of the power structure, with females being controlled by male domination. A low masculinity ranking indicates the country has a low level of differentiation and discrimination between genders. Women are treated equally to men in all aspects.

More individualist cultures show a lower probability of total-loss accidents; collectivist cultures exhibit a greater chance of accidents. A high level of uncertainty avoidance in a national culture has also been found to be associated with a greater chance of accidents (Soeters and Boer, 2000). As aircraft have become increasingly more reliable, human performance has played a proportionately increasing role in the causation of accidents. Recently, research comparing the underlying patterns of causal factors in accidents comparing Eastern and Western cultures has suggested underlying differences attributable to culture. Using the Human Factors Analysis and Classification System (HFACS), it was observed that issues concerning inadequate supervision at higher managerial levels and a suboptimal organizational process were more likely to be implicated in accidents involving aircraft from Eastern cultures (Li, Harris, and Chen, 2007). It was suggested that small-power-distance cultures with a high degree of individualism seemed to be superior to collective, high-power-distance cultures for promoting aviation safety, especially in terms of the processes and procedures at the higher organizational levels. Such an analysis may provide additional explanatory power to elucidate why national differences in accident rates occur.

Morley and Harris (2006) developed an open system model of safety culture—the Ripple Model (see Figure 1). This Model has been used to interpret the wider influences underlying several major accidents (e.g., the China Airlines 747 accident—Li and Harris, 2005; Dyrden Fokker F28 accident at Dryden—Harris, 2006). This Model identified three threads running throughout the personnel within (and without) an organization, irrespective of their level and role. These were labelled "*Concerns,*" "*Influ-*

ences," and "*Actions"* and were evident in line personnel, middle management, senior management, the industry regulator, government, and society as a whole.

- Concerns *were associated with threats to the needs of the individual and worries about meeting the requirements placed on them by others.*
- Influences *were concerned with the factors that dictated the methods by which safety needs could be accomplished.*
- Actions *described the behaviors that directly impacted upon safety, in either a positive or negative manner.*

In this Model, the authors argued that elements outside an organization have a profound effect on safety culture. The boundaries for the conceptualization of safety culture must be extended beyond the organization if a comprehensive model of the evolution of safety culture is to be developed. Authors such as Merritt and Helmreich (1995) and Glendon and Stanton (2000) propose that safety culture is a subculture of organizational culture, which is itself a subculture of the industry culture, which in turn is a subculture of national culture. If attempts to separate safety culture from organizational culture are difficult enough, trying to fully separate these entities from national culture is almost impossible.

Culture has already been demonstrated to have a considerable impact upon aviation safety and accident causation; however, as alluded to earlier, the effects of national culture have yet to be considered as part of the multinational, multicultural accident investigation process. It needs to be established if culture has an effect on the interpretation of the underlying causes of accidents as well as their causation. To this end, the manner in which accident investigators from Eastern and Western (high power distance versus low power distance) cultures attributed the underlying causes of the Ueberlingen midair crash of a Boeing 757 and Tu-154 were investigated using the HFACS analytical framework.

The inter-rater reliability of HFACS has been demonstrated to be quite good both by using a simple percentage rate of agreement and Cohen's Kappa (e.g., Wiegmann and Shappell, 2001; Gaur, 2005; Li and Harris, 2005 and 2006). However, in all these cases reliability was established between two raters coding multiple accidents. In this study, a different approach is undertaken to evaluate reliability. In this case, many raters (from two different cultures—a high-power-distance and a low-power-distance culture) code a single accident.

Method

Participants

There were 29 Chinese accident investigators including pilots, air traffic controllers, airlines safety managers, and maintenance staff and 16 British accident investigators consisting of pilots, air traffic controllers, airlines safety officers, and maintenance staff.

Stimulus material

The data were derived from the narrative descriptions of accident reports occurring at Ueberling on July 1, 2002. The synopsis of the accident is as follows (BFU: AX001-1-2/02).

The investigation was carried out in accordance with the international standards and recommended practices contained in ICAO Annex 13 and the German investigation law under the responsibility of the BFU. The Kingdom of Bahrain, the Russian Federation, Switzerland, and the United States were involved in the investigation through their accredited representatives and advisers. In the first phase of the investigation, the investigation team worked simultaneously in a headquarter at the airport Friedrichshafen, at ACC Zurich, at the different accident sites in the area around the city of Ueberlingen, and at the BFU in Braunschweig. On July 1, 2002, at 21:35:32 hours, a collision between a Tupolev Tu-154M, which was on a flight from Moscow to Barcelona, and a Boeing B-757-200, on a flight from Bergamo to Brussels, occurred north of the city of Ueberlingen (Lake of Constance). Both aircraft flew according to IFR (instrument flight rules) and were under control of ACC Zurich. After the collision, both aircraft crashed into an area north of Ueberlingen. There were a total of 71 people on board the two airplanes, and none survived the crash.

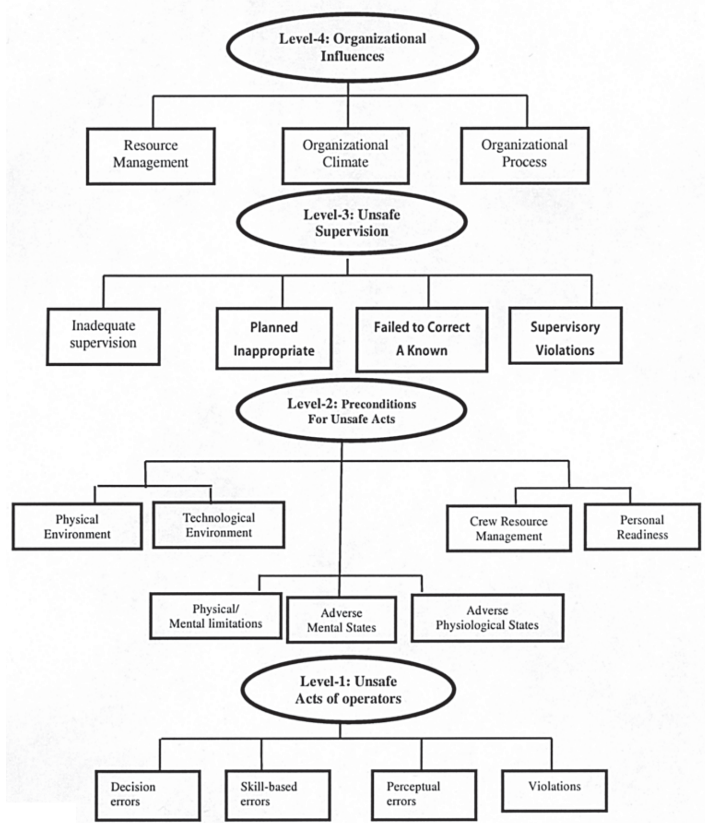


Figure 2. The HFACS framework—each upper level would affect downward level, proposed by Wiegmann and Shappell (2003).

The following immediate causes have been identified: (1) The imminent separation infringement was not noticed by ATC in time. The instruction for the Tu-154M to descend was given at a time when the prescribed separation to the B-757-200 could not be ensured anymore; (2) The Tu-154M crew followed the ATC instruction to descend and continued to do so even after TCAS advised them to climb. This maneuver was performed contrary to the generated TCAS RA.

The following systemic causes have been identified: (1) The integration of ACAS/TCAS II into the aviation system was insufficient and did not correspond in all points with the system philosophy. The regulations concerning ACAS/TCAS published by ICAO and as a result the regulations of national aviation authorities, operations, and procedural instructions of the TCAS manufacturer and the operators were not standardized, were incomplete, and were partially contradictory. (2) Management and quality assurance of the air navigation service company did not ensure that during the night all open workstations were continuously staffed by controllers. (3) Management and quality assurance of the air navigation service company tolerated for years that during times of low traffic flow at night only one controller worked and the other one retired to rest.

Classification framework

The Human Factors Analysis and Classification System is based upon Reason's (1990) model of human error in which active failures are associated with the performance of front-line operators in complex systems and latent failures are characterized as inadequacies or mis-specifications that might lie dormant within a system for a long time and are only triggered when combined with other factors to breach the system's defenses. HFACS was developed as an analytical framework for the investigation of the role of human factors in aviation accidents. This study used the version of the HFACS framework described in Wiegmann and Shappell (2003). The presence (coded 1) or the absence (coded 0) of each HFACS category was assessed in each category of HFACS. To avoid over-representation from any single accident, each HFACS category was counted a maximum of only once per accident. The count acted simply as an indicator of presence or absence of each of the 18 categories in the Ueberlingen accident.

The first (operational) level of HFACS classifies events under the general heading of "unsafe acts of operators." The second level of HFACS concerns "preconditions for unsafe acts." The third level is "unsafe supervision," and the fourth (and highest) organizational level of HFACS is "organizational influences." This is described diagrammatically in Figure 2.

Procedure

All participants were trained for 2 hours by an aviation human factors specialist in the use of the Human Factors Analysis and Classification System. This was followed by a debriefing and a summary of the events in the Ueberlingen midair crash. Finally, all participants received a blank form for coding their HFACS data before watching the film of Ueberling midair crash accident investigation to code the contributing factors underlying this accident.

Results and discussions

The frequency of participants indicating that a particular HFACS category was a factor in contributing to the Ueberlingen accident is given in Table 1.

According to Wiegmann and Shappell (2001) and Li and Harris (2006), factors at the level of "unsafe acts of operators" were involved in 63.4% of accidents in U.S. sample and 41.1% in Taiwan; factors at the level of "preconditions for unsafe acts" were involved in 26.8% of accidents in United States and 31.3% in Taiwan; at the level of "unsafe supervision," 4.5% of causal factors were associated with accidents in United States and 12.5% in Taiwan; at the level of "organizational influences," 5.3% of causal factors were associated with accidents in United States and 15% in Taiwan. However, it is difficult to suggest with any certainty if the true explanation for the differences in the data were attributable to the U.S. data being taken from civil aviation or if it was a national, cultural difference between the United States and Taiwan.

As Hofstede (1991) pointed out, the culture of the United States is characterized as small-power-distance and individualist. Subordinates acknowledge the authority of their superiors but do not bow to it, and emphasis is firmly placed on individual initiative (and reward). This supports the findings of Wiegmann and Shappell (2001) that individual operators have greater bearing on accidents in the United States. On the other hand, in Taiwan, a high-power-distance collectivist culture, it has been found in this research that supervisory and organizational influences have a greater influence in accidents. The U.K., from which the comparison data in this study were derived, is also a low-power-distance culture (according to Hofstede's classification system).

The results in Table 1 show that at HFACS Levels 3 and 4 (the higher organizational levels) there were significant difference between the Taiwanese and U.K. sample in two categories: "Organizational Climate" and "Planned Inadequate Operations." In both cases, participants in the U.K. sample were more likely to attribute shortcomings at the organizational level than were their Taiwanese counterparts. This may reflect the differences on Hofstede's power-distance dimension, where, as a result of being a low-power distance culture, U.K. participants were more likely to be critical of higher level management than the Taiwanese participants who are more likely to defer to superiors.

According to Hofstede's classification, the Taiwanese culture is predisposed toward organizations with tall, centralized decision structures and that have a large proportion of supervisory personnel. In these cultures, subordinates expect to be told what to do. However, members of these high-power-distance cultures frequently experience role ambiguity and overload. Group decisions are preferred, but information is constrained and controlled by the hierarchy and there is resistance to change. Members of society in high-power-distance countries are also unlikely to speak out when their opinions may contradict those of their superiors. Confrontation is generally avoided. Low power distance and high individualism promote greater autonomy of action at the lower levels of an organization. The Taiwanese culture, on the other hand, which is less reactive as a result of its preferred organizational structures that discourage autonomy, is also resistant to change.

U.K. participants were also more likely to attribute "adverse mental state" as a psychological precursor to the accident, whereas the Taiwanese participants were predisposed to attributing the accident to a perceptual error (see Table 1). This may reflect some reluctance on the part of Eastern participants to utilize the category of "adverse mental state," which may have a certain degree of stigma attached to it. Instead, they opted to use the (perhaps) less blameworthy category of "perceptual error."

In all previous studies, the reliability of HFACS has been demonstrated using just two raters coding multiple accidents. Inter-rater reliability, calculated either by simple percentage agreement or Cohen's Kappa, has demonstrated the categorization system to be moderately highly reliable. The method for demonstrating reliability in this study, however, suggests that reliability estimated using multiple raters and a single accident is somewhat lower. Looking at the third column in Table 1, it can be seen that the overall percentage use of each category differs across the categories. However, some care should be taken when interpreting this table.

For example, in instances where the overall count for a category was low (e.g., "Adverse Physiological States"), this was indicative of agreement across the raters that a particular category was not a factor (i.e., high rater reliability). Nevertheless, reliability calculated this way is significantly lower than that calculated the more conventional manner. However, this could be a product of either the degree of training received on the HFACS framework or the clarity of the factors in the stimulus material or HFACS itself. Further research is required to clarify this issue.

Level	HFACS Categories	Taiwan (n=29)	U.K. (n=16)	Overall (n=45)	Chi-Square (df=1)
HFACS Level 1	Decision Error	29 (100%)	15 (93.8%)	44 (97.8%)	c^2=0.093*; p=0.760
	Skill-Based Error	24 (82.8%)	14 (87.5%)	38 (84.4%)	c^2=0.000*; p=1.000
	Perceptual Error	24 (82.8%)	5 (31.3%)	29 (64.4%)	c^2=11.939; p=0.001
	Violation	20 (62.1%)	13 (81.3%)	31 (68.9%)	c^2=0.988; p=0.320
HFACS Level 2	Adverse Mental State	15 (51.7%)	15 (98.3%)	30 (66.7%)	c^2=8.195; p= 0.004
	Adverse Physiological State	9 (31.0%)	2 (18.2%)	11 (24.4%)	c^2=1.046*; p=0.307
	Mental/Physical Limitation	17 (58.6%)	10 (62.5%)	27 (60.0%)	c^2=0.000; p=1.000
	Crew Resource Management	28 (96.6%)	15 (93.8%)	43 (95.6%)	c^2=0.000*; p=1.000
	Personal Readiness	15 (51.7%)	5 (31.3%)	20 (44.4%)	c^2=1.751; p=0.186
	Physical Environment	11 (37.9%)	5 (31.3%)	16 (35.6%)	c^2=0.201; p=0.654
	Technological Environment	23 (79.3%)	11 (68.8%)	34 (75.6%)	c^2=0.182*; p=0.670
HFACS Level 3	Inadequate Supervision	25 (86.2%)	12 (86.2%)	37 (82.2%)	c^2=0.285*; p=0.593
	Planned Inadequate Operations	12 (41.4%)	12 (75.0%)	24 (53.3%)	c^2=4.683; p=0.030
	Failed to Correct a Known Problem	25 (86.2%)	10 (62.5%)	35 (77.8%)	c^2=2.121*; p=0.145
	Supervisory Violation	18 (62.1%)	12 (75.0%)	30 (66.7%)	c^2=0.776; p=0.378
HFACS Level 4	Resource Management	22 (75.9%)	13 (81.3%)	35 (77.8%)	c^2=0.002*; p=0.967
	Organizational Climate	12 (41.4%)	12 (75.0%)	24 (53.3%)	c^2=4.683; p=0.030
	Organizational Process	27 (93.1%)	15 (93.8%)	42 (93.3%)	c^2=0.000*; p=1.000

Table 1. Number (and percentage) of participants who indicated an HFACS category was a factor in contributing or causing the Ueberlingen accident, broken down by country and overall. In instances where the expected cell count for one (or more) cells was less than five, Yates's correction was applied (designated by *).

Conclusion

There seems to be some evidence that there are cultural differences in the manner in which participants from different cultures interpret the same factors in a sequence of events leading to an accident. This is something that investigators from different cultures need to be aware of as the same events will be interpreted quite differently by representatives from different cultures, especially when interpreting human actions. This demonstrates that despite the best efforts of all concerned, there is sometimes no such thing as an objective truth when analyzing and interpreting the events leading to an accident. These cultural differences are evident in the interpretation of the influences and subsequent actions (as described in Figure 1) surrounding an accident. Investigators need to understand this when working in multicultural teams, not only when interpreting the events leading to an accident but also when suggesting remedial actions to ensure that they are congruent with the national culture of the operators. ◆

References

Braithwaite, G. (2001), Attitude or Latitude: Australian Aviation Safety. Aldershot, U.K.; Ashgate.

Glendon, A.I., and Stanton, N.A. (2000), Perspectives on Safety Culture. Safety Science, 34, 193-214.

Gaur, D. (2005), Human Factors Analysis and Classification System Applied to Civil Aircraft Accidents in India. Aviat Space Environ Med; 76:501-5.

Harris, D. (2006), Keynote Address: An Open Systems Approach to Safety Culture: Actions, Influences, and Concerns. Australian Aviation Psychology Association (AAvPA) International Conference—Evolving System Safety 2006. Sydney, Australia, November 9-12.

Hawkins, F.H. (1993), Human Factors in Flight, Ashgate, Aldershot, England.

Helmreich, R.L., and Merritt, A.C. (1998), Culture at Work in Aviation and Medicine: National, Organizational and Professional Influence. Aldershot, U.K.; Ashgate.

Hofstede, G. (2001), Culture's Consequences: Comparing Values, Behaviors, Institutions, and Organizations Across Nations. California: Sage Publications.

Hofstede, G. (1984), Culture's Consequences: International Differences in Work-Related Values. Beverly Hills: Sage Publications.

Hofstede, G. (1991), Cultures and Organizations: Software of the Mind. London: McGraw-Hill Book Company.

Jing, H.S., Lu, C.J., and Peng, S.J. (2001), Culture, Authoritarianism, and Commercial Aircraft Accidents. Human Factors and Aerospace Safety, 1, 341-359.

Johnston, N. (1993), Regional and Cross-Cultural Aspects of CRM, in Hayward, B.J., and Lowe, A.R. (Editor), Australian Aviation Psychology Symposium, Sydney.

Klein, H.A. (2004), Cognition in Natural Settings: The Cultural Lens Model, in Kaplan, M. (Editor), Cultural Ergonomics, Elsevier, San Diego, pp. 249-280.

Kluckhohm, C. (1951), The Study of Culture. Lerner D, Lasswell HD, Editor. The Policy Sciences. Stanford, CA: Standford University Press, 1951: 86-101.

Li, W-C., and Harris, D. (2005), HFACS Analysis of ROC Air Force Aviation Accidents: Reliability Analysis and Cross-Cultural Comparison, International Journal of Applied Aviation Studies, Vol. 5, No. 1, pp. 65-81.

Li, W-C., and Harris, D. (2005), Where Safety Culture Meets National Culture: The How and Why of the China Airlines CI-611 Accident. Human Factors and Aerospace Safety 5(4), 345-353.

Li, W-C., and Harris, D. (2006), Breaking the Chain: An Empirical Analysis of Accident Causal Factors by Human Factors Analysis and Classification System (HFACS), in Stewart, J. (Editor), International Society of Air Safety Investigators Conference: Incidents to Accidents, Breaking the Chain, Cancun, Mexico.

Li, W-C., Harris, D., and Chen, S-Y. (2007), Eastern Minds in Western Cockpits: Meta-Analysis of Human Factors in Mishaps from Three Nations. Aviation, Space, and Environmental Medicine, 78(4), 420-425.

Lund, J., and Aaro, L.E. (2004), Accident Prevention. Presentation of a Model Placing Emphasis on Human, Structural, and Cultural Factors. Safety Science, 42, 271-324.

Merritt, A., and Helmreich, R.L. (1995), Creating and Sustaining a Safety Culture: Some Practical Suggestions. Proceedings of the Third Australian Aviation Safety Symposium; 1995 November 20-24 Sydney Australia. Australian Association of Aviation Psychologists.

Merritt, A., and Maurino, D. (2004), Cross-cultural Factors in Aviation Safety. In M. Kaplan (Ed) Advances in Human Performance and Cognitive Engineering Research. San Diego, CA; Elsevier Science (pp. 147-181).

Morley, F.J., and Harris, D. (2006), Ripples in a Pond: An Open System Model of the Evaluation of Safety Culture. International Journal of Occupational Safety and Ergonomics, 12, 3-15.

Orasanu, J., and Connolly, T. (1993), The Reinvention of Decision-Making in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), Decision-Making in Action: Models and Methods, Ablex, Norwood, New Jersey, pp. 3-20.

Patankar, M.S. (2003), A Study of Safety Culture at an Aviation Organization. International Journal of Aviation Studies, 3, 243-258.

Reason, J. (1990), Human Error, Cambridge University, New York.

Rose, K. (2004), The Development of Culture-Oriented Human Machine Systems: Specification, Analysis, and Integration of Relevant Intercultural Variables. In M. Kaplan (Ed), Cultural Ergonomics. San Diego, CA; Elsevier (pp. 61-103).

Soeters, J.L., and Boer, P.C. (2000), Culture and Flight Safety in Military Aviation. International Journal of Aviation Psychology, 10, 111-133.

Wiegmann, D.A., and Shappell, S.A. (2001), Human Error Analysis of Commercial Aviation Accidents: Application of the Human Factors Analysis and Classification System, Aviation, Space, and Environmental Medicine, Vol. 72, No. 11, pp. 1006-1016.

Wiegmann, D.A., and Shappell, S.A. (2003), A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System, Ashgate, Aldershot, England.

Very Light Jets: Implications for Safety And Accident Investigation

By Robert Matthews, Ph.D., Senior Safety Analyst, Office of Accident Investigation, U.S. Federal Aviation Administration

Dr. Robert Matthews *is a senior analyst with FAA's Office of Accident Investigation. He has worked 9 years in national transport legislation with the U.S. DOT and several years as an aviation analyst for the Office of the Secretary at the U.S. DOT. He has also worked with the Organization for Economic Cooperation and Development as a consultant. Dr. Matthews earned his Ph.D. at Virginia Tech's Center for Public Administration and Policy Analysis and is an assistant professor, adjunct, at the University of Maryland.*

Abstract

The next revolution in aviation markets and aviation safety is under way. Its source is a new class of "very light jets" (VLJs), which are relatively low-cost small jets designed for single-pilot operations. VLJs have recently begun to enter the fleet in modest numbers, with the Cessna Mustang and the first deliveries of the Eclipse 500, but VLJs soon will enter the fleet in very large numbers.

This paper addresses three basic issues regarding VLJs. Part one examines the characteristics of VLJs and their market. Part Two assesses the effects that VLJs likely will have on aviation safety. This is based in part on a detailed review of a large body of fatal accidents involving air taxi operators, corporate operators, and business operators[1] and cross-country personal operators in the United States in the past 5 fiscal or financial years (FY). Part Three assesses new challenges that VLJs may present for accident investigators and investigative authorities.

Part One: Characteristics and Markets

Very light jets sometimes are called micro-jets, mini-jets, or personal jets. Whatever we call them, VLJs are about to revolutionize the air taxi industry and business aviation, and they likely will affect the market for high-performance personal aircraft.

Though the term "VLJ" remains a term of art, generally it denotes relatively inexpensive turbofan airplanes that weigh less than 10,000 pounds (most under 7,500 pounds) and sell for prices that range from US$1.5 million to US$4 million. VLJs typically will have four to six seats, including crew, with service ceilings up to 41,000 feet, and a range of up to 2,000 miles. They will offer the increased reliability of jet engines and will be highly automated, with flight management systems, multifunction displays, real-time weather displays, integrated electronic flight bags, and state-of-the-art avionics and navigation, complete with moving maps, terrain maps, terrain warning and traffic alerting, plus the traditional altimeter, airspeed, heading, vertical speed and horizon—and all this will be integrated with an autopilot and will be displayed more simply on high-definition flat screens. The first VLJs to reach the market will be twin-engine jets, but they will be followed quickly by the single-engine Diamond DJet and eventually by a single-engine Cirrus Jet.

VLJ manufacturers already have undergone some shakeout, as several companies that were active early have failed to sustain their financing or have abandoned the field for other reasons. The Eclipse 500 and the Adam 700 are the best known survivors of the early hopefuls. They have been followed by better-known names, including Cessna with its CJ3-Mustang, Diamond with its DJet, Embraer with its Phenom, and HondaJet, while Cirrus and Piper are preparing to enter the field.

If manufacturers' estimates are even close to being accurate, up to 5,000 VLJs could enter service within just the next several years. The aviation community has no experience with a new class of aircraft entering the fleet at such a pace. For example, 5 years after air transport jets entered the U.S. airline fleet in December 1958, just 550 were in service. Five years after first-generation business jets entered the fleet just, 440 were in service in the U.S. civil fleet. VLJs are poised to overwhelm the scale at which these once-revolutionary aircraft entered the fleet.

