ISASI Proceedings

VOLUME 7, NUMBER 1

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 34th Annual International Seminar held in Washington, D.C., 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 "From the Wright Brothers to the Right Solutions—100 Years of Identifying Safety Deficiencies and Solutions."

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* 2002 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 34th Annual International Seminar

'From the Wright Brothers to the Right Solutions— 100 Years of Identifying Safety Deficiencies and Solutions'

August 26–28, 2003 • Washington, D.C., USA

ISASI Information

OFFICERS

President, Frank Del Gandio
Executive Advisor, Richard Stone
Vice-President, Ron Schleede
Secretary, Keith Hagy
Treasurer, Tom McCarthy

COUNCILLORS

United States, Curt Lewis
International, Caj Frostell
Australian, Lindsay Naylor
Canadian, Barbara Dunn
European, Max Saint-Germain
New Zealand, Ron Chippindale

UNITED STATES REGIONAL CHAPTER PRESIDENTS

Arizona, Bill Waldock
Mid-Atlantic, Ron Schleede
Alaska, Craig Beldsoe
Northeast, David W. Graham
Dallas-Ft. Worth, Curt Lewis
Pacific Northwest, Kevin Darcy
Florida, Ben Coleman
Rocky Mountain, Richard L. Perry
Great Lakes, Rodney Schaeffer
San Francisco, Peter Axelrod
Southeastern, Inactive

NATIONAL AND REGIONAL SOCIETY PRESIDENTS

Australian, Kenneth S. Lewis
SESA-France Chap., Vincent Fave
Canadian, Barbara M. Dunn
New Zealand, Ron Chippindale
European, Ken Smart
United States, Curt Lewis
Russian, V. Venkov
Latin American, Marco A. de M. Rocha

CORPORATE MEMBERS

Accident Investigation Board, Finland
Accident Investigation Board/Norway
ACE USA Aerospace
Aeronautical & Maritime Research Laboratory
Air Accident Investigation Bureau of Singapore
Air Accident Investigation Unit—Ireland
Air Accidents Investigation Branch—U.K.
Air Canada
Air Canada Pilots Association
Air Line Pilots Association
Air New Zealand, Ltd.
Airbus S.A.S.
Airclaims Limited
Airservices Australia
AirTran Airways
Alaska Airlines
All Nippon Airways Company Limited
Allied Pilots Association
American Airlines
American Eagle Airlines
American Underwater Search & Survey, Ltd.
ASPA Mexico
Association of Professional Flight Attendants
Atlantic Southeast Airlines—Delta Connection
Austin Digital, Inc.
Australian Transport Safety Bureau
Avianca & SAM Airlines
Aviation Safety Council
Avions de Transport Regional (ATR)
Belgian Air Force, Air Staff Brussels, VSF
Bell Helicopter Textron, Inc.
Board of Accident Investigation—Sweden
Boeing Commercial Airplanes
Bombardier Aerospace
Bombardier Aerospace Regional Aircraft/ de Havilland, Inc.
Cathay Pacific Airways Limited
Cavok, International, Inc.
Civil Aviation Safety Authority, Australia
COMAIR, Inc.
Continental Airlines
Continental Express
DCI/Branch AIRCO
Delta Air Lines, Inc.
Directorate of Flight Safety (Canadian Forces)
Directorate of Flying Safety—ADF
Dutch Transport Safety Board
EMBRAER—Empresa Brasileira de Aeronautica S.A.
Embry-Riddle Aeronautical University
Emirates Airline
Era Aviation, Inc.
EVA Airways Corporation
Exponent, Inc.
Federal Aviation Administration
FedEx Pilots Association
Finnair Oyj
Flightscape, Inc.
Flight Safety Foundation—Taiwan
FTI Consulting, Inc.
GE Aircraft Engines
Global Aerospace, Inc.
Hall & Associates LLC
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
Japan Air System Co., Ltd.
Japanese Aviation Insurance Pool
JetBlue Airways
KLM Royal Dutch Airlines
L-3 Communications Aviation Recorders
Learjet, Inc.
Lufthansa German Airlines
Middle East Airlines
National Aeronautics and Space Administration
National Air Traffic Controllers Assn.
National Business Aviation Association
National Transportation Safety Board
NAV Canada
Northwest Airlines
Phoenix International, Inc.
Pratt & Whitney
Qantas Airways Limited
Republic of Singapore Air Force
Rolls- Royce Corporation
Royal New Zealand Air Force
Sandia National Laboratories
Saudi Arabian Airlines
Scandinavian Airlines
School of Aviation Safety and Management, ROC Air Force Academy
SICOFAA/SPS
Sikorsky Aircraft Corporation
Singapore Airlines, Ltd.
Smith, Anderson, Blount, Dorsett, Mitchell & Jernigan, L.L.P.
SNECMA Moteurs
South African Airways
Southern California Safety Institute
Southwest Airlines Company
SystemWare, Inc.
TAM Brazilian Airlines
The Ministry of Land, Infrastructure, & Transport, AAIC, Japan
Transport Canada Aviation
Transportation Safety Board of Canada
U.K.-Civil Aviation Authority
University of NSW AVIATION
University of Southern California
Volvo Aero Corporation
WestJet ◆

Table of Contents

SESSION I

SESSION II

SESSION III

SESSION IV

SESSION V

SESSION VI

PREFACE
100 Years of Powered Flight

By Frank Del Gandio, President

(President Del Gandio's welcoming remarks to ISASI 2003 attendees in Washington, D.C.—Editor)

In a few months we will celebrate 100 years of powered light. Orville and Wilbur spent many years experimenting before they achieved their goal of powered flight. The preponderance of their work was with gliders and wind tunnels where they constantly improved the wings and structure. Finally, on Dec. 17, 1903, after numerous failures, they achieved their dream. The first flight lasted 12 seconds and traveled 121 feet over the sand dunes. Before the day was over they accomplished four flights, and the last flight was 59 seconds and traveled 852 feet. But as we celebrate 100 years of powered flight on December 17, we also celebrate 100 years of accident investigation. The fourth flight crashed on landing, which resulted in an investigation by the Wright brothers as to why the aircraft crashed.

In reality, the first aircraft accident happened on Dec. 14, 1903, three days before the historic first flight. On December 14, Wilbur tried to coax the Flyer into the air. He almost made it but was surprised by the sensitivity of the aircraft's elevator. The aircraft nosed up, stalled, and dove into the dunes. Wilbur's reaction, "There is no question of final success." It took three days to repair the Flyer in preparation for the historic first flight.

Aviation has progressed and expanded faster than any other industry. Normally a statement such as "This has not happened by accident" would be appropriate. However, I believe I can make the statement that our industry has "grown by accident" or, more appropriately, by "accident investigation."

The phenomenal improvement in safety, I believe, has been the direct result of two things: The first is that people with ideas or dreams like the Wright brothers and the many who followed like Jerry Lederer, who is here with us today. They are the stars and the legends of our profession. The second is a result of accident investigation and our constant quest to improve the man, the machine, and the environment to prevent further reoccurrence.

The people with ideas and dreams usually receive the accolades because their goal is to attain a new altitude, a new speed, to carry more passengers, or something to surpass a previous goal. These folks have been very important and influential in fostering and improving our industry. Another group would be the military and space pioneers who have improved our airspace system and greatly improved aviation safety and reliability, because of their accomplishments in the military use of air power and space explorations.

The group that we are most concerned about is the unsung heroes of accident investigation and many of them are here today. When an air disaster occurs, it brings darkness to our industry, but the stars of accident investigation shine bright as we accomplish our task of determining what caused the accident and initiate change to prevent reoccurrence. Thousands of changes have been developed and incorporated because of the work of investigators following air disasters and non-disastrous accidents and incidents.

E. MARTINEZ

We, as accident investigators, are an integral part of the aviation community. We are a part of the main group because we participate in the airspace system by flying, maintaining, training, dispatching, etc. When a disaster happens, it affects everyone in the industry, and we—as investigators—are eager to help solve the mystery. Traditionally, we don't get much notoriety or accolades. But we don't need it. We get our satisfaction from accomplishments that enhance the safety and efficiency of our industry.

Our profession is a classic example of intrinsic rewards. We as aircraft accident investigators are ordinary people accomplishing extraordinary things. As we meet here over the next three days, we will do what we as investigators do best. We will learn from one another.

The real hope is that at the 150th anniversary of the first flight, people will speak of the enormous gains made since the centennial celebration. I hope that safety continues to improve at such a pace that today's safety levels will seem outlandish in 50 years or sooner. A related hope and real possibility is that a few folks sitting right here today will be recognized in 50 years as having driven those next great leaps in safety because of your ideas, your dreams, or your investigative skills. ◆

Caj Frostell: 2003 Lederer Award Winner

By Esperison Martinez, Editor

The Jerome F. Lederer Award is conferred for outstanding lifetime contributions in the field of aircraft accident investigation and prevention. The award was created by ISASI to honor Jerry Lederer, a leader in the world of aviation safety since its infancy. A lifelong friend of Charles Lindbergh, Lederer was the first director of the Bureau of Air Safety in the Civil Aeronautics Board, established the Flight Safety Foundation, and organized the first flight safety office for NASA. At 101 years old, he was on hand to present the award to Caj Frostell (MO3596), recipient of the 2003 Award.