The recent growth of "technologically advanced aircraft" (TAA) may be the experience closest to what can be anticipated with VLJs. Figure 1 uses the Cirrus SR20/22 and the Diamond DA-40 to illustrate how quickly glass cockpits have penetrated the small-aircraft fleet in the U.S. As of June 2007, just several years after first entering the U.S. fleet, Cirrus had nearly 3,000 active aircraft on the FAA registry, with several hundred registrations pending and more aircraft entering the fleet every month. The DA-40, albeit at more modest levels, also is expanding rapidly in the U.S., particularly since late 2004. VLJs likely will surpass the experience of the Cirrus and DA-40 both in the pace of fleet ex-

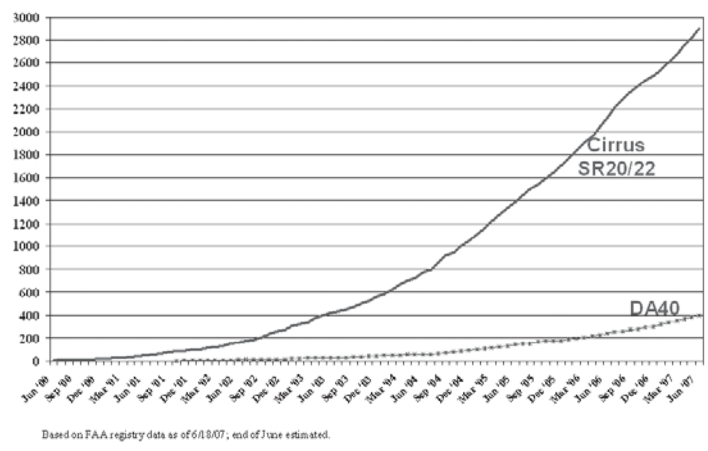


Figure 1. Cirrus SR20/22 and Diamond DA-40 with FAA airworthiness and registry certificates, June 2000 to June 2007 (end-of-month data).

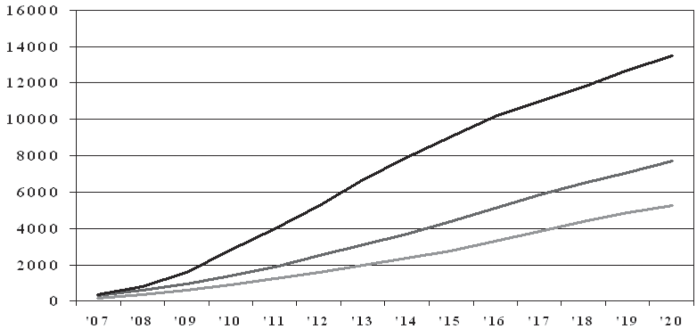


Figure 2. Three conceptual growth rates, very light jets.

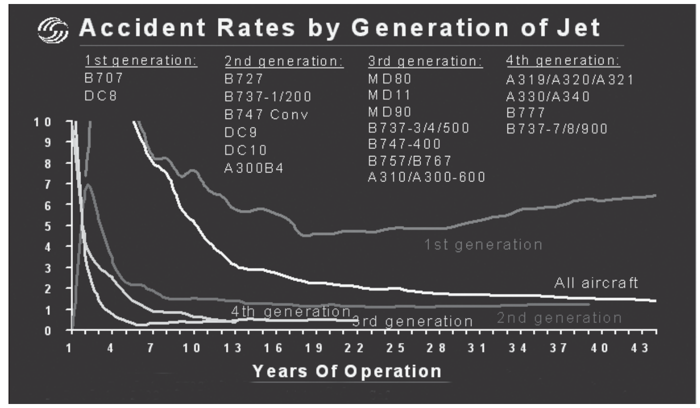


Figure 3. Typical accident experience, air transport aircraft.

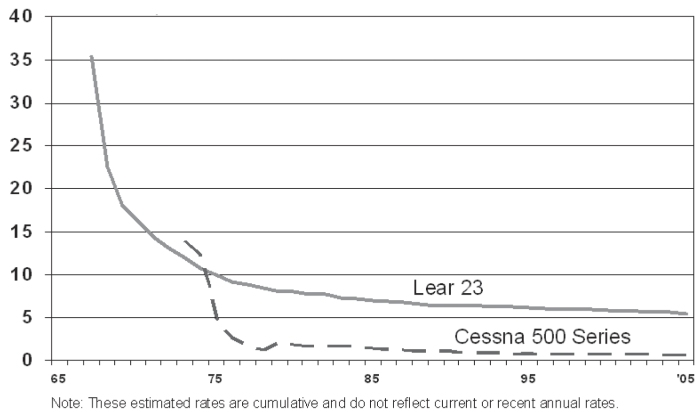


Figure 4. Estimated cumulative accident rates, Lear 23 and Cessna 500 series.

pansion and in the fundamental changes they bring to aviation.

The real revolution with VLJs lies in price and operating costs. Prices now start at US$1.53 million for the Eclipse and are expected to start around $2.25 million for the Adam 700, $2.55 million for the Cessna Mustang, and about $2.85 million for the Embraer Phenom. The single-engine Diamond DJet currently estimates an entry price of just $1.38 million.

As of mid-June 2007, Airclaims, which defines "orders" rather conservatively, identified nearly 1,500 orders from 19 countries for VLJs. Less-demanding definitions produce much higher estimates. About 90 percent of the orders currently come from North America and Western Europe, but operators in other regions likely will soon follow suit in large numbers.

The pace of change will be most apparent in air taxi operations. This is the field in which entirely new business models are being discussed. Dayjet is positioned to be the first large operator in the U.S., with more than 300 firm orders for the Eclipse, with long-term plans to operate as many as 1,000 VLJs. Another prospective U.S. operator, MagnumJet, has firm orders for 100 Embraer Phenoms and 100 Adam 700s. Three prospective operators in Europe also have large orders in place: ETIRC Aviation of Luxembourg has 181 orders for the Eclipse, Aviace of Switzerland has 112 firm orders for the Eclipse, and JetBird, also of Switzerland, has 100 Eclipses on order.

Yet the aviation community continues to debate the size of the VLJ market. Most estimates range from 5,000 units by 2020 to as many as 15,000 units by 2020. Typical estimates also suggest 1,000 to 1,500 VLJs will enter the fleet annually within several years after their introduction, though some organizations believe that such numbers are high. However, since some of the more capable twin-engine business aircraft currently sell for US$3 million and some single-engine turboprops sell for $1.5 million to $2 million, demand should be very substantial.

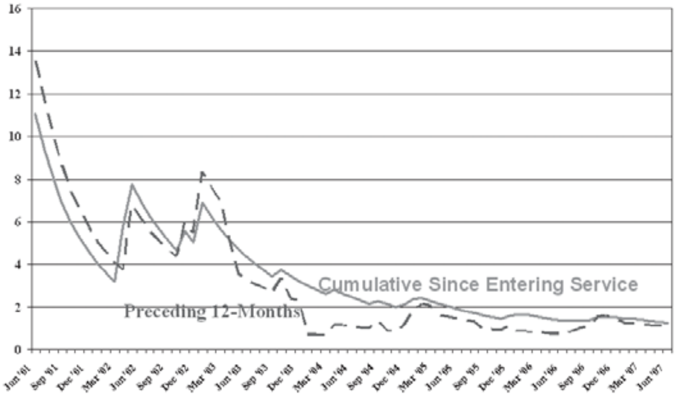
Common estimates also suggest average rates of use approaching 1,500 or even 2,000 hours per year per VLJ among air taxi operators. Again, some observers believe this is too high, but with US$1.5 to $4 million invested, these aircraft are not likely to sit on the ground for days or weeks at a time. These airplanes will be purchased to be flown. Despite some skepticism about the highest estimates, the bottom line is clear: the VLJ fleet quickly will reach big numbers and will produce more flight hours per unit than current fleets produce. In short, VLJs will account for a substantial share of flight hours in the not-too-distant future. Figure 2 illustrates the pace of entry that might be expected under three broad scenarios.

If we assume the middle curve on Figure 2, some 8,000 VLJs would be operating by 2020. If we also assume that the majority of VLJs will operate as air taxis or in business aviation, VLJs likely will average something on the order of 750 to 1,000 hours per year, fleetwide.

If these numbers are close, they suggest 6 million to 8 million flight hours (or more) per year in 10 years just in the U.S., and these numbers may prove to be low. This type of fleet will place real pressure on the availability of qualified pilots and mechanics. Some of these pilots and mechanics will come from existing jet segments in the industry, but many will come from non-jet backgrounds. In sum, the central point here is a sense of scale. Aviation has never experienced as rapid a change in the fleet or in business models as VLJs promise to deliver. This unprecedented pace of change is the source of substantial concern about the possibility of new risks being introduced into air taxis, business aviation, and personal operations.

Part Two: New Risks Versus Positive Characteristics of VLJs

VLJs will have both negative and positive effects on safety. Based on their characteristics, the net effect of VLJs should be very positive, but any new class of aircraft has always added some new risk—at least during a learning period, even if the aircraft later significantly improves safety. The most common concerns include the pace at which VLJs will enter the fleet, the daily prospect of thousands of single-pilot jet operations, and fears that too many pilots will upgrade into single-pilot operations before they are properly prepared for the more-demanding environment of jet operations.



Based on the number of SR20s and SR22s on the FAA Aircraft Registry with airworthiness certificates and valid registrations as of mid-June, 2007. Rates assume a monthly average of 325 hours, as reported by Cirrus and confirmed as reasonable by unpublished data from the FAA's General Aviation and Air Taxi Activity Survey.

Figure 5. Fatal Cirrus accidents per 100,000 hours; U.S. June 2001–May 2007

New risks

Rapid changes in aircraft fleets have been persistent sources both of new short-term risk and substantial long-term improvements in aviation safety. Whether we speak of air carrier aircraft, business-corporate aircraft, or more broadly based general aviation fleets, each new generation of aircraft has produced accident rates that resemble "elbow" curves, in which rates start out high, fall sharply, and then stabilize at lower levels. Equally important, each new generation of aircraft enters the fleet with a lower initial accident rate than did the preceding generation, and each new generation has a shorter learning curve, with rates stabilizing more quickly and at lower levels than the preceding generation. Large jets operated by major airlines provide the most familiar illustration of this point. Figure 3 shows data from Airbus to illustrate the point, and Boeing regularly publishes comparable data.

Though documentation is not as well established for lighter aircraft, their experience appears to be comparable to the experience of air transport aircraft. Figure 4 illustrates cumulative accident rates for the Lear 23, which was one of the earliest corporate-type jets to enter the fleet in appreciable numbers, and for the more numerous Cessna 500 series. Both fleets clearly exhibit the "elbow" curve in their cumulative accident rates.

The Lear 23 was a revolutionary aircraft in its own right, with swept wings, turbojet engines, and high-altitude and high-speed flight. The Lear 23 was a very different aircraft from anything that most of its early pilots had ever experienced, and its early accident rate reflected this. However, after a steep learning curve, the Lear 23 established a stable and much-reduced accident rate. The Cessna 500s entered service just 7 years after the Lear 23, but lessons had been learned and the Cessna 500s entered service with an initial accident rate that was lower than the early Lear 23 rate. The Cessna 500 accident rate then fell quickly and stabilized at a lower cumulative level than the earlier Lear.

The early accident experience with technologically advanced reciprocating aircraft (TAA) in business and general aviation appears to follow a similar path. Figure 6 estimates cumulative accident and fatal accident rates for the Cirrus SR20 and SR22. The lines follow the same general shape as those experienced by each generation of air carrier jets, as well as the Lear 23 and the Cessna 500 series. Rates were high very early then, fell sharply and stabilized more quickly than did rates for the earlier generation of aircraft illustrated here.

The FAA anticipates similar accident curves for VLJs. Like other new aircraft of earlier eras, VLJs are likely to confront a learning curve with relatively high accident rates at first, but at lower starting points than experienced by earlier generation aircraft. The early high rates are simple to explain. By definition, since it is a new-generation aircraft, all pilots, mechanics, and commercial operators have little or no experience with the aircraft. However, as experience builds and as any residual design issues are resolved, the initially high rate is followed by sharp and sustained improvements, followed by yet lower and stabilized rates that are lower than earlier generation aircraft.

However, the pace at which VLJs are expected to enter the fleet will produce a paradox for air taxis. The sheer size of the VLJ fleet in air taxi operations and their more-intensive use could quickly double total air taxi exposure. Consequently, the total number of accidents and fatal accidents may increase among air taxi operators even while overall rates decrease. The paradox, therefore, will be a "safer" system, as measured by rates, but one that may generate an increase in fatal accidents due to sharp increases in volume. This paradox will not be so apparent in personal flight, where a much larger scale of activity will minimize the effects of VLJs on overall rates.

Single-pilot operations

The core concerns about single-pilot operations can be stated rather simply. Things happen faster in jets, and pilots must stay further ahead of an airplane traveling at 350 knots than when traveling at 150 knots. Global Aerospace, the insurance underwriter, estimates that accident rates for single pilots in turbine-powered aircraft (including turboprops) are 50% greater than for twin-pilot operations. Global adds that the single-pilot issue generally is more important among private pilots rather than among air taxi operators, as private pilots have much higher accident rates in general. A brief review at the FAA of accidents involving the Cessna 500/501, the Cessna 525, and the Raytheon Premier supports these observations from Global Aerospace and may even suggest that the ratio is slightly higher. The Cessna 500 series and the Premier are used here because they are certificated for single-pilot operations, and the Cessna series is well established in the fleet with about 2,800 currently in service in the United States.

The NTSB accident database includes 71 accidents involving those aircraft; just 18 had two-pilot crews. All but 1 of the 53 single-pilot accidents involved personal flights or business flights with non-professional pilots. If we add selected twin-engine turboprops from 1983 (the Metro, Embraer Bandeirante, and the MU-2), the number of accidents reaches 371, of which 207 had single pilots. No data on flight hours for single-pilot operations versus twin-pilot operations are available in the U.S. However, given the accident numbers cited above, in order for single-pilot operations to have an accident rate that is 50% greater than the two-pilot rate, two-pilot operations would have to account for just 55% of total hours in the selected fleet. In fact two-pilot crews probably account for more than 55% of this fleet's hours, suggesting that the accident rate for single pilots in turbine-powered aircraft may exceed the rate for two-pilot crews by more than 50% .

Factors that explain higher accident rates for single-pilot operations may include differences in the mix of airports used, different rates of IFR flight versus VFR flight, the presence or extent of dispatch support, the presence of structured maintenance programs, pilot training, etc. However, the most significant factor in explaining a higher accident rate for single-pilot operations appears to be the number of pilots on board.

Pilot experience does not appear to be among those factors. In the selected fleet identified above, single pilots averaged 25% more total flight hours than did pilots-in-command (or "commanders"), and far more flight hours than first officers. The picture changes only modestly when we examine hours in make-model: commanders then have about 25% more experience than single pilots, but single pilots again have much more experience than first officers. The bottom line is that single pilots in complex aircraft generally are not inexperienced.

However, the sheer number of VLJs coming into the fleet will lead to thousands of pilots suddenly upgrading into VLJs. The concern is especially acute in air taxi operations, where the sale of seats to the general public substantially increases government interest. Can air taxi operators find enough pilots and mechanics with adequate jet experience? Will the thousands of new pilot positions in the air taxi industry be filled by pilots whose proficiency and knowledge are adequate to operate highly automated jets at high speeds, sometimes near the upper limits of civilian airspace, and do so without another pilot in the right seat? Similarly, will air taxi companies be properly equipped to hire and train this new workforce, and are those companies properly prepared to operate jets?

An additional risk could be introduced for air taxi operators that do not have dispatch functions. The absence of a dispatch function increases pilot workload as pilots must secure their own weather information and determine their own performance specifications for landing distance, fuel burn, weight and balance, etc. In contrast, a dispatch function would include weather support, NOTAMS, and a pilot operating Handbook with specifications for every runway. The possible increase in workload could be more intense for single-pilot operations. This risk could be reduced by the flight monitoring and dispatch programs some manufacturers are planning, as discussed later in this paper.

Finally, some pilots may place too much faith in the avionics and the improved weather information, or may simply use those tools to expand their envelopes of risk taking. The early accident history in so-called technologically advanced general aviation aircraft clearly indicates that this happens, but it happens less frequently than evolving folklore would suggest. Nevertheless, it will happen to some degree with VLJs, particularly in their early operational history. The bottom line here is obvious: even the best technology can not always save pilots from terrible decisions.

The National Business Aircraft Association (NBAA) has produced a short list of the most important safety issues for which pilots, operators, and regulators must be prepared. The list below is a synopsis of key items in the NBAA list. Note that all these issues relate in varying degrees to the experience and knowledge of the pilot and operator, as well as the provision of Air Traffic Services.

- Pilots must be adequately prepared for high-speed, high-altitude operations, with a sound understanding of the aircraft's performance capabilities, full understanding of "coffin corner" risks, and adequate skills for recovery from low-speed or high-speed stalls. These issues clearly relate to pilot training and experience, but they also relate to operators' experience and knowledge of jet operations.
- Pilots must adequately prepare for high-speed climbs, descents, and approaches to avoid overshooting altitudes, fixes, or prescribed flightpaths. While these issues apply to some aircraft . . . today, they can be especially important to VLJ operations if a large share of the pilot workforce has limited experience in jets or in other high-performance aircraft.
- Pilots, especially those flying as single pilots, must adhere strictly to checklists and must avoid being lulled into complacency from the relative simplicity of VLJ cockpits.
- Pilots and operators must have adequate knowledge of the capabilities and limitations of autopilots and FMS. Pilots must avoid becoming reluctant either to use or to abandon autoflight and autopilots. Similarly, pilots and operators must ensure that basic piloting skills are maintained in full.
- Pilots must have adequate knowledge of high-altitude weather and of winter operations, including winds aloft, clear air turbulence, wake vortices at altitude (and in traffic patterns), windshear, etc. These issues will require appropriate preflight planning, complete with alternate airports and alternate enroute flightpaths. These requirements, in turn, suggest the need for dispatch functions and for general experience in jets both for pilots and operators.
- Similarly, pilots must choose appropriate cruise profiles, based on weather, fuel burn, range, etc. Again, this suggests the need for dispatch functions and for general experience in jets both for pilots and operators.
- Pilots-in-command must be fully prepared to exercise command. With two-pilot operations, this requires that pilots be groomed for positions as captains, complete with CRM and scenario-based training. Single-pilot operators must add single-pilot resource training.
- Finally, ATC must be educated to ensure that controllers provide proper spacing behind heavy jets, avoid unintentionally exposing VLJs to jet blast on the ground, and ensure proper spacing during taxiing operations. Pilot training can help pilots to recognize when ATC instructions might place them at higher risk, as with requests from ATC to maintain high speed to approach fixes, or to maintain high speed in terminal areas.

To the list above, we might add the risk of landing at smaller airports with shorter runways and less supporting infrastructure. Though VLJs will be designed to land and take off on short runways, VLJs will operate into many short fields that have no ILS and, therefore, no coupled approaches. This could increase the frequency of unstable approaches, which are a common factor in several categories of typically severe accidents, such as CFIT, approach and landing, loss of control in flight, and high-speed runway excursions.[2]

Similarly, most air taxi, business, and personal flights in VLJs will involve busy urban airspace, even when flights operate to or from satellite airports. Will pilots with limited or no previous experience in jets or with FMS adequately handle potentially high workloads in busy airspace, with ATC barking instructions at them, and with the need to change flightpaths abruptly? Will this invite excessive head-down time for a single pilot? Will the recently upgraded portion of VLJ pilots be ready for this environment? Finally, will new operators face competitive pressure to dispatch an aircraft into marginal environments?

The good news is that most of these risks are well recognized by manufacturers, governments, and the organizations that will operate the first generation of VLJs. Manufacturers and air taxi companies have developed training programs, and the completion of those training programs will be a requirement under the manufacturer's warranty in many cases. Training programs will include Level-D simulators and human resource training for single pilots. Similarly, in the U.S. and elsewhere, most prospective air taxi operators have explicitly identified the need for extensive training programs and have already begun developing such programs, along with required maintenance programs and operational procedures as those companies prepare for certification. Governments also will require jet ratings, with IFR ratings, for all VLJ pilots, plus commercial ratings for VLJ pilots in air taxi operations.

In the air taxi industry, the risks associated with single pilots will be reduced further by customers who will insist on two-pilot operations. Similarly, insurance policies will require two-pilot crews of most air taxi operators and of many corporate operators. Currently all the companies planning to use VLJs in air taxi service in the U.S. are planning to use two-pilot crews.

Some risks noted above for personal and small business operators, such as the absence of support structures, will be at least partly addressed by the marketplace. For example, Eclipse plans to provide dispatch services to operators, complete with flight following, flight planning, NWS-certified weather briefers, pilot operating handbooks, etc. Eclipse is working with the FAA to establish operating procedures for this service. Similarly, a number of companies currently offering aircraft management services likely will fill some of the remaining voids.

Price will be the primary factor that limits the penetration of these services among aircraft owners and operators, as these market-based services will not be free. If price theory has any validity, these services will confront some degree of resistance at any price, regardless of their quality or their net benefits to safety and risk. Nevertheless, all these efforts, plus the aircraft characteristics, will combine to reduce risk among private operators and they should help to shorten the anticipated learning curve.

Finally, many of the small businesses and private pilots who purchase VLJs are likely to depend on aircraft management companies to maintain their aircraft or will join fractional ownership programs. This will reduce still further some of the risk associated with new-generation fleets.

All these factors will reduce the severity of the learning curve, but they are unlikely to eliminate it, particularly with single-pilot private operators. The bottom line is that the introduction of at least some new risk is inevitable. New risks will be especially high for small business users and for pilots who buy VLJs for their personal use. On average, they will be the least experienced overall, the least experienced in jets, and on average they will have limited support structures.

Positive effects of VLJs

The risks identified above will be real and will produce some accidents that otherwise may not have occurred, particularly in the early period of VLJ operations. However, likely practices and policies among manufacturers, operating companies, insurers, governments, and some customer demands will shorten the anticipated learning curve. In addition, much of the learning curve will spend itself fairly quickly as VLJs become more established in the fleet.

More importantly, several common characteristics of VLJs should produce major improvements in safety that more than offset any new risks. In the end, VLJs should provide a significant net improvement in safety for air taxis, small business operators, and cross-country personal flights.

The most important safety characteristics of VLJs include the following.

High-altitude capability means that VLJs will fly above the terrain and above much of the weather, at least in cruise flight. Consequently, VLJs will be much less vulnerable to CFIT accidents and loss of control in flight, which are the biggest killers in air taxi operations, personal flights, and small business flights.

The "J" in VLJ means a turbofan engine. The obvious fact that VLJs will employ jet engines should substantially reduce the frequency of accidents related to power loss and will improve the capacity of multiengine aircraft to maintain altitude if one engine fails.

Flight Information System (FIS) weather should reduce the frequency of accidents related to unanticipated weather encounters.

Other avionics and equipment typically will include an Electronic Flight Information System (EFIS), MultiFunction Display, Moving Map with terrain depiction and terrain awareness and depiction, terrain and obstacle warning systems, and autopilots with coupled approaches. All this will be accompanied by improved and simpler displays. These characteristics should reduce workload in most environments and will substantially improve pilots' information and situational awareness.

To quantify the positive effects that VLJs should have on safety, each of the above characteristics has been tested against recent fatal accidents in the U.S. involving flight activities that will be major parts of the VLJ market. Those activities include the following airplane operations: cross-country personal flights; air taxi operations, small commuters, corporate aviation, and business aviation. These activities accounted for 850 fatal accidents or 45 percent of all non-airline fatal accidents in the U.S. for FY 2002 through FY 2006, and 55% of all fatalities. The scoring excluded fatal accidents involving helicopters, recreational flying, banner towing, aerobatics, most public-use flights, heavy lift operations, aerial application, instruction, and other activities.

If a characteristic would have had no effect on an accident, the characteristic was assigned a score of zero. Conversely, if a single characteristic would have eliminated the risk of a particular accident, that characteristic would receive a score of 100. Based on the premise that no technological characteristic can ever eliminate all risk, no characteristic received a score of 100 against any accident. In addition, a simple algorithm was used to ensure that no single accident received a combined score of more than 100, as each characteristic was assessed for its capacity to eliminate the risk that remained in each accident. For example, assume we are assessing the VLJ against a CFIT accident that occurred in cruise flight. The capacity for high-altitude flight might be scored very high against this accident, say 90%, while the avionics package might also be scored rather high, say at 75%. The two scores can not simply be added because no single accident can be avoided 1.65 times. Instead, the combined score would be 97.5%, as the avionics would be scored only against the portion of risk that remained after applying the benefits of high-altitude flight, as follows: (1-90%) + [(1-90%) x 75%] = 90% + 7.5% = 97.5%.