Awarded annually by the International Society of Air Safety Investigators (ISASI), the award recognizes achievement of the Society's objectives and technical excellence of the recipient. The presentation is the highlight of the ISASI 2003 seminar awards. In introducing the winner to the audience, ISASI President Frank Del Gandio said, "The Jerry Lederer Award is the most prestigious award you can get in accident investigation, the highest award you can get from ISASI. Caj stands out as a beacon of dedication, objectivity, professionalism, and leadership among the world's experts in aircraft accident investigation. Further, he can be justly called the creator of the aviation accident investigation system in his native Finland." He began his civil aviation career at the Finnish Civil Aviation Authority (CAA) as an airworthiness inspector. Gradually he participated in more accident investigations and began acting as chief of the accident investigation section in 1972. During the 70s, he investigated some 300 aviation accidents.

In his current position with ICAO as chief, Accident Investigation and Prevention Section (AIG), Caj plays a major role in the international efforts to promote aviation safety. On the job he is responsible for Annex 13, the bible of the world's investigators, as well as other major issues and publications. He worked on AIG 92 and was responsible for the success of the recent AIG 99 meeting, both of which resulted in major revisions to Annex 13. He is currently deeply involved in the overhaul and rewriting of the ICAO accident investigation manual.

"All who work with him consider Caj a superb asset to the organization and to the world of aviation safety. Because of the international role he plays, he must remain independent, yet he displays a talent for fairness that continues to reflect his commitment to aircraft accident investigation and prevention. His assignments require every ounce of diplomacy he can muster to bring about successful conclusions, often under extremely tense situations," Del Gandio told the audience.

He added, "In his position in ICAO he is good friend and supporter of ISASI where he serves as its International Councillor. He is able to travel the world and spread the word of aviation safety, especially in those remote areas that truly need it. He has been a major contributor to ISASI's Reachout seminars, participating in at least five (Prague, Beirut, New Delhi, Dar-es-Salaam, and San Jose). Further, he is a welcome source for ISASI members giving papers, readily providing needed background information and materials on various ICAO subjects. ISASI is indeed blessed to have such an outstanding individual in its ranks. We are lucky to have the support of a person of such dedication, energy, and talent. Caj Frostell is uniquely qualified to receive the honor of being named the 2003 Jerry Lederer Award winner."


E. MARTINEZ

Jerry Lederer, center, makes a few comments after presenting the coveted Jerome Lederer Award to Caj Frostell, right. Looking on is ISASI President Frank Del Gandio.

After the acceptance ceremony, Caj addressed the audience. He said, "I am overwhelmed. This is a great surprise and a great honor. Thank you very much, Jerry."

In a switch of roles, he praised the award's namesake: "In 1999, Jerry Lederer received ICAO's highest award, the Edward Warner Award. The president of the ICAO Council, Dr. Assad Kotaite, was delighted to personally bestow the Edward Warner Award on Jerry, whose acceptance speech was profound, significant, and embedded with excellent humor. It was the best acceptance speech that I have heard in my 23 years with ICAO.

"Behind the scene, in the ICAO selection process for the award, I had the opportunity to read numerous articles and publications written by Jerry, much of these works were from the 1930s. My task was to prepare a 1.5-page justification summary. It was fascinating reading. At this seminar we have talked about the need for change and reform. But Jerry's articles have transcended time; they are as valid and relevant today as they were in the 1930s. They are true proof of an aviation safety prophet."

He then turned to the present: "I wish to thank Frank Del Gandio for the excellent way he is leading ISASI. I appreciated very much his opening of this seminar and the introduction of numerous accident investigation agencies as an indication of the international forum that ISASI represents.

"The ISASI Reachout seminars are close to my heart. I wish to thank Jim Stewart, the chairman of the Reachout Committee, for his excellent work, and I wish to thank Ladi Mika from the Czech Republic as the host of the first ISASI Reachout seminar. Jim and Ladi could well be called the fathers of 'Reachout.' I also wish to thank the corporate sponsors whose financial support is essential for us to be able to carry out the Reachout program.