VLJ characteristics scored best against controlled flight into terrain, accidents related to engine failures, enroute icing or other loss of control in flight where aircraft could not climb above weather, accidents in which better weather information in the cockpit would have reduced risk, and accidents in which pilots became lost in flight. Conversely VLJs scored zero against 28% of the cases and received only minimal scores against another 5% of the accident set. Those cases were dominated by accidents in which aircraft characteristics and performance were irrelevant or nearly irrelevant. These cases included fuel exhaustion, system or component failures, and pilots knowingly accepting high risks, such as knowingly flying into severe weather or knowingly flying with a poorly performing engine. Some zero or minimal scores also involved aircraft that were equipped with several of the important VLJ characteristics and the addition of several other characteristics would have had either no influence or limited influence.

The review concluded that 49% of the fatal accidents and 53% of the fatalities among the targeted flight activities would have been averted if those flights had taken place in VLJs. The avionics packages proved to be the most effective characteristic against the accident set. This was especially true for CFIT accidents in which a terrain display or alerting system would have reduced risk significantly. However, the avionics and automation also proved effective against loss of control in flight, approach-and-landing accidents, and generally against cases in which better navigational awareness would have helped. The avionics packages alone would have averted an estimated 22.8% of the risk in the accident set and 28% of fatalities in the accident set.

The capacity to operate at higher altitudes was the second-most effective characteristic. Like avionics, altitude would have been particularly effective against enroute CFIT, enroute icing, and some loss-of-control accidents in which the need for maneuvering would have been eliminated. Higher altitude alone would have eliminated an estimated 17.1% of risk in the accident set. However, avionics (at 22.8%) and altitude (at 17.1%) often addressed the same risks. Consequently, the two characteristics combined would have eliminated "only" 34.3% of the risk in the accident set. However, because these characteristics addressed the accidents that typically have more severe outcomes, they would have avoided an estimated 39% of all fatalities in the accident set.

The presence of a turbine engine was the third-most effective of the four characteristics, based largely on greater reliability and a twin-engine jet's capacity to sustain altitude or a 1% climb rate with one engine out. Turbine power also influenced some accidents on takeoff in which engine run-ups were inadequate. By itself, the use of jet engines would have eliminated an estimated 10.7% of risk in the accident set. Since the accidents addressed by jet performance had very little overlap with accidents addressed by avionics and altitude, the 10.7% was almost entirely additive. When combined with the two characteristics already assessed, jet performance would bring the total risk reduction to 44.7% of the accident set.

Finally, the better weather information that will be available in the cockpits of most VLJs had a stand-alone effect that was nearly identical to that of jet performance, at 10.6% of the accident set. However, because other characteristics often addressed the same accidents, the net effect increased total risk reduction from 44.7% to "only" 49.1%.

All Fatal Accidents in Data Set (850)	Avionics	High Altitude	Jet Engine	Weather	Total
Stand-Alone Total	22.8	17.1	10.7	10.6	N/A
Cumulative	22.8	34.3	44.7	49.1	49.1

Selected Flight Activities (Airplanes)	Avionics	High Altitude	Jet Engine	Weather	Total
Air Taxi (77)	26.7	16.4	4.4	9.7	45.7
Business (82)	22.0	16.2	10.2	10.8	49.6
Personal Cross-Country (672)	22.6	17.6	11.3	10.6	49.6

Selected Accident Types (Airplanes)	Avionics	High Altitude	Jet Engine	Weather	Total
CFIT (163)	45.5	50.1	0	15.9	76.9
Loss of Control In Flight (198)	18.2	25.6	6.7	16.2	52.3
Approach-Landing (213)	24.2	1.4	5.6	10.2	33.9
Loss of Control, T/O-Climb-out (160)	11.7	2.4	20.4	5.1	36.2
Emergency Maneuver (68)	0.8	2.6	48.4	1.5	51.2

Figure 6. Positive effects of VLJ characteristics total, selected flight activity, and selected accident types.

Figure 6 summarizes the effectiveness of VLJ characteristics against the accident set and shows effectiveness against the three types of activities that account for all but a small share of the accident set. The Figure also shows the effectiveness of VLJ characteristics against selected accident types. The four characteristics had comparable effects on each of the three types of flight activity shown, but each characteristic had significantly different effects on the various accident types.

Summary of new risk and positive effects of VLJ characteristics

In sum, the basic characteristics of VLJs should eliminate half of the risk experienced in the past 5 years in the U.S. by the targeted VLJ markets. The positive effects should be enhanced by better maintenance than much of the current fleet experiences. They also will be enhanced by operators' and manufacturers' training programs, by the presence of two pilots in a large share of operations, and by the IFR ratings required to operate above 18,000 feet. Finally, VLJ flights also will benefit from operating in the IFR system at a much higher rate than most general aviation pilots.

Yet, some tradeoffs will be introduced, particularly early in the operational history of VLJs. Some single pilots will find they are not really ready to fly a jet by themselves. Some pilots will rely on the technology to expand their envelope of risk taking, and, generally, errors will be made as the aviation community builds experience with the new fleet. However, on balance, the positive effects should provide a major, net improvement in safety, particularly after the anticipated learning curve has been overcome. Given the positive characteristics of VLJs, plus the anticipated operating practices, etc., the net effect should be to produce a fatal accident rate that is at least 60% lower than the rates currently experienced by the targeted market. The paradox could be that the sheer size of the VLJ fleet might increase total activity in air taxis and business aviation to a level where, despite lower accident rates, total accidents could increase. The result may be a safer system that produces more accidents.

Part Three: How VLJs Will Affect Accident Investigation

Parts 1 and 2 have established that large numbers of VLJs will be entering the fleet soon, with significantly lower accident rates than the targeted markets currently have, but not before a learning curve is overcome. The remaining issue for this paper is how the inevitable VLJ accidents will affect accident investigation and investigators. The short answer is that the core process of accident investigation will not change in fundamental ways. Nevertheless, some changes will occur in the details of investigations and those changes will be most challenging in countries where VLJs enter the private aviation market in large numbers.

Whether an accident involves a VLJ or any other aircraft, the core purpose of any investigation will remain unchanged. The purpose is well stated by the United Kingdom's AAIB: "to determine the circumstances and causes of an accident" in order to prevent future accidents and thereby preserve life. Similarly, basic procedures will remain in place, regardless of whether an aircraft is a VLJ or not. Investigators on scene will continue to document ground scars, wreckage paths, the position of switches and control systems, evidence of fuel, evidence of airframe icing, runway conditions, the presence of hazardous materials, visible signs of corrosion or fatigue, weather conditions, etc. Investigators also will continue to research air traffic communications and service, crew history, the history of the airplane, the condition of the airplane on the accident flight, statements from surviving crew and passengers or other witnesses, and so on.

However, some important elements will change. The most obvious change may simply be the number of cases involving complex airplanes as VLJs expand in the fleet. Other changes will include more common involvement with composite materials on relatively small aircraft, more involvement with jet engines and, perhaps, more high-energy impacts.

Basic workload and the necessary skill mixes may be among the most apparent changes for investigative agencies in countries with significant VLJ fleets. Particularly early in VLJs' operating history, any VLJ accident is likely to generate broadly based interest among governments, manufacturers, operating companies, pilot unions, mechanics' unions, and others.

Generally, as aircraft complexity increases, investigations ultimately rely more and more on data recorders in order to understand the accident thoroughly. The typical VLJ will enter service with a capable quick access recorder (QAR). Early QARs evolved for use in large air transports as a less costly alternative to removing flight data recorders (FDR) in order to gain access to operational data and to system faults. Depending on design, contemporary QARs can transmit data at the end of every flight (upon opening an aircraft door), or data can be stored onboard until the QAR's disc or card is removed and downloaded. Finally, QARs can transmit real-time data in flight to a server via satellite communication systems or based on cell phone technology.

Some VLJ manufacturers expect to rely eventually on routine, in-flight transmission of QAR data, while others plan to use onboard storage of up to 300 hours, with data being downloaded whenever an aircraft enters a maintenance facility. Either type of approach presents a new opportunity and a new challenge for investigative authorities. For example, as a practical matter, in any investigation that involves data recorders, investigators must determine the point on the recording at which the data becomes relevant to the accident. With up to 300 hours of data available, that basic task will become more time-consuming.

Similarly, the need or the desire to download and interpret more recorders after accidents could severely tax the capacity of some investigative authorities to conduct this work. While the use of data recorders is routine in air transport accidents and in some business jets, the use of recorders in the investigation of general aviation and business accidents will increase substantially. The bottom line will be more reliance on recorded data and more demand placed upon those professionals who interpret and display the data.

Similarly, because VLJs are complex aircraft and are real jets, the mixture of specialists involved and the distribution of workload will change somewhat. Investigators on the scene will continue to look for evidence that an engine was or was not producing power at impact. However, since investigators will be working with jet engines, in most cases on-scene engine work will be limited to checking fuel and oil filters, evidence of over-temping, scoring, or obvious signs of blade or turbine separation. However, as with other jet engines, if engine tear-down is required, investigators will need to rely more and more on other professionals who perform the work off site.

Though fatal accident rates may be fairly low for VLJs, when accidents occur they likely will include a higher share of high-energy impacts in which the ability to obtain extensive understanding on scene will be limited. Again, we will find ourselves depending more on the readout and interpretation of data recorders.

Finally, despite lower fatal accident rates, when accidents occur we are far more likely to confront composite materials at the scene. That increases the likelihood of a shattered airframe once the composites are compromised. In the case of fires, composites will reduce the survival of evidence with which to determine the point of origin and whether the fire ignited in flight or after impact. This, again, will make us more dependent upon the readout of data recorders.

Yet, none of these changes suggest any fundamental change in the structure of accident investigations. We will continue to gather evidence, continue to interpret that evidence, and continue trying to understand an accident thoroughly enough to help us prevent future accidents. Instead, the anticipated changes will affect issues like workload, the distribution of workload among various professionals, and much greater reliance on data recorders in the investigation of accidents involving small business and personal flights.

Conclusions

Aviation has never experienced as rapid a change in the fleet or in air taxi business models as the VLJ promises to deliver. Their relatively low prices, their design for single-pilot operations, their speeds, and other characteristics will impose new risks. The most obvious new risks will address the qualifications of single pilots who upgrade from other types of airplanes, plus questions about commercial companies that may be new to jets, and the typical learning curve that is associated with any new category of airplanes.

However, these new risks will be more than offset by the positive characteristics of VLJs. They will offer the increased reliability of jet engines and will be highly automated, with flight management systems, multifunction displays, real-time weather displays, integrated electronic flight bags, and state-of-the-art avionics and navigation, complete with moving maps, terrain maps, terrain warning and traffic alerting—and all this will be integrated with an autopilot and will be displayed more simply on high-definition flat screens. These characteristics will produce far lower fatal accident rates than small business operators and cross-country personal flights currently produce. The high-altitude capability and avionics will be especially effective in reducing risk. The characteristics of VLJs alone will offset half of the known risks associated with recent accidents.

In addition, new training programs from manufacturers and commercial operators, plus fractional operations and the use of aircraft management companies by private operators, will further reduce the remaining risk. Maintenance programs will be more professionalized than many small business and private operators currently experience, and many pilots will have some of the benefits of a de-facto dispatch function. Governments also will play their part, with requirements for jet ratings, IFR ratings, plus maintenance programs and operating requirements for commercial operators. Finally, insurers and passengers will add pressure in some segments to minimize single-pilot operations. In the end, VLJs should produce a fatal accident rate that is at least 60 percent lower than the rates currently experienced by the targeted markets.

Nevertheless, the anticipated learning curve and the sheer volume of VLJs will produce accidents to which investigators and investigative authorities will have to respond. Though the fundamental process of accident investigation and its core objectives will not change, the volume of accidents involving complex, turbine-powered aircraft likely will increase, and perhaps increase substantially in the general aviation community, even if rates are relatively low. Any such increase will affect workload, the distribution of work among various professional disciplines, and the reliance on data recorders as we try to understand what happened, why it happened, and how to reduce the risk of its happening again. ◆

Endnotes

1 The U.S. distinguishes between "business" and "corporate" aviation. Corporate/executive aviation is "any use of an aircraft by a corporation, company, or other organization (not for compensation or hire) for the purpose of transporting its employees and/or property, ***and employing professional pilots*** for the operation of the aircraft." Business aviation is "any use of an aircraft (not for compensation or hire) by an individual for transportation required by the business in which the individual is engaged." In short, each provides not-for-hire transportation and the central difference is the use of professional pilots in corporate/executive aviation.

2 See several studies by CAST and the Flight Safety Foundation and the Commercial Aviation Safety Team (CAST).

Enhanced Airborne Flight Recorder (EAFR)—The New Black Box

By Jim Elliott, G.E. Aviation

Jim Elliott is a systems applications engineer with G.E. Aviation in the Data Acquisition and Recording Systems (DARS) product area. He joined G.E. Aviation in 1981 and has performed various systems engineering roles in the DARS product areas for the past 22 years. Elliot was a member of the EUROCAE Working Group 50 during the development of ED-112. Before joining G.E. Aviation, he served in the U.S. Navy where he performed repairs and maintenance on data systems and supervised the data systems technicians aboard the USS Elliot.

Introduction

For many years, aircraft accident investigators have been recommending essential improvements to crash-protected airborne flight recorders and their installation requirements. These recommended improvements are based on the lack of important and valuable information during the investigation of several aircraft accidents where the airborne recorders yielded less-than-complete information during the mishap event. In the United States, these recommended improvements are identified in the National Transportation Safety Board (NTSB) Most Wanted Transportation Safety Improvements list for Aviation—"Improve Audio and Data Recorders/Require Video Recorders," dated November 2006. GE Aviation's Enhanced Airborne Flight Recorder (EAFR) is the next generation of solid-state digital Crash Protected Airborne Recorder Systems, and it incorporates many lessons learned during previous recorder developments. The EAFR also addresses and resolves the improvements identified in the NTSB "Most Wanted" aviation list.

A summary of the NTSB Most Wanted aviation list includes the following objectives:

- Require cockpit voice recorders to retain at least 2 hours of high-quality audio.
- Require back-up power sources so cockpit voice recorders can record an extra 10 minutes of data when an aircraft's main power fails.
- Install cockpit image recorders in cockpits to give investigators more information to solve complex accidents.
- Install dual combination recorders.
- Expanded parameters recorded on Boeing 737 airplanes.

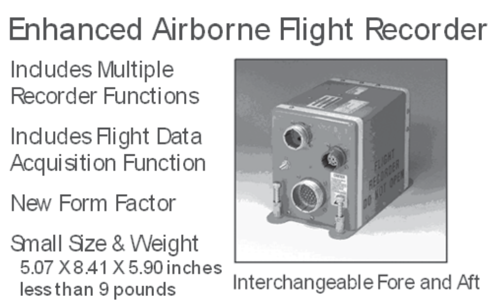
The EAFR system meets or has the growth capability to meet all of these improvement objectives. The Boeing 737 airplane specific objective is being addressed under a supplemental notice of proposed rulemaking (SNPRM), and the EAFR is very capable of recording the expanded parameters when they are made available.

A significant number of lessons learned and the recorder improvements desired by accident investigators are also specified in ED-112, the EUROCAE Minimum Operational Performance Specification (MOPS) for Crash Protected Airborne Recorder Systems. ED-112 was prepared by Working Group 50, an international committee with a broad membership comprised of regulatory agencies, aircraft manufacturers, avionics manufacturers, recorder manufacturers, military representatives and safety centers, airlines representatives, pilots unions, and many accident investigators. ED-112 supersedes ED-55 "Minimum Operational Performance Specification for Flight Data Recorder Systems" and ED-56A "Minimum Operational Performance Specification for Cockpit Voice Recorder Systems," two previously published EUROCAE documents. One of the important objectives identified during the drafting of ED-112 was harmonization. ED-112 harmonizes the requirements of the earlier CVR and FDR MOPS, including the survivability requirements, the environmental test requirements, the recording start/stop criteria, and provides for harmonization of the FDR recording requirement with ICAO Annex 6. ED-112 also introduces completely new recorder functionality including Communications, Navigation and Surveillance/Air Traffic Management (CNS/ATM) data link recording, image recording, elaborates on the concept of combined recorders (which inherently provide harmonization), and establishes the Recorder Independent Power Supply (RIPS) requirements. ED-112 additionally prohibits recording audio data at a reduced quality using merged crew channels for data older than 30 minutes and prohibits the use of magnetic tape, wire, and photographic methods of recording in Crash Protected Airborne Recorder Systems. By prohibiting these items, some of the obstacles that have hampered previous accident investigations due to the lack or survival of information or poor quality information have been removed.

The EAFR meets the ED-112 recorder requirements for the Cockpit Voice Recorder System, Flight Data Recorder System and the CNS/ATM Data Link Recorder System. The EAFR has the necessary crash-protected memory capacity and a dedicated Ethernet interface for image recording to support the ED-112 Image Recorder Systems requirements. Should rulemaking require image recording, the EAFR is capable of acquiring and storing this additional information.

What is the EAFR and what does it do?

As described in ARINC Characteristic 767, an EAFR is capable of providing combinations of any or all of the following functions in a single line replaceable unit (LRU); the digital flight data recorder (DFDR) function, the cockpit voice



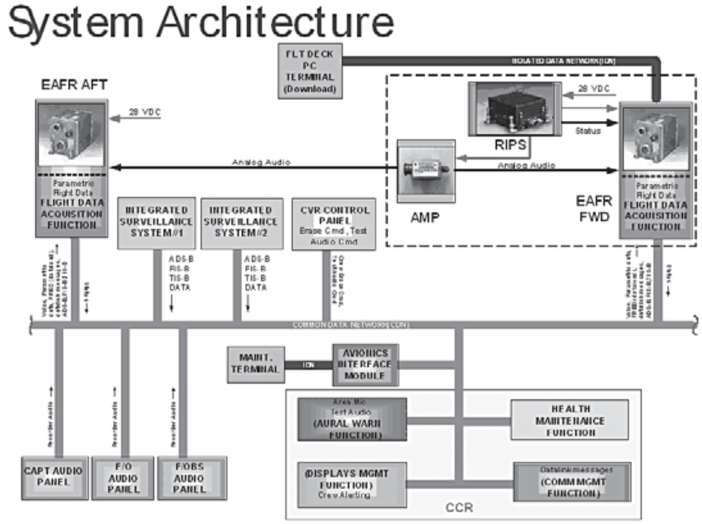
recorder function, the data link recording function, and an image recording function. These functions are described in the following paragraphs.

The DFDR function records parametric flight data from aircraft sensors and systems provided by the Flight Data Acquisition function. The Flight Data Acquisition function resides in the EAFR and acquires the mandatory flight data recording parameters at the specified rates from the aircraft's fiber optic avionics full duplex switched Ethernet data stream. This functionality is hosted inside the EAFR and made possible by the digital architecture of the aircraft and the availability of the data parameters on the aircraft fiber optic aircraft data network interface. The flight data is stored in the crash-protected memory in a segregated memory partition separate from the other data types. The first EAFR application is currently configured for recording approximately 2,000 flight data parameters and records approximately 50 hours of flight data before overwriting the oldest data. Current FDR recording systems are required to be capable of retaining 88 data parameters recorded during at least the last 25 hours of its operation. The DFDR flight data information can be downloaded rapidly on board the aircraft using a high-speed Ethernet interface.

The cockpit voice recorder function records the flightdeck communications between crew members and also captures the general acoustical sound environment of the flight deck. The CVR function receives audio from three digital audio crew channels provided by the Flight Deck Audio System and one analog audio channel from the cockpit area microphone and preamplifier. The cockpit area microphone and preamplifier, along with the forward-installed EAFR, are connected to the RIPS, providing a back-up power source for 10 minutes in the event of power interruptions. The analog cockpit area audio is provided to and recorded in both the forward- and the aft-installed EAFR recorders. The three digital audio crew channels are also recorded in both the forward- and aft-installed EAFRs. The EAFR processes and stores this information in the crash-protected memory in separate memory partitions, one for the area microphone audio and one for the crew channels, per ED-112. The CVR recording duration is 2 hours. Recorded audio can only be downloaded when the EAFR is off the aircraft.

The data link recorder function is used to record the digital data link messages provided to and from the crew. The data link recorder function receives digital messages from the aircraft air to ground communication system when digital air to ground communication is used. These data link messages are provided by the aircraft's communication management and integrated surveillance functions. The EAFR processes and stores this information in the crash-protected memory for a 2-hour duration, the same as the audio recording duration. The EAFR stores this data link information in the crew audio channels memory partition. Even though the data link information is stored in the crew audio channels memory partition, the data link information, unlike the crew audio, can be downloaded rapidly on board the aircraft using a high-speed Ethernet interface.

The image recorder growth function is used to record visual images of the flightdeck instruments, flight deck, the aircraft structures, and engines as required. The image recorder function is capable of receiving a digital data stream of cockpit images and stores this data in the crash-protected memory in a separate partition. The image recording duration will be governed by regulations, and the EAFR crash-protected memory capacity has the



storage capacity for 2 hours of image data recording. Data in the image recording crash-protected memory partition can only be downloaded when the EAFR is off the aircraft.

ARINC 767 also identifies optional enhanced features that the EAFR incorporates, including a high-speed digital manufacturer test interface and the integrated flight data acquisition function.

Size matters—the EAFR weighs in

The EAFR replaces both the FDR and CVR LRUs of previous recorder systems with a single, small, low-weight LRU combined recorder that also records CNS/ATM data link information and has the capability to support image recording if regulations should require it. Although one EAFR has the capabilities of both an FDR and a CVR, current regulations require that two EAFRs are installed on the aircraft. The EAFR also includes an integrated digital flight data acquisition function eliminating the need for a flight data acquisition unit LRU. No special tools or software are required for support of the EAFR since it includes built-in integrated ground tools for maintenance and ground support.

The EAFR is much smaller and lighter than previous FDR and CVR recorders. The EAFR has a small form factor that measures 5.07 inches wide x 8.41 inches long x 5.90 inches high, weighs only 9.0 pounds, and consumes 12 watts of +28VDC power. This reduced size, weight, and power consumption will provide airline operators operating cost savings over the older FDR and CVR recorder systems.

A typical EAFR system installation includes:

- Two Enhanced Airborne Flight Recorders.
- One recorder independent power supply for the forward-installed EAFR.
- One cockpit area microphone and preamplifier that provides CAM output to both the forward-installed and aft-installed EAFRs.
- EAFR loadable software airplane part (LSAP).

The EAFR meets investigators needs

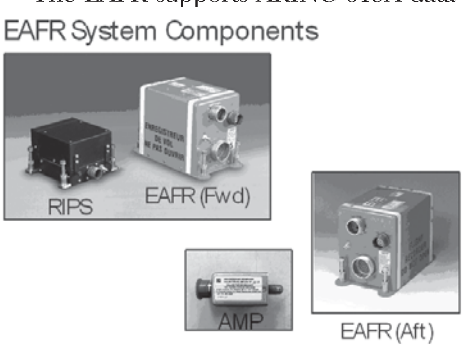
The EAFR provides significant improvements to the quality and the quantity of the recorded information and increases the potential for retaining this information needed during the course of an aircraft accident or incident investigation. The EAFR meets the NTSB's Most Wanted list objectives for the CVR to record at least 2 hours of audio, provide a back-up power source so cockpit voice recorders collect an extra 10 minutes of data when an aircraft's main power fails, provide the growth capability to install image recorders in cockpits to give investigators more information to solve complex accidents, and meets the objective to install dual combination recorders. An important benefit of the dual combined recorder installation is that there are now two complete copies of all of the recorded information available to the investigators. The enhanced flight data capacity of 2,000 parameters for 50 hours is a huge increase over previous recorder systems.

Implementation

For its first application, two identical EAFR combination recorders are installed in forward and aft aircraft locations, providing dual combined recorder capabilities. The forward recorder installation includes a RIPS, which provides continuation of the flightdeck audio recording for 10 minutes during electrical power interruptions to this EAFR. The forward EAFR monitors the status of the RIPS and reports this information to the health management function.

To ensure proper operation and reliable cockpit audio recording, the EAFR performs an audio self-test of the system. The flightdeck EAFR audio test is very robust and includes an active test of the cockpit area microphone and the flightdeck aural environment. This test is automatic during the Aural Warning System (AWS) power up or it can be manually initiated via a panel TEST button. Crew or maintenance action initiates the test and the AWS notifies the recorders to expect the test tone. The AWS emits a 1 kHz test tone for 3 seconds, and the recorders search for the tone and absence of the tone in the area microphone audio signal. This test verifies the functionality of the cockpit area microphone, the preamplifier, the interface wiring, and the EAFR audio input circuitry. A successful test or failure is reported to flightdeck displays and to the health management function.

The EAFR supports ARINC 615A data loading and uses two different loadable software airline parts (LSAP). The first LSAP contains the operational software which includes the functions for flight data recording, audio recording, CNS/ATM data link recording, flight data acquisition, network and system input/output (Ethernet and avionics full duplex switched Ethernet), and built-in test and health management. The other LSAP contains the aircraft specific configuration information and includes the end system configuration, recording configuration database, and the flight recorder electronic documentation. This LSAP is created by the airplane manufacturer using the recorder configuration tool (RCT).



For ground and maintenance operations, the EAFR includes integrated ground tools for downloading, installation checks and annual check verification. The built-in ground tools are web page based tools that are accessed with a personal computer using an Ethernet Internet web browser and provide capabilities for configuration, readout, replay, and flight test support. These ground tools include the operational ground program (OGP) web pages for data downloading and the direct parameter display (DPD) web pages that allows the display of operator selected data parameters in real time.

The EAFR also includes integrated electronic documentation of the flight data parameters using the Flight Recorder Electronic Documentation (FRED) compliant with ARINC specification 647A. FRED is an international standard that defines the content and the format of electronic files that document Flight Data Recording Systems. FRED provides the complete configuration description of the flight recorder data frame and is stored inside the crash-protected memory, a significant improvement in flight data recovery techniques. FRED provides accident investigators with a consistent, accessible, complete, and accurate interpretation of the flight data documentation required for the timely recovery and analysis of the FDR accident data. This is especially important with the increased number of flight data parameters being recorded.

Due to the extent of the increased EAFR capabilities, many ARINC standards are supported to ensure interoperability with the various systems and capabilities that comprise the system architecture. The EAFR design supports numerous ARINC standards including ARINC 767 Enhanced Airborne Flight Recorder (EAFR), ARINC 777 Recorder Independent Power Supply (RIPS), ARINC 647A—Flight Recorder Electronic Documentation (FRED) for ARINC 767 Recorders, ARINC 664 Avionics Full Duplex Switched Ethernet, ARINC 615A Software Data Loader Using Ethernet Interface, ARINC 619 ACARS Protocols For Avionic End Systems, and ARINC 624 Design Guidance For Onboard Maintenance System, to name a few.

This extended capability also involves more technical standard order (TSO) authorizations than the past recorder systems. The EAFR system will include authorizations to FAA TSO C-123b for Cockpit Voice Recorder Systems, TSO C-124b for Flight Data Recorder Systems, and TSO-C177 for Data Link Recorder Systems. Additionally, TSO C-155 will be applied to the recorder independent power supply, and TSO C-121 applied to the underwater locating devices.

Concluding remarks

These EAFR features provide the investigator with much more information and additional types of information than previous recorder designs and make it quickly available in an efficient and easily accessible manner. These significant improvements in airborne crash-protected recorders provide accident investigators worldwide the extended capability to share their lessons learned from accident investigation data collection. Sharing the lessons learned and the information gained in airline safety is a core value of the International Society of Air Safety Investigators (ISASI). This recorder addresses the specific need of accident investigators of achieving timely safety recommendations that may help prevent a recurrence of an accident.

The EAFR is being developed to EUROCAE ED-112 and certified for a new, high-efficiency, long-range, mid-sizes commercial airplane. The EAFR is a modern airborne crash-protected recorder system with huge improvements over previous recorders, capitalizing on the latest technology, conforming to new standards and requirements, providing increased capability, reliability, performance, capacity and growth. The EAFR contains a significant number of industry firsts and provides an abundance of various types of crash-protected data for investigators in a smaller and lighter package. The EAFR is a new generation of airborne crash-protected recorders that is small on the outside but huge on the inside! ◆

RSAF Analysis and Investigation; Tool and Techniques

By LTC Suresh Navaratnam, Republic of Singapore Air Force (RSAF)

Bio not available

Part 1: Incident Investigation in the RSAF

Introduction

1. Investigation is an important element of a robust safety management system in any flying organization. Detailed, conscientious, and impartial investigation and analysis of aircraft or ground incidents are essential to determine the cause so that improvements can be made to prevent a similar occurrence. Investigators must analyze each incident to determine all possible causal factors, e.g., human factors, training of operators, adequacy of equipment, suitability of procedures, etc. The analysis, comments, and recommendations of the investigators will be submitted in a report to higher management.

2. The purpose of an investigation should be clearly understood to yield the greatest benefits. Few mishaps result from a single cause. Very commonly, a sequence of events occurs; the elimination of any one of which could have prevented the mishap. Therefore, to prevent future occurrences, it is imperative that all causal factors be determined. An incomplete investigation resulting in erroneous conclusions nullifies completely the only possible benefit that could be derived from a costly mishap.

3. The investigation of the circumstances surrounding an aircraft mishap is a methodical accumulation of small bits of information, which eventually form a pattern. The wreckage itself contains valuable evidence that, if correctly identified and assessed, will provide certain causal factors. All factors, both mechanical and human, must be determined and their proper interrelationship established. Only then can intelligent, corrective actions be taken.

4. The purpose of a safety investigation is to prevent mishaps and not to apportion blame. The safety investigation will establish primary causal factors as well as contributory factors and is independent of any other board of inquiry.

Mishap investigation in RSAF

5. In the RSAF, there are two different bodies that may be set up to investigate incident. They are

a. the Safety Investigation (SI)
b. the Unit Safety Investigation (USI)

6. The Air Force Inspectorate (AFI) may investigate or order an investigation into an incident or high mishap potential occurrence. In the event that such an investigation is initiated, the AFI investigation is to be carried out expeditiously without influencing or being influenced by any board of inquiry concurrently being conducted. The AFI safety investigation will furnish an initial report as soon as possible and then a full report expeditiously thereafter. The purpose of the AFI investigation is to independently investigate all possible causal factors and propose immediate measures to prevent recurrence of events of a similar nature.

Safety investigation (SIT)

7. The Safety Investigation Team (SIT) is an independent fact-finding body convened whenever there is a mishap/incident or a high mishap potential incident that warrants an investigation. The primary objective of the SI is to determine the causal factors of the incident, both active failure and latent precondition, and make recommendations to address any weaknesses to prevent recurrence of similar events. The team reports to RSAF management. The SI team is set up to study or investigate any near-accidents like an air proximity occurrence, or in cases involving violation of air space, or rules and regulations that may have serious consequences. It could also be activated if an increasing trend of high accident-potential incidents (i.e., near-misses or near accidents) is observed. The basis for convening a SIT should be to investigate and make an assessment of the events leading up to the incident through evidence and witness interviews and establish the cause(s) of the near-accidents and the latent factors for corrective and preventive actions. Hence, the purpose of convening a SIT is solely for the purpose of accident prevention. It is not meant to discriminate or assess an individual's performances or as a basis for any disciplinary actions. The views and evidence are gathered in confidence and in a non-attributive manner.

8. The composition of the SIT will vary dependent on the nature of the accident. The team shall investigate all relevant details of the accident/incident. Specialist officers in the relevant agencies may be co-opted into the team to look into the respective areas. For instance, a doctor from the medical services may be co-opted to look into the human factor aspect for incidents involving human errors.

9. Phases of a safety investigation. The conduct of the safety investigation can be divided into six different phases:

a. Preparation
b. Notification
c. Arrival
d. Investigation and writing
e. Reporting
f. Follow-up

10. The SIT should also aim to complete its investigation *within 2 weeks* with the preliminary update report within first 48 hrs. If further extension is required, the chairperson will seek approval from the convening authority.

11. The SIT report format should capture the following:

a. A factual account of the near-accident or incident(s).

b. Findings and opinions of the team as to the cause(s) and latent factors.

c. Recommendations and proposals.

Unit safety investigation (USI)

12. Incidents with a "HIGH" mishap potential will automatically qualify for a USI. Its aim is to determine the active and latent failures and make necessary recommendations for the *purpose of preventing the next similar occurrence.* An USI can also be convened at the discretion of the Formation or Unit CO.

13. The USI is to be led by an officer of minimum CPT rank. He will be assisted by two-three other members, who may be from the different vocations, to provide the depth and breadth in the investigation.

14. Like the SIT, the USI should aim to complete its investigation within 2 weeks, and similarly, if further extension is required, the convening authority's approval will be sought. The format of the USI report will be similar to that mentioned earlier of the SI report.

Responsibilities

15. Management at all levels will be responsible for ensuring that the investigation is completed in accordance with the guidelines of this paper.

16. Safety personnel at each level must be capable and readily available to assist in the investigation, and maybe to conduct assigned investigations.

17. Investigators, management, and safety personnel at all levels must ensure that the following essential requirements are accomplished:

a. Each incident must be thoroughly investigated and all causes identified. Often in investigations, certain causes may be obvious; however, the investigations should not be terminated until all possible causal factors have been examined.

b. The findings of investigations have little value until the information is disseminated so that the appropriate corrective actions can be taken. Although timeliness is important, premature reporting of inaccurate or unsubstantiated information can be damaging to prevention efforts. Findings must be accurately stated, fully substantiated, and directly related to the investigation. Recommendations, where appropriate, must provide positive corrective or preventive actions where possible. The importance of accuracy cannot be overemphasized, as recommendations are often the basis for expensive and far-reaching actions.

c. Investigations and reports remain virtually valueless in accident prevention until action is taken on the findings and/or recommendations. The part played by investigations and reports in the accident prevention effort is realized only at this step in the process. Therefore, follow-up procedures must ensure that appropriate actions are taken and are effective.

Crash site management

Initial briefing and safety at the site

18. An area of vital importance in investigation is the safety of the investigating team. Investigators, in their eagerness to seek out the causes, often ignore safe investigation practices and common safety precautions. In all field activities, especially when motivation to continue is high, fatigue is to be expected. Temper the need to continue site investigation without interruption with the observed fatigue levels of the investigating party. A tragic mishap involving a team member will lose the investigation time, resources, and insight. Care must be given to hazards described below during the initial briefing and throughout the whole investigation. It is hence the responsibility of the SIT leader to brief and highlight any potential hazards that may endanger his members.

19. The hazards are classified into six main categories:

a. Munitions

b. Pressure vessels

c. Flammables and toxins

d. Environment and climate

e. Composite materials

Preserving the evidence

20. In the event of an aircraft mishaps/incident, the incident commander and the salvage team will be the first party to arrive on scene. The incident commander will be the on scene commander. With the assistance of the salvage team, medical team and the field defense squadron (FDS) personnel, their duties include safe security of the site and offering medical assistance to the injured. They are also to ensure the "preservation of evidence." The incident commander or FSO will at the earliest opportunity brief and assist the SIT upon its arrival.

21. Soon after the impact and the arrival of officials and bystanders, the impact site deteriorates rapidly. All efforts to preserve the evidence should be understood and controlled. A deliberate plan to examine the site and its story must be formulated before the first attempt to draw conclusion.

22. All physical evidence must be protected from further damage. Edges of broken surfaces should be covered and kept away from contaminants such as oil, fuel, or other pieces. Do not rush to wash, clean, or brush off parts when examining wreckage, and do not mate together broken pieces, as this may destroy evidence of their failure mode.

23. A thorough check of the cockpit area should be made and include all controls, selectors, switches, and handles. Note the undisturbed reading on all instruments and indicators. Obviously, do not change settings of controls, dials, switches, or other components which may give a clue to control settings, engine power, flight control movement, or aircraft configuration and aircrew action before the crash. Photograph these items if at all possible.

Critical time evidence

24. Recover and protect any evidence likely to disappear or change with time. Photograph the evidence before disturbing its position. Wreckage and grounds should not be disturbed until all necessary evidence has been gathered; however, the wreckage should not be left longer than necessary on runways, public highways, or congested parts of a city or town. The following evidence is likely to be lost over time:

a. **Samples.** As investigators make their walk-through, they should be alert to substances that should be collected as samples for laboratory analysis. These samples could be fluids (fuel, lubrication oil, hydraulic fluid), gases (oxygen, fire-extinguishing agent), or solids (soot, fire residue, broken metal). Each member of the team participating in the walk-through should have an idea of these actions. When a need for taking a sample has been identified, there will be a trade-off between disturbing evidence and preserving it.

These trade-offs may involve some difficult decisions that only the team has the information to make. The point is to make sure the team is conscious of immediately taking a sample or deferring it to a later time.

NOTE: ***The local POL authority has sampling equipment and containers and can advise on sampling techniques.***

b. **Fire pattern.** Many fire patterns will not change; however, soot patterns and discoloration may be altered due to overnight moisture, precipitation, or winds. While the team is conducting its initial walk-through, it should be noting the ground fire pattern and any indications of inflight fire. This does not mean the team should be rooting around in the wreckage. IT should be looking for obvious clues—pieces of burned wreckage that are located outside the area of ground fire, unusual soot patterns, or deposits of molten metal typical to inflight fires. The objective here is not to prove inflight fire existed and identify its source. Instead, it is simply to determine what areas need further examination and if additional help is needed.

c. **Light bulbs**. Light bulbs may survive initial impacts if not illuminated at the time of the crash. Numerous small bulbs or bulb assemblies may be noticed during the initial walk-through. Each should be tagged or located for later recovery as soon as it is discovered. Personnel may inadvertently step on the bulbs later and cause them to be lost.

Handling death

25. When occupants of the aircraft are obviously deceased, the bodies should not be moved before being photographed and also examined by the medical officer. In such cases, the Medical Task Group shall advise the team leader on the course of action.

Removing wreckage

26. When the wreckage must be removed (to clear a runway, highway, etc.) before a detailed investigation can be conducted, additional documentation must be ensured. This includes preparing an accurate wreckage distribution diagram, along with a full photographic record. All aspects of the scene must be portrayed in documents, with as much detail as necessary for areas that may be obliterated. In moving the wreckage, every effort must be made to prevent further damage or loss of evidence. Any damage occurring during removal must be documented so that it later may be discounted.

Recording information

27. Having the evidence preserved, this information must be recorded and retrieved for further analysis. Basically, **interviewing witnesses** and **photography** can effectively accomplish this task of preservation. Unfortunately, these two areas are among the least understood skills in the process of many investigations. It is, therefore, important that during the initial briefing, the importance of interviewing witnesses and photography be highlighted.

Tools for mishap investigation

28. In any investigation, every available tool should be made available to assist in the investigation effort to determine the mishap causation. In the RSAF, five such tools exist, they are the 5M model, which allows the investigation process to drill down to the causation factor, be it man, machine, medium, mission, or management. Another tool is the Safety Information System, incorporating the newly developed and digitized HFACs to capture incident reporting for the sharing of lessons across the RSAF. Technical-related cases are dealt with by the Standard Technical Elimination Process, which concludes with the "probability of recurrence." Finally, the data mining program uses the extensive database (in excess of 5 years) to assist investigators in discovering latent issues that were not or inadequately addressed. These tools allow the RSAF to close these cases conclusively and methodically, thus at the same time generating a concrete and concise database in the SIS.

Conclusion

29. All incidents and mishaps are costly in terms of dollar value and operational capability. The sole purpose of the safety investigation is for mishap prevention and shall be convened as necessary to establish the cause of mishap/incident or near mishap so that expeditious control measures can be prevented to prevent similar occurrences.

Part 2: Investigation Tools

Chapter 1

RSAF Safety Information System (SIS)

Introduction

1. The RSAF Safety Information System (SIS) has been in place since July 96, providing management and working levels with safety information (by posting FAIRs/GAIRs via the OA system) and statistical data for analysis. Any undesirable safety trends can be derived for safety measures to be taken. However, the SIS was based on the technology available then (early 90s). With the current fast-paced growth of IT, it has become obsolete. Hence, SIS II was developed and put in place in October 2003 to provide more functionality and efficiency.

2. The RSAF depends greatly on the Safety Information System to provide possible clues to emerging trends that were not detected, hence resulting in the incident. Investigators can rely on the SIS to also investigate other aspects of current incidents that could have been not only latent but contributory.

Objectives

3. The objectives of the RSAF SIS II are to

a. provide timely alert of safety incidents.

b. reach out to a wider user base.

c. automate the safety information flow through the command hierarchy.

d. be more user friendly and interactive.

e. provide better value-add to the incidents being reported.

f. provide seamless interface with OA and other MIS applications.

Concept of SIS II

4. SIS II is a web-centric application for easy maintenance and accessibility. This is also in line with MINDEF's direction to tap the latest Intranet technology for faster data retrieval/ sharing. Users will receive only an e-mail containing a hyperlink for access to the SIS II application. This will allow easy maintenance and ease of changing business logic. The users will use a web browser to navigate and obtain information from the Intranet and database servers. With this set up, users will be able to access SIS II, as well as OA and other MIS applications seamlessly, through their workstations.

Modules

Safety report submission and routing

5. This is the main module in the RSAF SIS for the **creation, editing, amendment, and printing** of the following reports:

a. FAIRs Under this, the three categories/types of FAIRs available to be reported on are aircraft, C2, and UAV FAIRs.

b. GAIRs The types of GAIRs to be reported can be classified according to incidents that are either

(1) **Work-related**. Under this category will be **aircraft** and **non-aircraft related** incidents/accidents. The latter will include military transport (MT) cases.

(2) **Non-work-related**. This will be for incidents such as sports injuries, bee stings, and private-owned vehicles (POV) accidents.

c. **Hazards.** This is for raising concern on safety-related issues that if not timely accorded due consideration could lead to an accident/incident.

Under the FAIRs / GAIRs where the causal factor group is "Man," the HFACS[1] option must be provided for the analysis of the human factor contribution.

6. This module has a user friendly MMI (man-machine interface) to provide better navigation and usage of the application. The screens are designed to simplify data entries. Pop-up windows are available where needed to explain the expected input. **Pre-defined selections** are put in place, except for the description of the occurrence, to eliminate spelling errors that hamper analysis. **"Help"** is featured widely to provide definition of terms and explanations of choice of selections, caution signs, etc., and a troubleshooting guide. Guidelines are available on the types of events that should be classified as FAIRs/GAIRs, in their true context.

7. Besides describing the event itself in detail in one section, the originator is also able to relate and share personal experiences, reactions, and considerations during the course of the event in another section. The RSAF safety community can also give it value-add by sharing comments on the findings and lessons learned. Other personnel who have experienced similar cases can also share on their experiences.

8. After the initial assessment by the CO, the **broadcast** of the FAIR/GAIR is sent in the form of an e-mail through the OA to all SIS II users. The e-mail contains an executive summary of the FAIR/GAIR and a link to the SIS II. This link allows the user to launch the SIS II application through the Intranet, to access to details of the particular FAIR or GAIR. This way, the broadcast is not delayed as the amount of data transferred is reduced. The broadcast also indicates to the receiver whether it is for his/her action or information only. Upon clicking on the link, the SIS II is launched for the receiver/action party to enter comments/actions taken in the FAIR/GAIR. All comments on this report will be captured and archived in the SIS II.

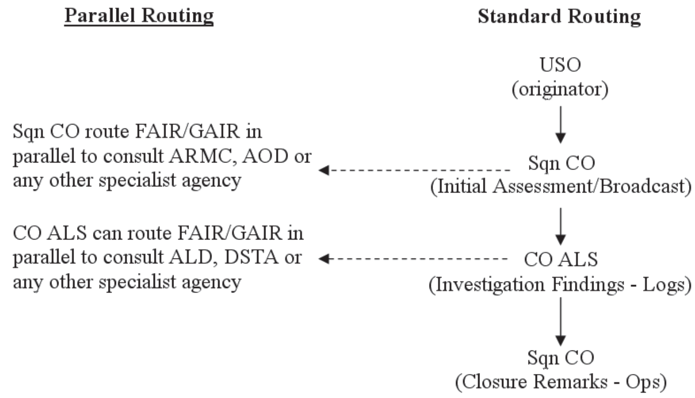


Figure 1. Parallel routing of FAIR/GAIR.

9. This module also allows **parallel routing** of FAIRs/GAIRs for soliciting specialist inputs (e.g., ALD, DSTA, ARMC). After each member of the usual command chain/hierarchy for FAIR/GAIR routing has input his part, he can select through a "drop down" e-mail address list who he wants to route the report to in parallel while the report is being routed to the next party in the standard routing process. The aim is to provide the flexibility for units to solicit the expertise from other agencies for the various types of FAIRs/GAIRs/Hazards. See Figure 1 for the FAIR/GAIR workflow for parallel routing.

10. To further improve the quality of information, this module caters to the events to be captured and described as best as possible through **various input formats**. To draw and share maximum lessons, the findings (can be a combination of texts and graphics) can be attached to the FAIR/GAIR and made available on line to allow better appreciation of the particular incident reported.

Tracking management

11. At each stage of the FAIR/GAIR workflow, SIS II is able to show the current status and the action party where the particular report is residing. Reports that are outstanding and the responsible parties are easy to identify.

12. A **time line** for the action party to respond is also designed into the SIS II. A **reminder** is autogenerated to the particular action party if the action is not duly attended to. At the same time, the sender is auto-notified that the mail he sent was not replied to / actioned accordingly. This will ensure that all FAIRs/ GAIRs are timely and completely closed.

Safety audit inspection

13. The module allows the capturing of audit findings in squadrons after the completion of a safety audit inspection. In addition, SIS II allows the compilation of inspections/audits reports for trend analysis of safety performance.

Triggering

14. For trend alerts, there is a **trigger mechanism** (via e-mail alert) built into the SIS II to trigger RSAF management of any predetermined undesirable trends. In addition, SIS II allows a criteria-based search or selection of parameters by any user and alerts them to any trend that has exceeded a pre-set value. The

trigger mechanism can be defined at the system level by AFI or by the user. For instance, BSO TAB can set the triggering to alert him when the number of birdstrikes in TAB exceeded more than a predefined number for each month.
15. Triggering is also incorporated to prompt action parties for FAIRs/GAIRs. E-mail prompts will inform a user that there is an action item that requires his attention when he logs onto the e-mail.

Search engine
16. Data search is also made less laborious and a faster process when compared to the earlier SIS. In SIS II, there are many options/fields and selection criteria available for selective information viewing and access.

Analysis
17. Complementing with an easy and efficient data search, SIS II is user friendly and interactive to enable a more robust and detailed analysis. For instance, analysis can be based on Causal Factors or the various occurrence types (logs or ops events) or even group of personnel involved for a specific period, location, or even aircraft type.

E-Bulletin board
18. A virtual bulletin board is built into the SIS II for the publishing of general non-sensitive RSAF safety information that can be accessed by personnel with Intranet account. Examples are selected FAIR/GAIR cases that have some value in sharing on a tri-service level, safety articles, alert messages, general information about AFI, events, manuals, publications, etc.

Reports
19. Preformatted reports are readily available on demand for better data analysis and presentations for all SIS users; especially for the USOs/BSOs/FSOs for their usual safety reports.
20. Besides this, customized reports can be generated based on the user's selection criteria within the SISII data query screens for specific presentations or analysis purposes.

SIS II interface with other RSAF information systems
21. SIS II is linked to the various systems. Hence, through such system interface, data error should be reduced and data duplication eliminated via single-source inputs and data sharing with other applications.

Accessibility by overseas
22. In the SIS II implementation, only local sites will be addressed where the system will be web-based and ride on the current RSAF Intranet network. The current arrangement for overseas detachments will still stand in the interim, i.e., faxing over FAIRs/GAIRs to the parent bases/units for the latter to key in the data and transmit via the SIS II.

System support requirements
23. The implementation of SIS II rides on the Enterprise Server Farm and supported by SISII Helpdesk, which is manned by DSTA personnel.

Contingencies during SIS system failures
24. In the event that SIS is down or inaccessible for any reason, the "manual" means of safety information dissemination can always used. To do this, one of the following modes could be used to address the immediate issue:

A. Use the "Reply All" mode with any previous SIS broadcast for FAIR/GAIR and key in the respective fields in the broadcast message for a new report. Subsequently (when eventually possible), the SIS can be accessed to key the information into the database. SIS helpdesk should be notified to "by-pass" the broadcast (to preclude repeat broadcasts since the broadcast was already done).

B. Key in the respective fields in the soft copy version of the FAIR/GAIR. Use the "Reply All" mode with any previous SIS broadcast for FAIR/GAIR and attached the FAIR/GAIR document. Broadcast a message for this new report. Subsequently (when eventually possible), the SIS can be accessed to key the information into the database. SIS helpdesk should be notified to "by-pass" the broadcast (to preclude repeat broadcasts).

Part 2: Investigation Tools

Chapter 2

Human Factors Analysis and Classification System (HFACS)[2]

Introduction
1. The analysis and classification of human-induced cases (FAIRs and GAIRs) are aligned under a universal tool called the Human Factors Analysis and Classification System (HFACS). The merge ensures overall consistency and ease of presentation of statistics across both the operations and logistics fields.
2. The HFACS encompasses all aspects of human error, including the conditions of operators and organizational fail-

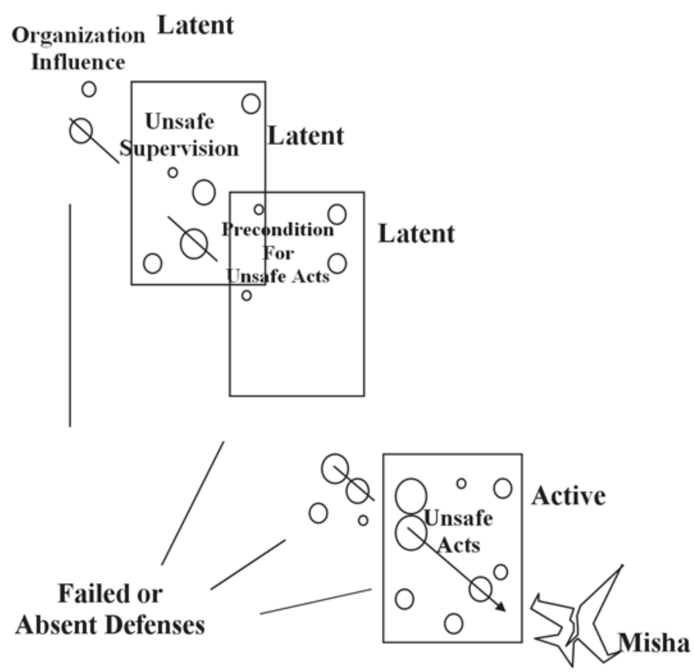
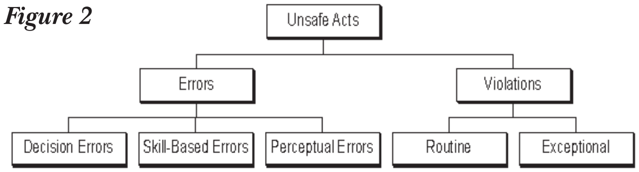


Figure 1. The "Swiss Cheese" Model of human error causation (adapted from Prof. James Reason, 1990).

Figure 2



Errors
Skill-based Errors ("Stick and rudder" and other basic flight skills that occur without significant conscious thought. Vulnerable to failures of attention, memory and/or technique.)

B. Breakdown in visual scan
C. Inadvertent use of flight controls
D. Poor technique/airmanship
E. Over-controlled the aircraft
F. Omitted checklist item
G. Omitted step in procedure
H. Over-reliance on automation
I. Failed to prioritize attention
J. Task overload
K. Negative habit
L. Failure to see and avoid
M. Distraction

Perceptual Errors (Occur when sensory input is degraded and a decision is made based on faulty information.)

- *Due to* visual illusion
- *Due to* spatial disorientation/vertigo
- *Due to* misjudged distance, altitude, airspeed, clearance

Decision Errors Mistakes occur when one does not have appropriate knowledge or made a poor choice, procedural error or problem-solving error.)

c. Inappropriate maneuver/procedure
d. Inadequate knowledge of systems, procedures
e. Poor decision
f. Exceeded ability
g. Wrong response to emergency

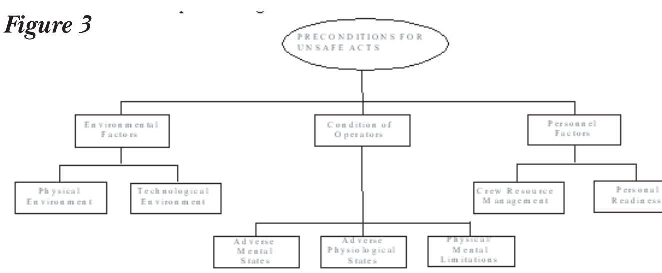
Violations
Routine Infractions ("Bending" the rules, habitual deviation from the rules and tolerated by management. Must look up the supervisory chain to identify those in authority that is not enforcing rules.)

- Inadequate briefing for flight
- Failed to use ATC radar advisories
- Flew an unauthorized approach
- Violated training rules
- Filed VFR in marginal weather conditions
- Violations of orders, regulations, SOPs
- Failed to inspect aircraft after inflight caution light

Exceptional (Isolated deviation from the rules, but NOT tolerated by management. Difficult to predict, since not indicative of one's behavior.)

- Performed unauthorized acrobatic maneuver
- Improper takeoff technique
- Failed to obtain valid weather brief
- Exceeded limits of aircraft
- Failed to complete performance computations for flight
- Accepted unnecessary hazard
- Not current/qualified for flight
- Unauthorized low-altitude canyon running

Figure 3



Environmental Factors
Physical Environment (Operational environment and ambient environment.)

- Weather
- Altitude
- Terrain
- Lighting
- Vibration
- Toxins in the cockpit

Technological Environment

- Equipment/controls design
- Checklist layout
- Display/interface characteristics
- Automation

Conditions of Operators
Adverse Mental States (Mental conditions that affect performance.)

- Loss of situational awareness
- Complacency
- Stress
- Overconfidence
- Poor flight vigilance
- Task saturation
- Alertness (drowsiness)
- Get-home-itis
- Mental fatigue
- Circadian dysrhythmia
- Channelized attention
- Distraction

Adverse Physiological States
(Medical/physiological conditions that preclude safe operations.)

- Medical illness
- Hypoxia
- Physical fatigue
- Intoxication
- Motion sickness
- Effects of OTC medications

Conditions of Operators (cont.)
Physical/Mental Limitations (Situation exceeds the capabilities of the operator.)

- Visual limitations
- Insufficient reaction time
- Information overload
- Inadequate experience for complexity of situation
- Incompatible physical capabilities
- Lack of aptitude to fly
- Lack of sensory input

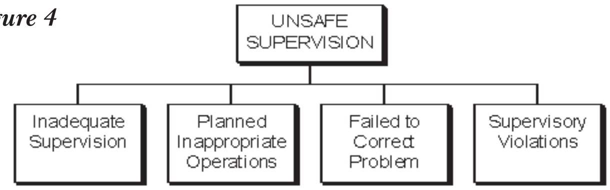
Personnel Factors
Crew Resource Management (Poor communications/coordination among personnel.)

- Failed to conduct adequate brief
- Lack of teamwork
- Lack of assertiveness
- Poor communication/coordination within and between aircraft, ATC, etc.
- Misinterpretation of traffic calls
- Failure of leadership

Personal Readiness (Failure to prepare mentally or physically for duty.)

- Failure to adhere to crew rest requirements
- Inadequate training
- Self-medicating
- Overexertion while off duty
- Poor dietary practices
- Pattern of poor risk judgment

Figure 4



Inadequate Supervision
(Role of supervisor.)

- Failed to provide proper training
- Failed to provide professional guidance/oversight
- Failed to provide current publications/adequate technical data and/or procedures
- Failed to provide adequate rest period
- Lack of accountability
- Perceived lack of authority
- Failed to track qualifications
- Failed to track performance
- Failed to provide operational doctrine
- Over-tasked/untrained supervisor
- Loss of supervisory situational awareness

Planned Inappropriate Operations
(Operations that are arguably unavoidable during emergencies, but unacceptable during normal operations.)

- Poor crew pairing
- Failed to provide adequate brief time/supervision
- Risk outweighs benefit
- Failed to provide adequate opportunity for crew rest
- Excessive tasking/workload

Failed to Correct Problem
(Deficiencies among individuals, equipment, training or other safety areas are known to a supervisor, but continue uncorrected.)

- Failed to correct inappropriate behavior/identify risky behavior
- Failed to correct a safety hazard
- Failed to initiate corrective action
- Failed to report unsafe tendencies

Supervisory Violations
(Occur when supervisors willfully disregard existing rules, regulations, instructions or standard operating procedures. It is considered an "intended" act and implies a willful disregard for authority.)

- Authorized unqualified crew for flight
- Failed to enforce rules and regulations
- Violated procedures
- Authorized unnecessary hazard
- Willful disregard for authority by supervisors
- Inadequate documentation
- Fraudulent documentation

ure. The framework is also employed to develop improved methods and techniques for investigating human factor issues during mishap investigations. The HFACS framework is useful as a tool for guiding future mishap/incident investigations and developing a more structured database, both of which would improve the overall quality and usefulness of human factors data.

3. The HFACS is based on upon Reason's model of latent and active failures (commonly known as the "Swiss Cheese" Model), encompassing all aspects of human error, including the conditions of operators and organizational failure. Specifically, HFACS describes four broad levels of failure (see Figure 1).

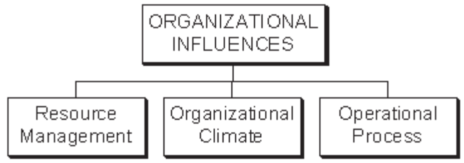
a. **Unsafe acts.** The unsafe acts of aircrew/maintainers can be loosely classified into 2 subcategories, i.e., Errors and Violations. Errors are classified into three basic types, i.e., Decision, Skill-Based, and Perceptual Errors. Violations (both Routine and Exceptional) are more serious as they represent a willful disregard for the rules and regulations that govern the safety of flight.

b. **Preconditions for unsafe acts.** Simply focusing on Unsafe Acts is not enough. We also need to understand why the unsafe acts took place. Hence, two major subdivisions of unsafe conditions are Substandard Conditions of Operators/Maintainers and Substandard Practices of Operators/Maintainers. The former addresses adverse mental and physiological states, and physical/mental limitations while the latter covers CRM and personal readiness.

c. **Unsafe supervision.** Professor James Reason also traced the causal chain of events back up the supervisory chain of command. As such, four categories of Unsafe Supervision have been identified, i.e., Inadequate Supervision, Planned Inappropriate Operations, Failure to Correct a Known Problem, and Supervisory Violations.

d. **Organizational influences.** Fallible decisions of upper-level

Figure 5



Resource Management
(Corporate-level decision-making regarding the allocation and maintenance of organizational assets such as human resources, monetary assets, and equipment/facilities.)

Human Resources

b. Selection
c. Staffing/manning
d. Training
e. Background checks

Monetary/Budget Resources

- Excessive cost cutting
- Lack of funding

Equipment/Facility Resources

- Poor aircraft/aircraft cockpit design
- Purchasing of unsuitable equipment
- Failure to correct known design flaws

Operational Process
(The formal process by which things get done within the organization. Divided into operations, procedures, and oversight.)

Operations

- Operational tempo
- Incentives
- Quotas
- Time pressure
- Schedules

Procedures

- Performance standards
- Clearly defined objectives
- Procedures/instructions about procedures

Oversight

- Established safety programs/risk management programs
- Management's monitoring and checking of resources, climate, and processes to ensure a safe work environment

Organizational Climate
(The working atmosphere within the organization. This is reflected in its' structure, policies, and culture.)

Structure

- Chain-of-command
- Communication
- Accessibility/visibility of supervisor
- Delegation of authority
- Formal accountability for actions

Policies

- Promotion
- Hiring, firing, retention
- Drugs and alcohol
- Accident investigations

Culture

- Norms and rules
- Organizational customs
- Values, beliefs, attitudes

management directly affect supervisory practices as well as the conditions and actions of the operators. Generally, it has been recognized that the most elusive of latent failures revolve around issues related to resource management, organizational climate, and operational processes.

4. Figure 3 is an illustration and summary of the categories and subcategories of each of the four levels of failure is appended[3]:

HFACS checklist for operational factors

Unsafe acts

5. When conducting an investigation to determine possible human performance weaknesses, each level of the HFACS model must be evaluated for latent conditions. Figure 2 is a list of unsafe acts to consider in an investigation. Note: this is not a complete listing.

Preconditions for unsafe acts

6. Figure 3 is a list of preconditions for Unsafe Acts to consider in an investigation. Note: This is not a complete listing.

Unsafe supervision

7. Figure 4 is a list of preconditions for unsafe supervision to consider in an investigation. Note: This is not a complete listing.

Organizational influences

8. Figure 5 is a list of organizational influences to consider in an investigation. Note: This is not a complete listing.

Part 2: Investigation Tools

Chapter 3

Probability of recurrence (POR)

Introduction

1. Presently, incidents are classified by the type of occurrence (OPS/LOGS) and through assessment in the occurrence summary, determined to have an mishap potential of LOW, MEDIUM, or HIGH. Additional comments provided by the unit allow insight into the causal factors accompanied by appropriate follow-up actions. For human-factors-related FAIRS, the HFACS[4] further drills into the various causal factors and allows clarity into prevention strategies thus precluding recurrence. Similar processes would also benefit and improve closure to Technical FAIRs.

2. The POR assists investigators in framing technical recommendations. The STEP has allowed investigators a more prescriptive and surgical method of assessing the probability of recurrence as opposed to earlier techniques that were based on assumptions rather than hard technical facts.

Probability of recurrence (POR)

3. Probability of recurrence determines the likelihood that an incident will repeat itself. However to determine the applicability of either end of this scale, a process to quantify the frequency of recurrence based on specific causal factors is necessary. Typically, Technical failures can be categorized into several main causal categories that stem from inherent flaws or man-induced complications. It is obvious that should a failure stem from poor design or suboptimal manufacturing standards, a recurrence is potentially existent unless corrective re-design of modification of the manufacturing process is effected. Similarly for man-induced failures, targeted efforts toward root causes through the identification of active and latent failures at the individual and management levels would preclude a repeat of the undesired occurrence.

4. Presently for man-related FAIRs, the Human Factors Analysis and Classification System has proven to be effective in identifying failures at the operator and management levels, inclusive of both active and latent shortcomings. This allows directed efforts for immediate recourse and the prescription of necessary control measures for prevention. However for technical FAIRs, the comprehensiveness as seen in the HFACS is admittedly absent. A similar identification-cum-elimination process is thus warranted.

Standard Technical Elimination Process (STEP)

5. Standard Technical Elimination Process—In order to determine the probability of recurrence in technical cases, a standard elimination processes is proposed. This should comprise the following as primary factors:

a. **Design flaw—**As the failure/unserviceability is due to a deficiency in design, the problem can be expected to present itself again, under similar circumstances. For consideration, is also the probability of this shortcoming in design to be read across other systems within the same platform. There may be cases where the defect or fault is known, hence preventive measures have already been implemented resulting in a less frequent occurrence.

b. **Manufacturing defect—**This would be due to an error in manufacture, assembly, production quality etc. It may be possible to isolate this anomaly to a particular batch with a common cause—be it the same factory, produced at same time, assembled by the same worker, etc. Additional considerations should include fleetwide impact—be it an impact on a large scale or an isolated one, i.e., one aircraft only.

c. **Misuse—**Such situations would be the result of usage beyond original design, or employment in conditions outside the original design parameters. Additionally for this category, there exists the risk in exceeding the designed safety and reliability parameters.

d. **Abnormal wear/aging—**There would be cases where the wear rate is unusual high or abnormal. Hence, maintenance and engineering should look again at the maintenance program and evaluate if additional maintenance program is required.

e. **Sporadic defects—**Such cases are intermittent mainly due to contact problems or wiring connectivity issues. These defects cannot be fully confirmed and, hence, the source and causal factor may not be definitive.

Conclusion

5. With the incorporation and implementation of the STEP and POR in investigations, with the aid of the SIS II tool, the investigation process for technical cases should benefit from insight into the causal factors (human factors and Non-human factors) and providing clarity for the appropriate follow-up actions and prevention strategies with the intent of preventing recurrence. ◆

Endnotes

[1] HFACS—Human Factors Analysis and Classification System.
[2] This model is based on the concept by Wiegmann-Shappell.
[3] Extracted from the document disseminated under the sponsorship of the U.S. Department of Transportation (Federal Aviation Administration).
[4] Human Factor Analysis and Classification System.

Wet Runway Accidents—The Role of Fatigue and Coercive Habits

By Capt. A. Ranganathan

***Capt. A. Ranganathan** is a B-737NG training captain, with 20,000 hours. He has been working on the ALAR India project for the last 6 years and compiled an "Adverse Weather Operations Training Kit," which is the standard training aid for all airline pilots in India. He is a specialist on wet runway operations study and is employed by a new low-cost carrier, SpiceJet of India. During his airline career, he has received two commendations: 1) Partial gear-up landing on a scheduled passenger flight with Indian Airlines in November 1987 and 2) Partial gear-up landing procedure while operating a scheduled passenger flight with SilkAir in Singapore in 1994.*

Figure 1

Figure 2

Fatigue has been cited as a factor in more than 20% of reported incidents and accidents in civil aviation. Apart from decreased concentration, fatigue, with the combination of positive G-forces and oxygen deficiency, is known to have a negative influence on vision. This, along with spatial disorientation, could have disastrous consequences while operating in adverse weather conditions.

Spatial disorientation has been identified in three categories, and the most pertinent one for aviation is what is called "Type I" disorientation. A disoriented aviator does not perceive any indication of spatial disorientation. In other words, he does not think anything is wrong. What he sees—or thinks he sees—is corroborated by his other senses. "Type I" disorientation is the **most dangerous** type of disorientation. The pilot—unaware of a problem—fails to recognize or correct the disorientation, usually resulting in a fatal aircraft mishap.

An example of this type of SD would be the height-/depth-perception illusion when the pilot descends into the ground or some obstacle above the ground because of a lack of situational awareness. Many CFIT accidents or runway overruns or excursions could be due to this type of disorientation

Performance can also be affected by cumulative fatigue buildup across multiple days. Gundel (1995) found that pilots flying two consecutive nights with 24 hours between flights slept about two-and-a-half hours less during their daytime layovers (8.66 hours versus 6.15 hours) and experienced a significant decline in alertness on the second night flight[1].

In the article "Fatigue and Desynchronosis in Air Crews," Dr. Virgil D. Wooten (the Federal Air Surgeon's Medical Bulletin—Summer 2002) has found that sleepiness and fatigue cause reduced ability to function. Lapses (the failure to respond to a situation) increase. Lapses may be associated with microsleeps (episodes of sleep lasting 0.5 to 10 seconds) but can also occur without sleep onset

To quote Dr. Wooten in his article, "The potential for catastrophe due to lapses is enormous. An aircraft going 250 kts on a glidepath, for example, can travel over 400 feet during a 1-second lapse. Microsleeps have been shown to occur in aircrew during landing approaches in commercial carriers. Reaction times may be markedly slowed, which can be critical when rapid reactions are necessary. False responding also increases, i.e., the pilot may take action when no action is warranted, especially when aware of having missed signals. The resulting anticipation of another event and over attention on individual signals or problems further reduces situational awareness."

Fatigue increases calculation errors, logical errors, and ineffective problem solving. The member is less able to think of new solutions and repeatedly tries the same approach to a situational problem.

Memory deficits progressively worsen with fatigue and sleep loss. The sleepy and tired crewmember reads or hears instructions repeatedly but cannot retain the information, leading to critical errors and uncertainty about the status of the situation. Decreased performance variability results from increased lapses and errors of omission.

Fatigue effects tend to be minimal when tasks are self-paced, brief, highly motivating, and feedback is given. On the other hand, tasks that involve sustained vigilance and attention, the use of newly acquired skills, and new information retention tend to challenge short-term memory. This is because work-paced tasks accelerate the rate of information processing, thereby decreasing

Figure 3

Figure 4

the reserve capacity of brain function. NASA studies have established that there is a tremendous increase in heart rate during all approaches and landings. In adverse weather conditions, the combination of increased heart rate, accelerated adrenal gland functions, and effects of fatigue can prove dangerous.

In an article based on the joint study[2] by Duke University and NUS Graduate Medical School, Singapore, a few important aspects that may be relevant to aviation accidents emerge. The study found that sleep deprivation was associated with increased activation in the brain for risky decisions, indicating a possible shift toward risk-taking behavior. In addition to altering risk preferences, sleep deprivation may also diminish the ability to learn from the negative consequences of risky behavior. Lack of adequate sleep impairs vigilance, flexible thinking, working memory, and executive functioning. This cognitive change may impair the ability to make correct decisions under conditions of risk.

The findings of cognitive neuroscientist Michael Chee, M.D., published online in the journal *Proceedings of the National Academy of Sciences* shows that sleep deprivation leads to short-term memory loss. It had been believed that it was the result of the brain not being able to assemble and "file away" the information it received in its proper place. To quote Dr. Chee, "We generally think of memory decline as a result of faulty storage of information. When people are sleep deprived, they may not be seeing what they think they should be seeing, and it appears that this is what contributes to memory declines following sleep deprivation."

A few years back, a study[3] of surgeons in a virtual-reality simulator illustrated the effect of lack of sleep on performance. The surgeons were allowed 8 hours of sleep for one trial and had to stay up all night for the other. In each case, they then had to perform a surgery simulation the next day. The results indicated that, without sleep, errors increased 20% and the procedures were carried out at a rate that was 14% slower than with 8 hours of sleep. These are significant drops in performance.

In another study by Dr. Drew Dawson of University of S. Australia, which has been quoted and used by the ATSB report on fatigue, a group of trainee doctors were divided into two teams. One had sufficient rest and the other had to be awake for long periods. What was interesting about the results were the findings on the team without sufficient rest. All of them took decisions based on "probabilistic" factors where they had encountered similar cases earlier.

These studies may explain the reasons why experienced pilots who have carried out their assigned tasks safely for several years, but have failed to recognize the effect of fatigue and sleep on the one occasion when their alertness was required. The AF A340 accident in Toronto is an example of this. The period of "time since awake" of the captain might be a pointer to the reason for the accident.

Coercive habits

Pilots tend to develop habits during their career. It takes just one hard landing to get them into a habit of doing "power-on touchdowns" or "extended floats." The subconscious mind takes over at the time of flare, especially when you are tired. Habits developed on one type of aircraft may carry over on another type, even though that technique may not be required for the new type of aircraft.

In Figure 1, the spoilers deploy immediately on touchdown, and in Figure 2 the aircraft design results in the spoilers deploying at a much later stage. This may result in complacency in the belief that spoilers and reversers are available immediately on touchdown. When you look at several wet runway overruns, the delayed deployment of reversers has been a prime factor. Similarly, a look at the following two figures brings out another induced habit.

The pilot had developed a habit of retracting the landing lights as soon as the aircraft touches down! Strangely, even while landing on a wet runway and in rain, the habit seems to have overtaken better judgment that positive control on the runway is more important. The captain, apparently, was on duty for the third night in a row, even though he had the "required" rest between duties.

With increased use of automation, complacency has become more dominant. Habits developed on one type of aircraft are not going to be forgotten in a hurry. A conscious effort is required to overcome habits. Approach and landing in heavy rain puts a lot of additional stress on the pilot's mind. An insufficient or incorrect runway condition report adds to the errors. What the tired mind perceives in limited time that is available during the landing run is not easy to fathom.

When accidents on wet runways are considered based on the above studies, it is apparent that fatigue plays a large part in strange decisions that the crewmembers have taken. During the briefing after the AF A340 accident in Toronto, the chief investigator, Real Levasseur, said, "Humans are humans and they are not machines. Unfortunately, in the present world of commercial aviation, the human side is forgotten and pilots are considered as machines." ◆

References

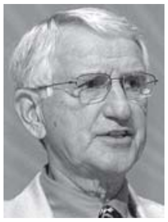
[1] Battelle Memorial Institute JIL Information Systems.

[2] Sleep Deprivation Elevates Expectation of Gains and Attenuates Response to Losses Following Risky Decisions. Vinod Venkatraman, Meng 1, 3; Y.M. Lisa Chuah, Ph.D. 1; Scott A. Huettel, Ph.D. 2, 3; Michael W.L. Chee, MBBS, MRCP (UK) 1, 2.

[3] Tools for Managing Fatigue in Transit October 26-27, 2000 ALERTNESS 2000—Mark Rosekind President/Chief Scientist.

ISASI International Working Group on Human Factors: A Progress Report

By Capt. Richard B. Stone (WO0837) and Dr. Randy Mumaw, Boeing



__Capt. Stone__ is the former president of ISASI and serves as the executive advisor to the International Council. He is the chairman of the ISASI International Working Group on Human Factors. After 35 years' experience as a pilot for Delta Air Lines, Stone retired in 1992 and is a Fellow of ISASI. Capt. Stone acted as an accident investigator in many important accidents during his career with Delta. He helped create the first Human Performance Committee at the Air Line Pilots Association.

__Dr. Randy Mumaw__ is a human factors specialist and associate technical fellow with the Aviation Safety Group in Boeing. He received his M.S. and Ph.D. in cognitive psychology from the University of Pittsburgh. He is the author of more than 80 papers, most of which address human performance and error in complex, high-risk systems.

Introduction

As some of you know, I learned to fly in the U.S. Air Force and joined Northeast Airlines in Boston in 1957, which merged with Delta Air Lines in 1972. I became part of the pilots' accident investigation group in the 1960s. One of my first contacts with the subject of human factors happened when I was invited by Professor Ross McFarland to speak to his class of flight surgeons at Harvard. Professor McFarland (author of the 1953 text entitled *Human Factors in Air Transportation*) directed a course leading to a master's of public health, which was required of all military flight surgeons. At that meeting, we spoke about many pilot performance issues, but at that time a formal method of analyzing pilot performance issues had not been designed. Human factors at that time dealt with issues such as selection, training, aging, fatigue, and health. Some 10 years later, the NTSB formed human performance groups within the investigation to deal with the critical issue of human performance. At that same time, I helped develop the pilot performance committee for the Air Line Pilots Association.

It was not until last year that I was drawn back into the human factors field by contact with an industry working group. I would like to share briefly some of the important elements of the work of the human factors working group. I don't want to bother you with details that have already been published in the *ISASI Forum* during the past year.

Why a working group on human performance?

Each new or revised summary of accidents and incidents in commercial aviation re-emphasizes the significance of the role of humans. Accidents attributed to failures in airplane systems have decreased over the years as those elements have become more reliable. Flight crews, maintenance technicians, air traffic controllers, airplane system designers, and others are identified as significant contributors to an event 60-70% of the time. To "break the chain," we need to become even better at understanding and addressing issues in human performance. In fact, even in cases where there are failures in airplane systems that precede a tragedy, accident investigations have revealed that human performance contributed to degraded system performance. This is not only true in commercial aviation; mishaps in other highly complex socio-technical systems also reveal the important role of humans in the accident chain. This influence on the accident chain may have links to system design, operational procedures, training, and organizational policies and practices.

The ISASI International Working Group on Human Factors (IIWGHF) Committee consists of

Steering Committee

Capt. Dick Stone—ISASI
Dr. Randy Mumaw—Boeing Commercial Airplanes, Human Factors Specialist Aviation Safety
Dr. Mike Walker—Australian Transport Safety Bureau, Senior Transport Safety Investigator

HP Module Development Team Members

Dr. Graham Braithwaite—Cranfield University, Director of the Safety and Accident Investigation Center
Dr. Evan Byrne—U.S. National Transportation Safety Board, Chief Human Performance Division Office of Aviation Safety
Dr. Leo Donati—Transportation Safety Board Canada, Acting Manager, Human Performance
Dr. Alan Hobbs—NASA Ames/San Jose State University, Senior Research Associate
Dr. Loukia Loukopoulos—NASA Ames/San Jose State University (currently in Athens, Greece), Human Factors Researcher
Dr. Claire Pelegrin—Airbus, Director Human Factors, Product Safety
Yann Pouliquen—Bureau d'Enquêtes et d'Analyses (BEA), Safety Analysis, France
Thomas Wang—Aviation Safety Council, Taiwan, Aviation Safety Investigator

IIWGHF Advisory Board

James Danaher (retired)—Chief, Operational Factors Division, Office of Aviation Safety, NTSB
Dr. Curt Graeber—Senior Technical Fellow, Human Factors Aviation Safety, Boeing Commercial Airplane
Dr. Rob Lee (retired)—Director, Human Factors, Systems Safety, and Communications, ATSB
Capt. Daniel Maurino—Director, Flight Safety and Human Factors Program, International Civil Aviation Organization
Dr. Claire Pelegrin—Airbus, Director Human Factors, Product Safety

Ron Schleede (retired)—Deputy Director, Office of Aviation Safety (NTSB) and Director for Air Investigations, Transportation Safety Board of Canada
Capt. Richard Stone (retired)—Delta Air Lines

The IIWGHF Vision provides

• that all agencies involved in accident investigation around the world endorse the belief that the investigation of human performance proceed without the presumption of human error or negligence. An investigative process that seeks to ascertain what occurred rather than who was at fault will yield more vital and accurate information.
• that appropriate human factors expertise is brought to bear on all investigations of human performance issues.
• that standardized and coordinated guidance modules be distributed to accident investigators around the world. The modules will be distributed in phases
—Phase 1: Initial set of guidance modules
—Phase 2: Revised/updated set of guidance modules
• that accident and incident databases worldwide share a common taxonomy for identifying and listing human performance issues so that the databases can be used to track trends over time.

Here are the IIWGHF investigation modules subjects that we propose to develop.

Guidance module topics have been put in four categories

1. *Human performance issues*—which are used to provide background on fundamental aspects of human performance.
• fatigue
• visual and vestibular illusions (spatial disorientation)
• stress, situational awareness
• decision-making limitations
• effects of drugs

2. *Human performance investigation techniques*—which are used to focus on techniques that can be used for analysis.
• fatigue-modeling tools
• workload
• barrier analysis
• speech analysis
• target detectability analysis

3. *Human factors investigation fundamentals*—which are broader treatments of human factors topics that are central to accident investigation.
• general human factors issues (orientation to human factors)
• organizational factors
• use of data vs. the need for speculation in investigating human performance
• tests of existence vs. tests of influence
• event sequence representation
• checklists—checklist for data collection in the first few days after an accident

A look at some of the things contained in the modules

So let's take a look at how the modules could help investigators in the field. Some nine modules are in the final stage of completion. Wider distribution of these modules will occur after further reviews and revisions within the team. But I can share my own impressions of how they can help the investigators who are not human performance experts.

My first example is from the module on visual and vestibular illusions (spatial disorientation). In this 10-page document, first you are indoctrinated into the language used by human performance scientists. As you review this, you are struck by the fact that the language becomes a checklist of what can happen during spatial disorientation—a great value to any accident investigator. Next the authors describe what kind of conditions can cause disorientation. Closing this section is a list of recognized experts in this field. The final section is an analysis of a number of accidents. The factual data are presented and then an analysis of human performance issues is presented. From the accident investigator's standpoint, you have what you need to gather the pertinent data in an accident, get human performance expert help, and prepare a report that is complete.

My next example is from the module dealing with fatigue. Here again the investigator is given a basic understanding of how sleep and fatigue are intertwined and the special language that is used in this field. Sleep requirements are discussed in detail and so are the consequences of sleep deprivation. Microsleep, a condition where the individual is asleep with eyes open but no mental processing occurs, is described. Such a specific condition can be invaluable to the investigator who has little knowledge of this condition. Next, the module discusses what to look for in an investigation. As in all modules, a list of recognized experts in the field is presented. A small number of accidents are reviewed as few accidents have carefully examined this important causal factor.

The third module I would like to discuss is the module on events sequence representation. I am sure many of us have been involved in charting the time sequence of events during an accident. It is a necessary task if you are to arrive at a reasonable description of the events preceding an accident. This module is being developed by a number of acknowledged experts in this field, so I think it will add a new dimension to your investigation toolkit. The module deals with the broad range of data required to describe an accident factually. It also warns of the trap of portraying data in a subjective instead of objective fashion. I think this is critical because all of us seem to want to rush to find the cause of the accident as quickly as possible and therein lies a huge trap. I was reminded, while reading this paper, of an article I read in *Scientific American* some years back. The article dealt with research into problem solving. When subjects were quick to choose how to solve a problem and found their method did not work, they were literally stymied and were unable to alter their thinking and start all over again in solving the problem. Sounds like some people I have worked with who think they have found the cause of an accident and will do anything to prove they have the answer. One final point about this module, the authors are human performance scientists and they have a keen eye for describing how to dig out the human performance issues in the events sequence.

The last module I would like to introduce is the workload module. It is a very important corollary of the events sequence representation as it deals in-depth with actions and decisions of the operator. While it provides basic information about techniques to evaluate recorder data, it also describes how to construct and evaluate simulation data. As in all the modules, the reader gains a grasp of the science and language of workload assessment. This can be invaluable as the investigator deals with consulting experts in the process of accident analysis.

What's next in the work schedule of the working group?

- The modules will be edited by experienced accident investigators.
- A review of completed modules will be completed by the IIWGHF Advisory Board.
- Modules will be circulated to stakeholders.
- Modules will be distributed to all investigative entities.

Module distribution

We hope that we can find some industry interest in helping us print the documents, although it seems the Internet and CD-ROMs may make it possible to do this at minimum cost. ISASI has had a very good relationship with ICAO, and we are hopeful it will help in the distribution of the product of the working group.

Conclusion

The hope is that the development of these concise modules will enable investigators to raise the standard of human performance investigations.

Right now the level of human performance investigations is inconsistent because of the unavailability of special subject experts, limited financial resources, and competing interests of criminal prosecution.

Much of the introductory material that will accompany the modules will make the case for objective, unbiased, and patient investigations. While finding fault seems to be still the point of some investigation authorities, we believe this objective corrupts the investigation process and leads to covering up important facts. ◆

International Cooperation During Recent Major Aircraft Accident Investigations in Nigeria

By Dennis Jones, Senior Air Safety Investigator, U.S. NTSB

Dennis L. Jones, senior air safety investigator, has been with the NTSB for 28 years and has been in charge of more than 500 aircraft accident investigations during his career. He is currently an investigator in the NTSB Major Accident Investigation Division based in Washington, D.C. He has been appointed as U.S. accredited representative, heading several U.S. teams, for major accident investigations in Africa over the past 10 years.

Introduction

During a 1-year period between 2005 and 2006, there were three major aircraft accidents in the country of Nigeria. The accidents involved three domestic airlines, and the crashes resulted in the deaths of 321 persons. The investigations of these occurrences brought together government and industry air safety investigators from Nigeria and the United States of America. This paper will focus primarily on the interactions and activities during the investigation to provide a description of the cooperative spirit that occurred within the international team. Also, the findings of the one completed investigation will be described.

Overview

Nigeria, located in West Africa, is the most populous country in Africa, with a population of about 140 million. According to the Nigerian Civil Aviation Authority (NCAA), the aviation market in the country, in part, consists of 17 domestic and 20 foreign airlines that operate in the country, as well as 5 Nigerian carriers that operate international routes. Nigeria is also served by 21 domestic and 5 international airports. The annual international airline passenger traffic is 2.8 million and domestically, 2.6 million. NCAA records indicate there are 544 pilots, 490 air traffic controllers, and 913 aircraft maintenance engineers.

The NCAA reported that between 1996 and 2006, Nigeria ranked fourth behind the Democratic Republic of Congo, Angola, and Sudan in the number of fatal accidents that occurred in the region. The single crash in the country in 2006 was the deadliest accident on the African continent for the year.

The Nigeria Accident Investigation and Prevention Board[1] (AIPB), the aircraft accident/incident investigative authority, was responsible for the conduct of the investigations. The U.S. National Transportation Safety Board participated as the representative of the state of manufacturer/design. An NTSB investigator was appointed as the U.S. accredited representative (USAR) and he was assisted by technical advisors from the U.S. Federal Aviation Administration, Boeing airplane, and Pratt & Whitney engines.

The AIPB at the time was a department under the Federal Ministry of Aviation. The AIPB would be later reestablished as the accident investigation board with the passage of the Nigeria Civil Aviation Act of 2006, and after the investigation of the accidents were initiated. The AIPB was staffed with investigators, trained and experienced in aircraft accident investigation, and supported by administrative personnel. The department was divided into airworthiness and operation units. The National Transportation Safety Board is the U.S. government agency responsible, in part, for the investigation of aircraft accident investigation. The AIPB and NTSB had developed a working relationship over many years, achieved from involvement with investigations and participation in training initiatives.

Bellview Airlines, Sosoliso Airlines, and Aviation Development Company/ADC Airlines were the operators of the airplanes involved in the accidents. Bellview was formed in 1991 and began scheduled service in 1993. At the time of the accident, the airline was operating a fleet of seven aircraft. Sosoliso and ADC were domestic airlines founded in 1984 and 1994, respectively, and both companies had an operating fleet size of less than five airplanes. Sosoliso and Bellview did not have any previous accidents. ADC had four previous accidents, including an occurrence in 1996 resulting in 134 fatalities.

The AIPB conducted the investigations in compliance with the standards and recommended practices under the provisions of Annex 13, and accordingly, an investigator-in-charge (IIC) was designated for each of the investigations. The IIC was given full responsibility for the conduct of the investigations. In addition

Scene of Bellview Flight 210.

to the U.S. team, personnel from the Nigeria Civil Aviation and the applicable airlines officials participated in the investigations.

Bellview Airlines (BLV) Flight 210

On Oct. 25, 2005, about 2035 hours, BLV 210, 5N-BFN, a Boeing 737-200, with 117 persons aboard, crashed shortly after takeoff from Murtala Mohammed Airport, Lagos, Nigeria. There were no survivors. The flight was destined for Abuja, Nigeria.

About 2030 hours, BLV 210 was cleared to take off on Runway 18L, turn right, and proceed northbound on course at FL210. Soon afterwards, the pilot reported climbing through 1,600 ft, and he acknowledged instructions to report passing FL130. There were no further transmissions from the flight, despite repeated attempts by air traffic control to reestablish radio contact.

The AIPB investigators were returning to Abuja from an organization retreat when they were notified that Flight 1145 was missing and a search was in progress. They notified the NTSB and continued to provide periodical updates while the search for the airplane was being conducted.

The wreckage of BLV 210 was found about 1000 hours the following morning. The crash site was located in a wooded area, about 14 miles north of the airport. By the time the wreckage was found, many of the Nigerian investigators had already arrived in Lagos, and subsequently reached the crash site by 1200 hours.

Often during the early stages of an investigation, erroneous and/or incomplete information is reported by a variety of sources, some of which is misleading. However, the AIPB provided update briefings to the USAR with the best available information. The briefings were especially beneficial to the U.S. team, and the information assisted with determining the team composition, required equipment, and technical material to be carried.

During the days preceding the arrival of the U.S. team, the AIPB surveyed the crash site, searched for the flight recorders, interviewed eyewitnesses, and began collecting documents for further evaluations. Despite an exhaustive search, the flight recorders were not recovered.

The IIC held after an organizational meeting when the U.S. team joined the investigation. The meeting included a briefing of the factual information that had been developed to date and the situation at the accident site. Representatives from the NCAA and Bellview Airlines were in attendance and provided information about the flight crew, aircraft, and history of the flight. The Nigeria Minister of Aviation would later welcome the arrival of the U.S. team and to express his gratitude and appreciation for their participation.

The crash site consisted of an initial and principal impact crater more than 35 feet deep, indicative of the airplane colliding with the ground at a high speed in a steep descent. The majority of the wreckage was imbedded in the crater, with other debris scattered around the general area of the crash. The crash site activities continued for about 10 days, hampered frequently by heavy rain that often prevented work at the crash site.

The on-scene activities included, but were not limited to, the examination of the aircraft wreckage, determination of crash site dynamics, interviews, wreckage recovery, a two-dimensional layout of wreckage, review of aircraft and pilot records. The wreckage was transported to a hangar at the Lagos Airport where the layout was done to an outline in the dimensions of the model airplane. Although, no more than 30 to 40% of the aircraft was recovered, the layout confirmed that the major structures of the airplane were at the crash site. Also, the layout provided a better understanding of the crash dynamics, and aided in the identification of components for further testing.

Progress meeting were held daily to discuss the results of the day's activities. Several accident scenarios were discussed among the investigators; the suggestions and comments from all participants were given full consideration. The on-scene investigation culminated with identification of follow-up activities, including examination of aircraft components at facilities in the U.S., which included those of NTSB and Boeing. The NTSB, in conjunction with the technical advisors, coordinated the activities.

Several progress meetings occurred during the months after the investigation, two of which were in conjunction with the component examinations in the U.S. The meetings, to the extent possible, included all members of the investigation team. The AIPB produced an interim report for the Ministry, and the IIC solicited input from the U.S. team in the drafting of the document. The investigation is still ongoing.

Sosoliso Airlines (OSL) Flight 1145

On the morning of Dec. 10, 2005, 5N-BFD, OSL Flight 1145, a McDonnell Douglas DC-9-32, crashed during an instrument approach to Port Harcourt, Nigeria. The accident occurred during a heavy rain shower. There were 110 persons aboard, and 2 passengers survived. The aircraft was destroyed and there was a post-crash fire. The flight originated at Abuja, Nigeria, and among the fatalities were more than 60 students of a prestigious boarding school who were returning home for the Christmas holiday.

The AIPB investigators were in Lagos, having arrived the day before the accident occurred, in preparation for a planned progress meeting for the Bellview investigation. The USAR was also in Lagos with the AIPB, having arrived in advance of the other U.S. team members for the meeting. Notification of the Sosoliso crash came quickly to the AIPB, and plans were made to launch to the accident site. The USAR notified the technical advisors, and specifically communicated with the U.S. investigators who were about to depart for the Bellview meeting. These investigators would now join the Sosoliso investigation.

The IIC, USAR, and other Nigerian aviation government officials arrived at the crash site the next day on a chartered aircraft, and soon realized that contrary to early reports, the aircraft had crashed on airport property. The tail section of the airplane had impacted a concrete drainage culvert located 70 meters left from the edge of Runway 21 and broke up during the subsequent impact sequences across the ground over a distance of more than 1,100 meters. The aircraft broke up into three major sections—nose section, main cabin section, and tail section. The nose section, consisting of the flight crew compartment ,came to rest at the end of the debris path.

Local and airport officials had secured the crash site shortly after the crash to preserve the wreckage. Consequently, other than removal of the recovery of the victims, there was minimal disturbance of the wreckage. The airport officials located the flight recorders on the day of the accident. The transfer of the recorders from the local official to the AIPB would be later broadcasted on national television.

Scene of Sosoliso Flight 1145.

The flight recorders were taken to the AAIB in the U.K. for analysis, and an NTSB investigator from Washington, D.C., participated in the activities. The flight data recorder was a solid-state type and contained about 26 hours of data. The FDR recorded five parameters, including pressure altitude, indicated airspeed, magnetic heading, vertical acceleration, and VHF keying. Sink rate was calculated based on pressure altitude. The cockpit voice recorder was a polyester type and contained 30 minutes of audio data. The review of the recorders did not disclose evidence of mechanical malfunction.

The U.S. team further assisted with analyzing the CVR audio rerecording, in an effort to help identify cockpit sounds. The team also assisted with the FDR evaluation to help determine aircraft performance.

Less than 6 months after the accident, the AIPB produced a draft report of the investigation. A copy of the draft was provided to the NTSB for review and comments, allowing 60 days to respond.

The final report was released in July 2006. According to report, *"The cockpit conversation within the environment reveals that the flight was uneventful until the final approach to land. The CVR readout shows that the aircraft was configured for landing when one of the pilots called for gear down approach checklist.*

"At about 16 seconds to crash, the captain called for a go-around, gear up, and flaps before the crash. A warning horn then came on followed by a 'too low gear' aural sound from the cockpit area microphone. It appears that the crew had difficulty in sighting the runway and should have carried out a missed approach at the decision altitude (DA) of 307 ft ASL instead of continuing descent below 204 ft (ASL).

"The gear was down and locked with the landing flap set prior to the go-around. When the crew decided to go around, the flap lever was selected up while the gear was still in the extended position, but probably not locked. The warning horn then sounded because the gears were no more in the landing position and flaps had not yet retracted to less than approximately 18 degrees. The warning horn was immediately followed by the 'too low gear' sound, i.e., Ground Proximity Warning System (GPWS).

"The FDR readout indicates that the flight was normal until the last moment into the final approach to Port Harcourt Airport. At 30 seconds before the crash, the airplane descended through 357 ft (ASL) at the airspeed of 153 knots and a heading of 207.3 degrees. The airplane heading at this point is a departure from its initial heading of 211 degrees. At 23 seconds before the crash, the airplane leveled off at an altitude of about 204 ft, which is below the decision altitude (DA) of 307 ft (ASL). The altitude then remains relatively steady for the next 14 seconds. During this time, the airspeed decreased below 145 knots.

"At 7 seconds before the crash, the airspeed began to increase reading 151.3 knots. The increase in speed would indicate an engine power input by the crew to initiate a go-around: Meanwhile, the aircraft sunk further below 204 ft (ASL), and its heading deviated to the left of the runway magnetic heading of 210 degrees. The aircraft could not recover when the crew later decided to initiate a go-around. At the time of impact when the FDR recording stopped, the aircraft [had a] heading of 196.9 degrees and airspeed of 160.2 knots and a descent rate of over 2000 ft/min."

The AIPB concluded the accident probable cause of the accident was *"The crew's decision to continue the approach beyond the decision altitude without having the runway and/or airport in sight."*

The contributory factors were *"The crew's delayed decision to carry out a missed approach and the application of improper procedure while executing the go-around. The aircraft encountered adverse weather conditions with the ingredients of windshear activity on approach. The reducing visibility in thunderstorm and rain at the time the aircraft came in to land was also a contributory factor to the accident. And the fact the airfield lightings were not on may also have also impaired the pilot from sighting the runway."*

Another contributory factor was the fact that the aircraft had an impact with the exposed drainage concrete culvert, which led to its disintegration and subsequent fire outbreak.

ADC Airline (ADK) Flight 053

On Oct. 25, 2005, 5N-BFK, ADK Flight 053, a Boeing 737-2B7, crashed shortly after takeoff from Runway 22 at Nnamdi Azikiwe International Airport, Abuja, Nigeria. There were 9 survivors and 96 fatalities, including the flight crew. The airplane impacted into a corn and bean field in Tungar Maje Village, about 1 nautical mile from the departure end of Runway 22. The airplane was destroyed by impacted forces and post-crash fire.

According to witnesses, a rainstorm was occurring at the time of departure. Airport fire and rescue officials quickly reached the scene and provided aide to survivors and secured the crash site. AIPB investigators quickly responded to the accident site and notified the NTSB. A survey of the accident site, photographic documentation, and a preliminary wreckage diagram was conducted. The flight recorders were also found and secured.

On the day of the accident, the AIPB began gathering documents, including records from air traffic service, the airline, and meteorological services. Also, the AIPB established communication with forensic personnel to establish postmortem protocol for the bodies of the flight crew.

The U.S. team arrived in Abuja 3 days after the accident. Similar to the previous investigations, the AIPB conducted an organizational meeting and briefed the U.S. team. It was later determined that the investigation team would be organized into operational and airworthiness groups with subgroups for weather, witnesses, aircraft performance, and air traffic.

During the course of the on-scene investigation, the U.S. team

Scene of ADC Flight 53.

assisted with the on-site documentation, wreckage diagram, examination of aircraft components, interview of witnesses and other persons knowledgeable of the accident, and review of aircraft records and audio recordings from air traffic service.

The flight recorders were analyzed at the NTSB facilities in Washington, D.C. The USAR coordinated with the U.S. Embassy-Abuja to secure visas for the urgent trip. The AIPB deputy director arrived in Washington on the weekend where NTSB recorder specialists were on hand to immediately start analysis of the recorders. A briefing of the data retrieved from the recorder readouts was conveyed to the investigators, and proved to be instrumental in identifying pertinent areas to address during the investigation.

Post on-scene activities have been under way in the U.S. involving component testing and aircraft performance. The investigation is still in progress.

Summary

The Nigerian and U.S. investigators worked closely together in a cooperative manner during the investigations. The AIPB emphasized the importance of adhering to the requirements of ICAO Annex 13 with the objective of developing all available information about the accident, determination of probable cause, issuance of safety recommendations, and completion of the final report.

There was an open exchange of information and AIPB created an atmosphere that encouraged different opinions and suggestions during the various phases of the investigations. The suggestions and comments discussed among the members were given full consideration, and problems were resolved quickly. The different accident scenarios presented within the team and externally were given full consideration, and when deemed appropriate, they were investigated to the fullest extent. The wide range of skills, knowledge, and abilities among the participants provided several opportunities for exchanges that contributed to the growth of not only individual investigators, but also for the team as a whole.

Overall, during the investigations the professional relationships were strengthened, as well as the level of confidence and trust among the Nigerian and U.S. investigators. The tragic occurrences brought together a diverse group of international investigators and resulted in the amalgamation of efforts in a harmonious manner toward the common goal to ultimately improve aviation safety in Nigeria and to ensure the lessons learned from the investigation benefit the global aviation community. ◆

Endnotes

1 The Nigeria Civil Aviation Act of 2006 reestablished the AIPB as the accident investigation board (AIB).

Critical Aspects of International Incident Investigations

By Deborah J. Lawrie, Robert N. van Gelder, and Jan Smeitink,
Independent Safety Investigation & Consultation Services

Deborah Lawrie *was born in Australia and graduated with a BSc and bachelor of education from Melbourne University. She taught mathematics and physics and was a flying instructor from 1976 until 1979, when she joined Ansett to become Australia's first female airline pilot. Deborah joined KLM cityhopper in 1993. She instructed on the Fokker 50 and later operated the Fokker 70/100. In 1998 she established the company's Flight Safety Department. She held the position of safety manager and chief investigator for 8 years. Deborah was chairman of the ERA Air Safety Working Group from 1998-2004. She is currently flying the A330 for KLM.*

Robert van Gelder *was born in the Netherlands. After his initial commercial pilot's flight training at the Royal Dutch Flight Academy in 1973, he graduated with a BSc. honors from Loughborough University of Technology in human factors/ergonomics in 1982. Robert joined KLM Royal Dutch Airlines in 1978 where he is currently employed as a Boeing 747-400 captain. During the last 17 years, Robert has held the positions of ergonomics engineer/human factors specialist, line and simulator instructor, chairman of the Standardization Committee on the Boeing 737, founder and editor-in-chief of KLM's flight safety magazine* in for SAFETY, *and chief investigator.*

Jan Smeitink *is a member of the management team of the Dutch Safety Board, which investigates transport accidents and incidents and other types of disasters, serious accidents and incidents, as well as crisis management and disaster control. He joined KLM shortly after graduating as a mechanical engineer at the polytechnic college in Arnhem, the Netherlands. He flew as a flight engineer on the B-747-200/300 and has more than 10,000 flying hours.*

General

Robert van Gelder, Jan Smetink, and I are founders of the ISIS group and part of our work is to teach others and, especially airline operators, how to investigate serious incidents. Today Robert and I are here to present a paper on the critical aspects of international incident investigations.

My first challenge, however, is how to illustrate the importance an incident. An accident is easy to illustrate—after all, there are usually several graphic pictures that can tell us a story, but an incident, on the other hand, is far more difficult to visualize.

After giving this some thought, I decided to use the topical subject of global warming as an analogy and some pictures of Greenland that I took from 38,000 feet on a flight from Amsterdam to Vancouver.

This is a Greenland glacier melting into the sea. Imagine these icebergs as the "incidents" that are occurring every day, representing the precursors of global warming. In much the same way we can think of incidents in aviation as being the precursors of accidents.

And these larger icebergs here, I like to think of as serious incidents and as being a very clear signal that global warming is a reality.

Introduction

This paper will feature a case study of a serious incident that had significant consequences for ground handling supervision and developed into a broad based international investigation that was conducted in accordance with ICAO Annex 13.

We will cover

- case study outline of a serious deicing incident.
- investigation Quality/the role of the airline investigator as advisor.
- airline investigator training within a flight safety program.
- benefits of interactive and customized training for airline investigators.

Case study outline of a serious deicing incident

Background information

Back in 2002, I was a line captain on the Fokker 70 and I had also had the function of chief investigator for the company for the previous 4 years. Up until that time I had managed several incident investigations such as GPWS warnings, loading errors and aircraft controllability problems, etc. Then in 2001, investigation of an accident involving a ground engineer who walked through the propeller of a Fokker 50 was delegated to me under the supervision of the Dutch national investigating authority. Such was my investigation experience until that point in time.

Early one very bleak and cold, typical winter morning in Holland in February 2002, while I was watching my son play soccer, the Fokker 70 chief pilot called me regarding a possible incident with one of our aircraft in Turin. As the chief investigator for the company it was my decision to go to Turin immediately. I contacted the Fokker 70 technical pilot to come with me, as I thought he would be able to provide some valuable assistance and this was to be the beginning of my involvement in an investigation that would last more than 2 years.

Turin incident

So what actually happened to the Fokker 70 in Turin?

The aircraft had been parked in Turin overnight. Rain and snow fell during the night with light and variable winds and the temperature/dew point ranged between 2/0°C and 0/-1°C, and enough fuel remained on board for the return flight to Amsterdam the next day.

During the pre-flight inspection the next morning, ridges of ice 1.5–2 cm thick were found under the leading edges of the wings, and a mixture of slush and ice was found in small areas on the top of the wings. The aircraft was deiced, and the captain performed a visual check of the wings after the deicing operation was finished. (Kilfrost ABC 3 Type 2/50%).

A short time later the aircraft taxied for departure from Runway 36. A special procedure with a right turn at 500 feet is specified in the case of engine failure during takeoff from this runway due to the close proximity of high terrain.

The takeoff was performed using full thrust with the engine anti-ice on. The wind was from the north/east at 3 knots. There was scattered cloud at 500 feet, light rain, and the temperature/dew point was 1/0° C.

All the engine indications were normal during the takeoff roll but during the rotation the fan vibration in engine No. 1 increased and at liftoff there was a sudden loss of oil pressure and fuel flow to engine No. 2 and the fan vibration in engine No. 1 increased above limits. We now know that as the wings flexed during the rotation large pieces of clear ice separated from both wings causing violent and immediate destruction of the right engine and damage to several fan blades in the left engine.

- Accessory gearbox and hydraulic pump housing were cracked.
- Power lever transducer was hanging on its wiring.
- Gear box housing was cracked in two places.
- Throttle linkage was detached from the fan case.

The situation on the flight deck was complicated by the turn that was now necessary at 500 feet, a jammed fuel lever on the right engine, which disrupted the engine shutdown procedure, and several other failures that occurred—those being an auto throttle failure, an auto pressurization failure, and eventually a fuel asymmetry warning.

The high-vibration warning on the left engine was temporarily "hidden" by all the other failures due to the priority allocation of the aircraft's warning system and insufficient space being available to display all the warnings at the same time on the Multi-Function Display Unit. Due to all the other failures, the crew remained unaware of the high-vibration problem with the left engine for the next 10 minutes.

When the high-vibration warning eventually surfaced on the Multi-Function Display Unit, the crew then became aware that the only remaining engine was not functioning normally. The first officer later described the situation as "the aircraft was not flying really well and the engine did not feel smooth." The captain declared a MAYDAY, and a request was made for vectors to return for an ILS approach on Runway 36 at Turin.

The aircraft finally landed safely back on Runway 36 after being airborne for 29 minutes.

The aftermath

By the time I arrived in Turin with the technical pilot, investigation of the incident had already commenced and was under the control of the investigator-in-charge from the ANSV (Italian Aviation Safety Board).

At this stage, it was not sure what had caused the damage to both engines.

Other damage to the fuselage and the surface of the right wing led to initial speculation that the damage to the left engine may have been caused by ingestion of debris from the catastrophic failure of the right engine.

As mentioned earlier, as chief investigator for the airline I had some previous experience with several incident investigations that had been conducted on an internal basis and an accident investigation that was conducted under supervision at a national level. Quite suddenly now, however, I found myself as the only party on site, in what was to be an international investigation involving several parties and I was dealing directly with the investigator-in-charge. This type of situation is more likely to develop in the case of a serious incident rather than an accident. While the formal procedure calls for an accredited representative under whose supervision the company investigator would act as an advisor, the Turin situation called for an approach that deviated from the ICAO Annex 13 philosophy.

In the Turin situation, a comprehensive knowledge and understanding of the ICAO investigation process as well as knowledge about my entitlements and responsibilities and those of the other parties involved was going to prove to be invaluable in what was going to develop into a lengthy and controversial investigation. I should add that at this stage, feelings of loyalty to the company and personal acquaintance of both pilots who were involved were other issues that I had to deal with and that are not normally matters for consideration for independent investigators.

Investigation quality/the role of airline investigator as advisor

This case study will also show that serious incident investigation is just as important as an accident investigation and, therefore, should be performed as comprehensively and with the same allocation of resources as if it had been an accident. In cases such as Turin where the operator had been fortunate to escape disaster, then investigation of this event had the potential to reveal as much, if not more, about all the contributing factors that led up to it.

It was later revealed that the Turin event had the same "footprint" as the Scandinavian Airlines accident that involved an MD-81 that took off from Stockholm's Arlanda Airport early in the morning of Dec. 27, 1991. Vibrations from the MD-81's engines were noticed 25 seconds after becoming airborne. Approximately 1 minute later, both engines failed. The aircraft was committed to a forced landing in a field where it broke into three parts after the impact. Remarkably, in this accident there were no fatalities, and later the investigation revealed that ice from the wings had entered both engines causing them to fail. The only difference between the MD-81 in 1991 resulting in an accident and the Fokker 70 in 2002 resulting in a serious incident was an element of luck.

In Turin during the first hours of the investigation, the technical pilot and I worked side by side with the Italian investigator-in-charge. Our operational knowledge was very much appreciated, and we managed to establish a good relationship with the IIC. Aircraft documents and operating manuals were identified and discussed, a detailed inspection of the cockpit was made, and a brief inspection of the engines and external condition of the aircraft was performed.

The IIC organized for us to inspect the runway and the surrounding area at the point where the aircraft had rotated. We retrieved pieces of engine acoustic lining among other broken bits and pieces. It was at this critical point in time, however, that the driver of the airport safety car casually mentioned that earlier that morning, just after the incident, he had found some very large pieces of ice at the same location. He was also able to describe the size and shape of the pieces of ice.

As the last thing on that day, we were invited by the IIC to go with him to interview the air traffic controllers who were on duty in the tower at the time of the incident.

I must emphasize that this event did not have the high-profile media attention that one associates with an accident, and it was not until much later that day that the seriousness of the event started to filter through to the interested parties. The company reported the matter to the Dutch investigation authority, which was known then as the RVTV. The following day, representatives from Fokker and Rolls-Royce arrived in Turin.

A formal international investigation had been commenced under the direction of the Italian Aviation Safety Board but our position as advisor to the Dutch accredited representative was not formalized until after we returned to Holland 2 days later.

By the time we returned to Holland we had, however,

- established a good working relationship with the IIC.
- met several of the other parties who would be involved in the investigation.
- established our value as advisors in terms of knowledge, expertise, and availability.

The operating company also commenced a formal investigation of the incident that was to be done in conjunction with the RVTV. An accredited investigator from Dutch ALPA was assigned to me, and together we acted as advisors to the RVTV.

Among the vast quantity of data that was collected, information from the digital flight data recorder was available, but information from the cockpit voice recorder was unfortunately not available due to the jammed fuel lever that had caused the CVR to keep recording for several hours after the incident.

After all the data were collected and extensive analysis of both engines had been performed by Rolls-Royce, the process of elimination led to the conclusion that the most probable cause of the event had been the ingestion of large amounts of ice by both engines. The focus of the investigation turned to the deicing operation, the post de-icing inspection and the operator's supervision of ground handling.

Deicing at European airports was a very controversial and high-profile safety concern at the time, and a few years earlier the DAQCP (De-icing and Quality Control Pool) had been established. The DAQCP was an organized group of operators who shared the auditing of several deicing contractors throughout Europe.

In the Turin investigation there was controversy over

- knowledge of and training of the correct techniques for the removal of clear ice.
- ownership of the final responsibility for the post deicing inspection.
- the operator's contractual arrangement with the handling agent that performed the de-icing and the agent that performed the inspection.
- the separate arrangement between the handling agent performing the deicing and the agent performing the post deicing inspection.
- the structural safety deficit at an international regulatory level with no certification rules for ground handling companies.
- evidence of previous substandard deicing operations in Italy.

In the case of Turin, the company had a written contract with a deicing agent but only a verbal contract with the post deicing inspecting company, which was a separate company to that which performed the deicing.

The crew documentation on board the aircraft indicated that the handling agent would perform the deicing and the post deicing inspection, but in this case no post deicing inspection was performed other than the visual check performed by the captain. Furthermore, several findings in relation to training and contracts remained open from the deicing pool audit that had been conducted in January of the previous year.

Tension between investigators was apparent and understandable. Pending insurance claims and political issues also added pressure to the investigation. The importance of the role and the entitlements of the Dutch accredited representative were absolutely vital to the progress of the investigation. In turn, the Dutch accredited representative relied heavily upon the support, knowledge, and objectiveness of his advisors.

Several analysis and recommendation meetings were convened, some of which were held in The Hague and some in Rome. The Dutch accredited representative could not attend all the meetings in Rome, so on some occasions we were present at these meetings as replacements. We were, therefore, playing a variety of roles on different occasions throughout the investigation ranging from a subordinate role to a leadership role. We had to balance diplomacy with assertiveness and, above, all we had to keep our focus on getting to the bottom of the true causes of the event.

As this was an international investigation, the importance of a final report in the English language was apparent. Because we were more fluent in English, the union investigator and I were given the very important job of writing the report under the supervision of the IIC. The task of writing the report was enormous and extremely time consuming, but one that we were grateful to have, given the importance of the report and its recommendations not only to our company but also to many other operators who had a vested interest in this very critical safety issue.

The costs of the investigation were never really evaluated. An analysis of costs, however, would have revealed that the operator had made a very significant contribution in both man-hours and expertise. Also significant was the comprehensive engine analysis performed by Rolls-Royce and a high-altitude test flight that was organized by the operator to obtain infrared camera measurements of temperature distribution on the wing surface area with the same amount of cold-soaked fuel in the fuel tanks as the incident aircraft.

Airline investigator training within a flight safety program

As illustrated by the example in Turin, proper training of airline investigators is a vital facet of the operator's flight safety program and more importantly the training should be within the reach of, and available to, all operators.

One of the most striking aspects of many formal accident investigation courses is that the bulk of such courses are not relevant to the airline investigator. Also many courses are out of the financial reach of smaller operators and those who it could be argued may need it most.

Fortunately, most airlines tend not to have accidents. Conversely, however, most airlines are mostly unaware of how many times an early break in a "chain of events" has prevented an occurrence developing into a serious incident or even an accident.

For example, pilots discuss the fact that an ATC instruction does not make sense so they request clarification. Why did they do this? It could be because of common sense, airmanship, training, or any other number of things. On this occasion, however, they actually prevent a runway incursion, but neither the company nor ATC for that matter will ever know this fact. It is just one of the many times each day someone, somewhere breaks the error chain.

If an airline does have an accident, the airline investigator will at best be an advisor and will certainly never be acting as an investigator-in-charge.

Airlines do, however, have incidents from time to time and sometimes these incidents are serious. Often, though, due to staff shortages or other investigations already in progress, the national investigation authorities do not have sufficient time or resources to investigate all serious incidents and at best are sometimes only able to give limited attention. Even though the investigation of serious incidents has been mandated in the latest version of ICAO Annex 13, the reality is that this task more often than not is allocated to the operator itself and, therefore, the quality of such an investigation depends upon the training of the operator's investigators. There is no doubt that valuable lessons can be learnt from incident investigations, and we are of the opinion that there is an industrywide underestimation of the importance of well-performed incident investigations and quality report writing.

In terms of an airline safety program it is important that

- the seriousness of an event is recognized and assessed accurately by means of a comprehensive risk-assessment program.
- the airline must be prepared to participate in investigations of serious incidents with or without the assistance of the state investigation authority.
- if the state investigation authority conducts an incident investigation, then the airline investigator should be aware of its responsibilities and entitlements.

The last point applies equally in an accident investigation.

So there are several important elements for an effective airline safety program.

We would argue that investigators should be trained how to recognize a serious incident, how to investigate a serious incident, how to write a report that supports effective recommendations, and to develop a sense of when risk should be mitigated.

Equally important is the airline investigator's ability to work with other investigators and the ability to manage a small investigation team.

Many small operators or less well-established operators are hampered by limited budget allocations and/or production problems. These operators are, however, just as vulnerable to serious incident occurrences and recognition and investigation of these incidents we maintain is vital to the improvement of safety.

In the case of Turin, the report also analyzed and produced recommendations in regard to

- fueling policy,
- crew hand-over procedures,
- preflight inspections,
- the De-icing and Quality Control Pool auditing system,
- organization and management of out station ground handling, and
- internal distribution and control of company documentation.

In view of the potential value of well-formulated recommendations that arise from a comprehensive investigation, it makes sense, therefore, to give consideration to affordable and appropriate investigator training courses. We also believe that due consideration should be given to airline investigator pools or investigator exchange programs.

During my years as chairman of the European Airlines Association Air Safety Work Group, it struck me that if investigator pools or exchange programs existed then several smaller airlines of limited resources and capability would benefit enormously from the opportunities not only for their investigators to improve their skills by working along side more experienced investigators but also that all companies would benefit from an exchange of ideas and incident investigations could be preformed more thoroughly and proficiently.

Benefits of interactive and customized training for airline investigators

At the time of the Fokker 70 incident, apart from my function as line captain on the Boeing 747-400, I was also chief investigator of the parent company KLM, Royal Dutch Airlines. Although the parent and daughter companies each had their own safety departments and the position of the safety departments was slightly different within each company, there was an active exchange of know-how and manpower between the safety management and personnel.

In 2003 an initiative was taken by Deborah, Jan, and me to develop the ISIS incident investigation course. This initiative was separate from our day-to-day airline safety business; however, the course was developed specifically with airline operators in mind.

The ISIS course is designed to train investigators in order that they may lead and manage an incident investigation and that they may be able to perform the role as advisor in an accident or incident investigation.

During the last 4 years, we have been training airline personnel from many countries. Apart from Holland, where our company ISIS is based, other attendees have been from operators from a variety of countries, including Greece, Norway, the United Kingdom, Luxembourg, Austria, Germany, Surinam, Latvia, and Australia. Dedicated in-house courses have been delivered in Latvia, Malaysia, and Greece.

The specific advantages of in-house courses for the companies involved have been

- More people were trained and ready to perform investigations, safety assessments, and analysis.
- Persons were trained in the same "vein" and were therefore able to think on the same wavelength.
- Persons from several different departments were trained together, which increased their individual knowledge and understanding of one another's roles within the company.
- Better capacity and more time to concentrate upon and discuss "regional" issues.
- Less costs per head for the company.
- Less down time for personnel due to no traveling away from home base being required.
- Increased flexibility for the company in case of production problems.

Why a stand-alone incident investigation course and not an integrated accident investigation course?

- Airlines have more incidents than accidents, and proper investigation of an incident can help to prevent an accident.
- Investigation training also requires consolidation, and working with other experienced investigators and advanced training is only of value after a suitable consolidation period.
- Cost, spread of costs, employees are only absent from duties for 1 week at a time instead of the usual 2 weeks or more.
- Specific learning—more concentration on the topics and disciplines that are relevant to airline operations.
- Learning over a longer period of time plus the opportunity to revise and update previous learning by doing the accident investigation training module 6 months to 1 year after the incident investigation module.

Why did ISIS set up this course, while there are already other courses available?

We wanted

- to see more emphasis placed on incident investigation.
- to see the inclusion of more relevant material and to give more hands on practice.
- this type of training to be available for all operators, large and small.
- investigators to be able to recognize the intrinsic value of other investigation reports.
- to create a course that is portable.

We believe that the delivery and teaching methods are just as important as the content of the course. Lecturers are trained in teaching skills in line with recognized university teacher training methods. The ISIS course is highly interactive, and the number of attendees is restricted to smaller groups in order to guarantee individual attention and feedback.

We place a very high value on incident investigations, not only from the cost aspect for smaller companies but for the added value to safety that will come with comprehensive, well-performed investigations and associated quality reports.

Investigation of an incident can provide

- "cheap" knowledge; try an accident.
- more information due to the availability of more data and witnesses who are still alive.
- a valuable precursor warning to an accident.

It is often the case that many serious incidents will have the same "footprint" as an accident but that a stroke of luck or good fortune breaks the error chain and an accident is avoided.

This was seen in the case of the Fokker 70 icing incident at Turin. Many accidents, on the other hand, would have or could have been serious incidents save for one factor such as in the case of Cali when the speed brakes remained extended when the B-757 attempted to clear the high terrain. If Cali had been a serious incident and not an accident, then the investigation of this event would have been vitally important. The interesting thing, however, from our point of view is that had Cali only been an incident, the investigation may have had to have been performed by the airline itself.

We believe that accidents such as the one at Cali and serious incidents such as the one at Turin clearly demonstrate the very fine line between incident and accident and clearly emphasize the importance of having well trained airline investigators.

Thank you. ◆

Links to the ANSV and the Flight Safety Foundation where the report may be found are
www.ansv.it/cgi-bin/eng/Final%20report%201-2-04PH-KZH.pdf.
www.flightsafety.org/ao/ao_jan-feb05.pdf (FSF Volume 31, No. 1).

National Transportation Safety Committee of Indonesia Presentation

By Tatang Kurniadi, Chairman, National Transportation Safety Committee, Indonesia
Presentation orally delivered by A. Toos Sanitoso

Good afternoon ladies and gentlemen.

First of all, I'd like to pass on a deep apology and regards from Tatang Kurniadi, our chairman of the Indonesia NTSC, for not being able to attend this meeting personally.

Mr. Tatang and some other NTSC team members are now somewhere around the Sulawesi Ocean conducting a very, very important mission: they are recovering the black boxes of an aircraft that was involved in an accident last January. I was lucky to be assigned here in presenting this material on be half of our NTSC chairman.

Let me also express our appreciation to the ISASI committee, to AAIB, and, of course, to the ISASI board. Let me also use this opportunity to introduce myself as a very new junior member of ISASI. My application was accepted last July, and I once again thank you very much for accepting me as a full ISASI member.

During the next 15 minutes, I'd like to present a little about the NTSC. My presentation will cover Indonesia NTSC background, organization, and challenges for the NTSC and give an overview of the current situation of the aviation industry in Indonesia.

- The longest distance of Indonesian airspace is equivalent to the distance between London to Teheran.
- Currently, we have 187 active airports in the country.
- We have 21 active domestic airlines, without taking into account air charter operators.
- The number of passengers has dramatically increased, from 10 million passengers back in 2000 to 30 million domestic passengers a year today, with the prediction of 70 million by year 2010.
- The international passenger number was 11 million, according to 2006 statistics.
- This increase in activities has resulted in very close to 1 million flights in 2006.
- According to ICAO observation, the overall volume has increased by about 300%.

In other words, we have been experiencing a growth of about 300% during the last 6 years.

The growth of aviation industries in Indonesia was not sufficiently followed by the growth of supporting infrastructure. This includes

- Regulatory: We are still facing problems in preparing a sufficient number of qualified inspectors.
- No-blame safety investigations: We are also facing problems due to a lack of full-time, qualified investigators.

Within the NTSC, 20 aviation investigators are mostly volunteers who come from various different institutions, including universities, the armed forces, airlines, and other organizations. They are supported by a numbers of administrative staff. The big advantage for the NTSC is that we have solid cooperation with the Institute Teknologi of Bandung, where metallurgical analysis and mechanical analysis normally take place. Having cooperation with the Indonesian aerospace facility has also been very useful for us.

We normally start conducting an investigation as soon as possible after an accident, following ICAO standards and recommended practices. We put all our efforts to accomplish the final report in a timely manner, in spite of all the handicaps we have.

The recent investigation of the accident involving our national flag carrier in Jogyakarta a couple months ago was a very good example of how everyone's safety concerns came together in a harmony of international collaboration and cooperation.

The NTSB, ATSB, and the Singapore AAIB spontaneously participated with the investigation team. The black boxes were sent to the ATSB facility in Canberra, Australia, for replay and analysis. The CVR malfunctioned so it was taken to the manufacturer's facility in Seattle, Washington, in the U.S., where the CVR points were reset and the reading data download took place. The CVR was transcribed in Canberra by NTSC investigators. We were internationally assisted in a very supportive collaboration. Once again, I'd like to express our appreciation to all of the accredited representatives, who represent NTSB America, ATSB Australia, and in particular Alan Stray, who put an enormous amount of effort in assisting us during the investigation and report preparation—which otherwise we would have not been able to finish and report our recommendations in a timely manner.

ICAO recently have sent a letter clarifying ICAO Annex 13, Standard 6.5, to make it clear that release means to make the report publicly available.

We face the following challenges as an organization:

- In line with the comment of the president of the Flight Safety Foundation, if I may quote one of his comments during the strategic summit on aviation in Indonesia: "Within Indonesia, structural reforms should be initiated to strengthen the DGCA and establish an independent and effective accident investigation body."
- We are expecting to see in the near future the NTSC become an independent body administratively as well as financially.
- We are also working on a transportation safety investigation act.
- We are addressing the recent ICAO audit findings, which will include revised policies and procedures.
- We are preparing the procedures and policies to monitor the

implementation of recommendations made by the NTSC.

- We are looking for a number of well-trained and qualified full-time investigators.
- We are hoping to have our own CVR/FDR laboratories, so we don't have to do it overseas.

We are facing these situations as challenges that we believe we will be able to solve nationally as well as internationally.

We strongly believe that aviation safety improvement will not only be a national issue, but also will more likely become our common goal as an international aviation community. So we, therefore, honestly invite every party in the world that could participate hand-in-hand with us as an aviation community in Indonesia to build a strong and solid international collaboration and walk and work together toward better and safer aviation industries throughout the world.

That concludes my presentation, and I would be happy to answer any questions you may have. Thank you very much for your attention. ◆

Going the Extra Mile*

By Donald F. Knutson (MO4529)

Donald Knutson*'s career has been focused entirely on aviation-related work. He is an experienced FAA-certificated A&P mechanic (with an IA), airplane and helicopter pilot, mechanical engineer, and aircraft accident investigator. He has conducted more than 175 comprehensive investigations throughout the world. Aviation is both his profession and hobby, where he enjoys flying and maintaining his own experimental aircraft. Don also develops and teaches accredited aircraft accident investigation courses to undergraduate and graduate engineering students as well as journeymen engineers.*

Introduction

Working as an air safety field investigator and engineer for Beech Aircraft (1990-1999) and an accident and wreckage reconstruction consultant (since 1999) has opened my eyes to how inaccurate and/or incomplete investigations can impact the entire aviation industry. One of the areas that has not changed much in the air safety world is the amount of attention dedicated to a high-visibility or "major" investigation versus a typical "field" investigation. Even though airline crashes receive more media coverage and typically result in a multitude of injuries/fatalities at once, the majority of investigations are related to general aviation.

To some extent, the limited efforts devoted to general aviation accidents are understandable due to the limited budgets of manufacturers and government agencies. However, we as investigators still can make substantial improvements to our methodologies without incurring substantial increases in cost. Inaccurate and/or incomplete probable causes litter the "field" investigation databases. This situation affects our ability to assist the aviation industry in making effective judgments to resolve immediate and long-term problems. This article will briefly discuss a "back-to-basics" approach to investigations. Then, some examples of actual "field" investigations are presented to show why this is so important.

Foundations of a proper investigation—defining the minimum criteria

Does a relatively simple accident change our approach to the investigation when compared to a complex accident? Theoretical answer: It shouldn't. Practical answer: It usually does. High visibility and liability typically drive the depth of an investigation, and it is human nature to "relax" when nobody gets hurt. We need to keep in mind that minor incidents can turn into major accidents; therefore, we should thoroughly document all events when possible. One way to achieve this is to maintain a consistent and comprehensive methodology for documenting both "accidents" and "incidents" (as defined by the NTSB). Empirical knowledge is one of our best friends. Obviously, engineers intend for aircraft system or component designs to be safe. Also, certification and regulations consider many possible failure scenarios that engineers attempt to design out of the equation. This usually, and fortunately, results in limited accidents; but this also means investigators end up with limited empirical data to compare with an aircraft accident. Inconsistent data and limited data result in lost opportunities to take advantage of empirical knowledge.

Complex investigations require a team with the appropriate expertise. As indicated in my introduction, general aviation may be neglected due to lack of resources. When comparing a Boeing 747 mid-air explosion with 500 fatalities versus a Cessna 152 stall/spin resulting in 2 fatalities, it doesn't take much thought to see which accident should get the most attention. Or does it? The money spent to conduct the investigation will differ, but the experts required to find the cause may not—pilot and mechanic experts, radar/flight data experts, structural and system engineers, meteorologists, metallurgists, etc., could all be needed for both accidents. Investigators sometimes wear several hats such as being the reconstructionist, metallurgist, and human factors expert—this can be a problem because it is rare for an "expert" to have enough background to properly cover all these areas. For example, in the consulting world it is common for a metallurgist to also be the accident reconstructionist. This approach may be successful in some cases, but we must remember that the accident reconstructionist is usually a generalist, compared with a metallurgist who is usually a specialist. Generalists, who include most field investigators, require a broad-based knowledge in the industry along with the ability to recognize what types of specialists are needed to support the investigation. It is not unusual to find specialists, who are not pilots or mechanics, analyze details involving flight and maintenance operations without actually having this experience. Likewise, it is typical for field investigators, who are not metallurgists or human factors experts, to analyze fatigue failures or cockpit resource management.

We normally have limited time and money to conduct our investigation. For instance, if aircraft wreckage is scattered along a major metropolitan highway and the investigation team is getting serious pressure by the local authorities to recover the wreckage ASAP, the investigation team needs to prioritize the most important parts to document and preserve. Another example is setting up a relatively inexpensive test to prove or disprove a theory, prior to deciding on a full-blown test program. This means an investigator must know how to think creatively and "outside the box" to solve problems practically. Typically, we become better at this concept as we gain investigation experience and work with experienced investigators on our team.

Even though investigators become savvier and more confident based upon their experience, we must guard against becoming overconfident or complacent. A fireman with 30 years' experience might investigate a house that burned down and determine that the fire started at the furnace. If his findings are based upon the fact that he has seen this happen 100 times during his career but no evidence exists to determine the origin of this particular

* Article accepted for presentation but not orally delivered due to exigent circumstances.

fire, then he has used flawed analysis. Investigators must base their conclusions on facts and scientific principles, not just experience. Remember this adage: "*Evidence is king*." We need to maintain the investigation's integrity by staying away from putting our "gut feelings" ahead of actual physical evidence. Investigators should be disciplined and patient about gathering all possible evidence and look past the perceived obvious, i.e., use in-depth analysis. Do not start forming any conclusions until the facts are completely documented and evaluated. Examples in this article will show how inaccurate or incomplete investigation findings result from selective gathering of evidence.

No matter how many investigations you conduct, there is always something new to experience. This means that there is always room for improvement when it comes to both our communication and learning process. The previously mentioned empirical knowledge can be enhanced when we share our investigation experiences and use them as lessons to be learned. Effective ways to do this include attending and presenting at seminars organized by the International Society of Air Safety investigators and general aviation air safety investigators.

Who's on the team?

Imagine a mechanic trying to fix an airplane without using the proper tools, or a pilot flying in unfamiliar airspace without using the proper aeronautical maps. This is similar to an investigator not being aware of all the expertise that is available and may be necessary for the investigation. We should develop a strong awareness of the following areas of expertise (I'm probably missing something):

- Air traffic control and radar
- Airport operation and design
- Biomechanics
- Certification and airworthiness
- Engineering (aerodynamics, safety, structural, systems, etc.)
- Fire and explosion
- Flight data and cockpit voice recording
- Human factors (machine-person-environment interface issues)
- Maintenance
- Materials (metal, composite, and plastic)
- Meteorology
- Pathology and toxicology
- Piloting (test, instruction, or general operation)
- Simulator and animation
- Sound spectrum analysis (tower recordings and CVR)
- Test and system modeling
- Tribology (lubrication, friction, and wear)
- Wreckage and accident reconstruction

As indicated before, we may possess knowledge in areas beyond our primary expertise, but we need to understand our limitations and know when to involve the appropriate generalists or specialists. Build a network of experts and learn as much as possible about what/how they can add to your investigation.

Concentrating on small pieces of evidence until understanding the big picture

When have you heard someone ask, "How do you take all those broken pieces and understand what happened?" The answer is, "One piece at a time." This seems so simple; yet our experience, knowledge, and ego can prompt us to cut corners or jump to conclusions. Sometimes we get away with this, but we are not exercising quality control no matter how we would like to justify it.

	Person (owner, operator, passengers, witnesses, etc.)	*Machine (aircraft, radar site, maintenance equipment, etc.)*	*Environment (weather, accident scene, work culture, etc.)*
Before			
During			
After			

Figure 1: Nine-box matrix.

Solve the following sentence: **KFDE W CWMDCWZZ XDZUDPDX FWM YZL MGVBNTVM, TED OTLZA MWG FD NFXTKM WN W YDPDX BUNOF.** First clue is **Z = *L***.

Tools needed to solve this puzzle are knowledge of the English language (reading, writing, and spelling), similar to understanding engineering and sciences. Also, knowledge of the American culture is required (e.g., sports, slangs, and humor), similar to understanding the various facets of aviation. We should logically start by replacing all the **Z**s with ***L***. Next, evaluate the small words to determine their vowels, knowing that one-letter words are either ***A*** or ***I***. Another helpful clue is that two words have the same suffix. Note that during this process we start by concentrating on the words in the sentence and not the entire sentence. Likewise, when we are documenting pieces of wreckage, our focus starts on each piece and not the entire wreckage. After we make some educated guesses on which letters can work, we start to string two or more words together. Then, we iterate the process until we see that the sentence makes sense. Likewise, as we accumulate our wreckage findings piece by piece, we theorize realistic possibilities based on the available evidence. Then, we compare relationships between two or more findings and iterate through logic and tests to find out whether we can connect the dots. Our goal is to eventually "visualize" the accident; in other words, establish the sequence of events leading to and including the accident.

An effective investigation tool is the "nine-box matrix" depicted in Figure 1. This tool helps us derive a comprehensive checklist in addition to the basic established report format. The nine-box matrix also prompts us to account for the small pieces of evidence before looking at the big picture and helps establish a game plan for further investigation needs. For example, questions involving the "Machine" should include radar and ground support equipment along with the aircraft. "Environment" involves the airport operations and company policies as well as the weather. Each box eventually evolves into a multitude of specific questions.

Scientific method

We want to minimize the influence of any bias or prejudice of the investigation team by evaluating a hypothesis or theory through accurate, reliable, consistent, and non-arbitrary representation of the investigative findings. The flow chart depicted in Figure 2 concisely shows the basic process. Integrating the nine-box matrix with this process will provide investigators with a comprehensive approach along with quality control of the investigative findings.

Art versus science

The old adage that "physics doesn't change" is alive and well. Mechanisms and structures have physical properties that "talk"

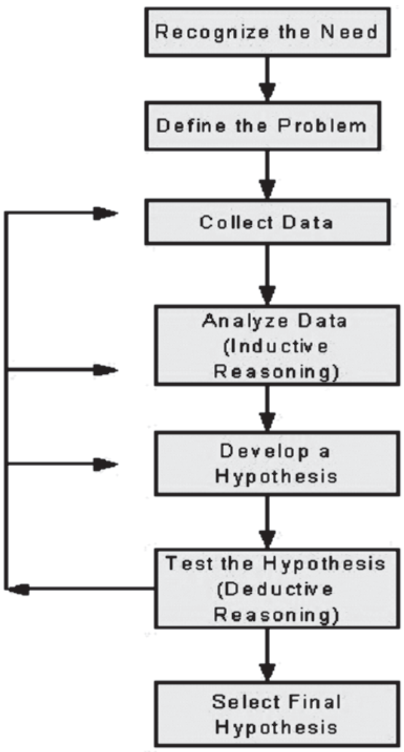


Figure 2: Basic scientific method flow chart.

to us. (No, I'm not eccentric!) Also, miniature pieces obey the physical laws of nature the same as big pieces, e.g., for every action there is an equal and opposite reaction. Physical properties of materials can be verified and quantified in many ways. We measure and describe the amount of damage or change in parts regarding their geometry, volume, direction, and orientation. One common method to visualize damage is by piecing wreckage together on a frame or during a wreckage layout. We try to distinguish impact versus pre-impact damage (or normal wear). This is typically the *scientific* part of wreckage reconstruction.

Specific details or *scientific* findings usually are what they are: Part A fracture profile fits together with part B fracture; radar data showed the aircraft flying at X ft and descending at Y ft per minute; autopsy revealed cause of death from blunt force trauma; metallurgical findings showed fatigue cracks and dissimilar metal corrosion; human factors studies show a person can optimally react to a specific emergency in Z seconds, etc. Our *artistic* side (skill acquired by a combination of experience, creativity, and imagination) comes into play when we need to globally consider evidence, then mix and match it with logical perception. This becomes even more necessary when conveniently related test or engineering data, proven empirical knowledge, or crash-recording devices (CVR, FDR, etc.) are unavailable.

To be creative and imaginative, we need to recognize our inherent biases such as preconceived notions based on our experience (or lack thereof) and have a willingness to consider the "absurd." For example, visualize a propeller-driven airplane flying level at cruise speed while crashing into gradually rising and densely forested terrain. The main wreckage comes to rest ~500 feet from the initial tree impact and sustains a post-impact fire. The propeller had separated from the engine and was found just downstream of the main wreckage. Study the three-bladed aluminum propeller damage depicted in Figure 3. Notice the pronounced aft curling of only one blade tip, with the other two blades exhibiting relatively simple bending. Also notice that two blades appear to be in a feathered position (~90° pitch angles from the plane of rotation), and the two non-curled blades are bent in opposite directions. Physics tells us that the curled blade tip did *not* impact a tree and wrap around a branch. In order for the blade curling to take place, the propeller needed to have been rotating under power (2,000-2,700 RPM) through a dense medium (cutting through trees), while systematically striking the trees with only one blade. Each strike of the blade tip incrementally twisted it toward low pitch until finally curling about 1½ times. Think about the odds of this happening. Now, think about what an investigator would possibly consider if the post-impact fire had consumed just the curled blade tip. This could easily create a false perception that the engine was not producing power during the impact sequence. The moral of this example is keeping an open mind along with being thorough during the wreckage examination.

Figure 3: Propeller blade curl.

"Proof is in the pudding"

Now let's look at a few examples of how failing to apply the aforementioned investigation principles can result in incomplete or inaccurate analysis. Please note that I've briefly summarized two

Cessna models *not* with the intention of picking on Cessna aircraft. Correspondingly, I've chosen two NTSB investigations *not* to single out the NTSB. These case studies just happen to demonstrate investigative concepts that are easy to follow in a concise format.

Case study #1—Cessna 525A (CJ2) runway overrun, NTSB Report No. NYC03FA002:

The pilot landed the airplane too fast down the runway and failed to properly abort and execute a go-around. The airplane rolled off the end of the runway and impacted upward-sloping terrain while trying to become airborne. Both front-seat (cockpit) occupants sustained serious facial injuries, and both rear-cabin occupants were uninjured. The NTSB probable cause was "the pilot's improper decision to land with excessive speed, and his delayed decision to perform an aborted landing, both of which resulted in a runway overrun. A factor was the tail wind." This case study discusses the implications of the field investigation falling short of looking into what caused the cockpit injuries.

Both front-seat occupants sustained serious head impact injuries, which rendered the pilot unconscious as well as required the right front-seat passenger to have facial reconstruction. NTSB investigative findings showed that the left front-seat inertia reel passed its acceptance test, and the right front-seat inertia reel did not. Both acceptance tests resulted in the reels locking at 1.5 G, yet both shoulder harness assemblies did not appear to adequately restrain the occupants.

Examination/comparison of the subject Cessna CJ2 wreckage and an exemplar CJ2 have revealed that significant crushing of the fuselage nose section absorbed most of the impact energy and prevented the occupants from sustaining fatal deceleration/G-loads. Per the wreckage recovery crew, both front-seat assemblies had remained attached to the cockpit floor structure, i.e., relative displacement of the floor and seat assemblies were similar. Both control column assemblies remained intact and were displaced aft and upward in concert with both front seat-tracks, i.e., relative displacement of the front-seat occupants in relation with their control wheels. The right side of fuselage nose section exhibited a 44-45° crush line, and the left side exhibited a 35-36° crush line, which are consistent with the occupants flailing primarily forward and slightly to the right during the ground impact. Biomechanics analysis and evaluation of the overall cockpit deformation revealed that the facial injuries sustained by both front-seat occupants were caused from striking their respective control wheel. Vertical G-loads sustained during the terrain impact did not result in serious back injuries.

During the exemplar CJ2 inspection, the accident pilot (6'3", 170 lbs) was positioned in the left front seat with the five-point restraint system properly adjusted against his body. The pilot positioned his seat the same as when he is flying—adjusted to its most aft-locked position on the seat tracks, with the seat back at its most upright setting. The pilot adjusted his seat height via the sight gage mounted above the center of the glare shield. The shoulder harness belts were jerked forward and locked at the least possible inertia reel payout length. Shoulder harness belt tension was maintained. The pilot's left hand held the control column full aft with the control wheel rotated approximately 45° from a neutral setting, and the pilot's right hand was on the engine controls in the full power position (normal positions when a pilot is trying to liftoff and avoid impact with terrain). The pilot was then able to droop his shoulders and thorax downward (simulating vertical G-loads), without exerting any excessive pull force on the seat back, and lean forward enough to make facial contact with the control wheel. Two other persons (5'11", 175 lbs, and 6'0", 230 lbs) duplicated the seated test without changing the seat and control positions—both were able to droop their shoulders and thorax downward, and lean forward enough to make facial contact with the control wheel.

In addition, static pull tests on the ends of both shoulder harness belts were conducted. The shoulder harness belts were jerked forward and held to the least possible inertia reel payout length. The straps were then pulled forward at 20, 40, 60, 80, and 100 lbs. During each pull force, the elastic displacement of the upper portion of the seat back was measured. The forward seat back deflections (i.e., roughly corresponding to the forward motion of the pilot's upper torso) were 1/8, 5/8, 7/8, 1-1/8, and 1-5/16 inches, respectively; therefore, the pilot's cheek would translate forward at least another one inch into the control wheel with a shoulder harness tension force of 100 lbs.

Per FAR 23.561, the pilot should be given "every reasonable chance of escaping serious injury" during emergency landing conditions, with static inertia loads of 9.0 G forward. Also, FAR 23.562 requires the seat assembly to withstand peak dynamic loads of about 26 G forward (with 10° yaw) and 19 G downward (with 30° pitch up). This means that the pilot's upper torso would easily exert more than 100 lbs of forward pull force on the shoulder harness and more than 1-5/8 inches of seat back deflection during a dynamic crash condition.

While researching cockpit seat certification, it's interesting to note that crash sled tests were conducted with the seat and restraint assembly, an instrumented crash dummy, and a mock instrument panel and glare shield. A control column and wheel assembly were not included because head impact with the glare shield, not the control wheel, was assumed. The occupant's chest is expected to impact the control wheel, and the crash dummy is not designed to simulate the drooping of the shoulders and thorax during the impact tests. Airplanes have to deal with both the horizontal and vertical components during an emergency landing. The normal response for a pilot preparing to contact terrain would be to pull the nose up to minimize a direct head-on collision; therefore, facial impact with the control wheel should be a practical consideration during the crash sled tests.

Case study #2—Cessna 152 stall/spin, NTSB Report No. NYC05FA069:

An instructor and student took off in good weather with full fuel. They apparently were practicing a stall/spin from approximately 3,000 feet AGL. Available radar data and witness statements indicated that the airplane maintained its descent until ground impact. Witnesses saw the airplane "spiraling" in a nose-down attitude but could not determine its direction of rotation. Both occupants sustained fatal injuries during terrain impact. Wreckage remained together and was resting upright, with no debris path or horizontal ground scars.Pertinent NTSB wreckage inspection findings included the following:

- No evidence of fire or smoke in cockpit
- Cockpit instrumentation and flight controls destroyed
- Engine mixture control (vernier type) pulled out and bent downward (?)
- Engine throttle control full in/forward (?)

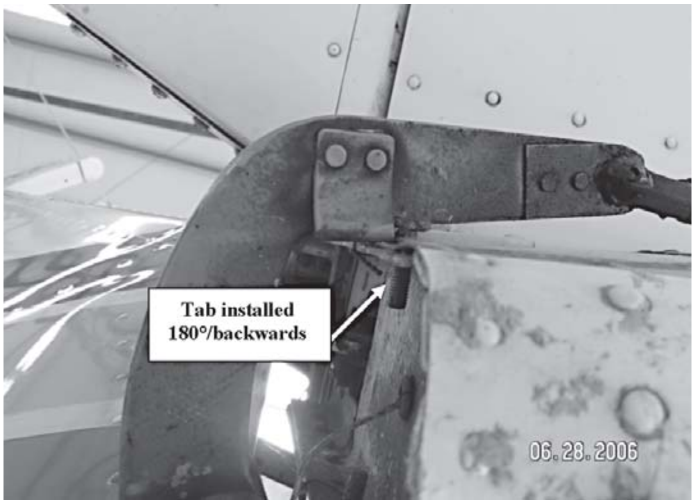


Figure 4: Subject Cessna 152 rudder stop over-travel condition—view of right stop plate snagged on its stop bolt head.

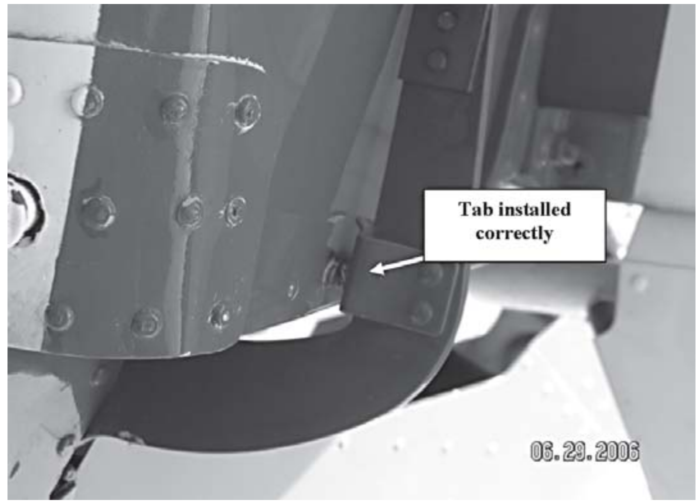


Figure 5: Exemplar Cessna 152 rudder stop installation—view of left stop plate against its stop bolt, i.e., full right rudder deflection.

- Propeller blades did not exhibit twisting or chordwise scratches, i.e., no evidence of engine torque during ground impact
- Flaps up/retracted
- Rudder exhibited full left deflection with its rudder horn stop plate over-traveled and snagged under the stop bolt head (refer to Figures 4 and 5)
- Rudder stop plates (riveted on rudder horn) were installed backwards
- Flight control continuity was established
- No structural anomalies were found (e.g., fatigue failures)

Maintenance records indicated that the airframe had at least 10,700 hours total time, and no major repairs or alterations were performed on the rudder control system. Cessna Service Bulletin SEB01-01 was issued about 3½ years prior to this accident, which provided an enhanced rudder stop installation designed to assist in preventing the possibility of the rudder overriding the stop bolt during a full left or right deflection. This service bulletin was not complied with. Records also indicate that the rudder stop plates were not replaced or repaired.

Research of other Cessna 150/152 stall/spin accidents revealed what appeared to be a closely related accident in Lac Saint-Francois, Quebec, Canada, on July 18, 1998 (Transportation Safety Board of Canada Report No. A98Q0114). The NTSB probable cause was an "improperly installed rudder bumper, which resulted in a rudder jam during spin training and subsequent uncontrolled descent into terrain. A factor was the operator did not comply with the service bulletin." Furthermore, the NTSB issued a safety recommendation (A-07-33) to the FAA on March 21, 2007, requiring an airworthiness directive to comply with Cessna Service Bulletin SEB01-01.

Beyond the NTSB investigation, further findings came to light that do not support the NTSB probable cause, nor the safety recommendation:

- Contact areas between the rudder stop plates and their respective bolt heads exhibited wear patterns consistent with properly rigged rudder travel (unlike reported findings from the Lac Saint-Francois accident).
- Elastic properties of rudder assembly only allowed a forced over-travel condition in aft direction (i.e., cannot be pulled via cables/pilot input).
- Extreme rudder pedal push tests (just short of damaging pedals) on exemplar/serviceable Cessna 150/152 models would not create a rudder over-travel condition, regardless of how the rudder stop plate was installed (tab forward versus aft).
- Rudder cable pull tests (>350 lbs tension on either right or left control cable) on both an exemplar tail section assembly mock-up/test fixture as well as the subject damaged tail section assembly would not create a rudder over-travel condition.In essence, a "cut-and-paste" analysis from the Lac Saint-Francois accident was applied to the subject accident without being substantiated. The above-noted clearly shows that the rudder over-travel occurred during terrain impact and that something else was involved with the pilots not regaining control of the airplane, e.g., improper engine control inputs and performing the stall/spin with inadequate altitude over terrain.

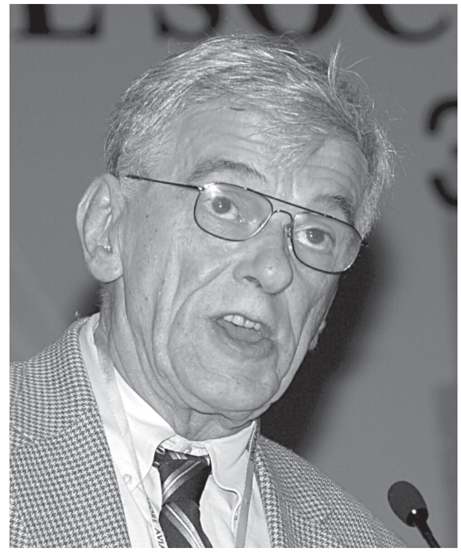
Summary

So, practically speaking, what can we do to reduce inaccurate and incomplete investigation findings?

1. Establish the criteria that *everyone* needs to buy into a sound philosophy.
2. Base the facts on scientific principles, not just experience.
3. Always look past the perceived obvious, and even the "absurd."
4. Completely document and evaluate facts before forming any conclusions.
5. No "cut-and-paste" analyses allowed—confirm other investigation findings.
6. Break investigators into generalists and specialists, and provide appropriate training where it's needed to help them understand *how* to support each other.
7. Foster teamwork and require generalists to work with specialists.
8. Share knowledge and work closely with *all* parties to the investigation.
9. Maintain a comprehensive database and thoroughly document *both* major and minor events when possible. ◆

ISASI 2007 Pictorial Review

Photos by Esperison Martinez




Guest-of-Honour


Guest-of-Honour


Guest-of-Honour
MR RAYMOND LIM
Minister for Transport and
Second Minister for Foreign Affairs


Hosted by: Air Accident


Second Minister for Foreign Affairs


Second Minister for


Accident


MR RAYMOND LIM
Minister for Foreign Affairs


SAA
Meet With Media & Families (2/2)
Use media as a tool
Timely and accurate information
Image deliver
Spokesperson selection
Coordinate info (A joint info center) before released
Web pages