"This is not only an honor for me, it is also an honor for my country Finland, a small country with five million people. We had two other participants from Finland at this seminar. I wish to acknowledge Capt. Pekka Kärmeniemi, safety manager with Finnair, and Lieutenant Colonel Jaakko Saatsi, the chief investigator in the Finnish Air Force. I am grateful to the Finnish Air Force for my first exposure to aviation, officer school, and flight training some 38 years ago. And I admit that flight safety and accident investigation was not in my thought process at that time. Simply stated, I was fascinated by the opportunity to fly an airplane.

"I also wish to thank Mr. Olof Fritsch, who hired me to ICAO 23 years ago. Many of you remember Olof as a former president of ISASI some 10-12 years ago. I also wish to acknowledge Ron Chippindale, whom I worked with for 2-3 months in 1986-1987 on the Samora Machel accident, a TU-134 accident just inside South Africa in which the president of Mozambique was fatally injured. Ron and I were assisting the accredited representative of Mozambique. The 3 months with Ron in Mozambique set the stage for a lifelong friendship.

"The aviation safety and accident investigation training institutes are also close to my heart, and I have been involved with several of them. Many of these training institutes are also ISASI corporate members. I wish to acknowledge and thank the University of Southern California and Mike Barr. May I ask Mr. Chan Wing Keong, the director of the AAIB in Singapore, to convey my thanks to the Singapore Aviation Academy for involving me in their accident investigation courses. And last but not least, I wish to thank the Southern California Safety Institute, Marlene Foulk, Gary Morphew, John Purvis, and Ron Schleede for involving me in their programs in the USA and the new courses in Prague, the Czech Republic.

"I apologize that time does not permit me to mention all numerous friends in the audience. I wish to thank you very much. May God bless you all, and may God bless Jerry Lederer, in particular. Thank you." ◆

Past Lederer Award winners

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

SESSION I

Human Spirit and Accomplishment Are Unlimited

By Ellen G. Engleman, Chairman, National Transportation Safety Board, Keynote Speaker

It is a privilege to serve as the 10th chairman of the National Transportation Safety Board. I follow in the footsteps of dedicated and gifted professionals and enjoy the unique opportunity to work with an amazing team of fellow Board Members and staff. On behalf of Vice-Chairman Rosenker, Members Goglia, Healing, and Carmody, as well as the 429 family members of the NTSB team, it is an honor to talk with you this morning.

Thanks to Frank Del Gandio, Ron Schleede, Nora Marshall, and Vicky Anderson and the ISASI membership for inviting me to join you this morning.

Much is to be celebrated with the centennial year of flight. As we look back in amazement at the last 100 years, from a wobbly flight of 12 seconds that went 121 feet at a height of about 10 feet to the development of an international airline industry that had more than 3 trillion miles of passenger flight in the year 2000, human spirit and accomplishment are unlimited.

As the Wright brothers worked toward their goal of human flight, they were meticulous in their experiments and adhered to the best scientific principles. As a result of analyzing their own glider experiments, they began to question some of the commonly accepted scientific data. They approached each problem methodically, keeping meticulous notes on the variations and results of each test. They would allow no guesswork, no hunt and peck—an approach to problem solving that was standard to the world of the 19th century.

The qualities that made the Wright brothers a success are still enormously important in aviation today. International sharing of information, the use of scientific testing to support hypotheses, questioning commonly held beliefs, and a desire to cut costs are all principles that we adhere to today when we conduct accident investigations.

The first official investigation of an aviation accident occurred five years after the Wright brother's historic flight and was due to the death of Lt. Thomas Selridge at Fort Meyer, Va., in 1908. Unfortunately other accidents would follow, and with each investigation changes were made to both improve aviation safety and the accident investigation process. The independent NTSB is one of the results of this.

We may not label the Wright brothers and other early pioneers as accident investigators, but clearly their approach to aviation is no different than our modern approach to accident investigation. The early pioneers had many more mishaps and accidents to learn from than we do today, but all of their improvements were a result of meticulous investigation into the problems of flight and a willingness to question commonly accepted theories and practices. As you all know, the NTSB does not have regulatory authority. Our power lies solely in our credibility. I have stated and will continue to say that the NTSB's credibility is based on our use of fact, science, and data, NOT supposition, guess, or desire in making our determinations of probable cause as well as issuing our safety recommendations. It is this strict discipline that gives the NTSB its worldwide credibility for unbiased, fact-based assessments and allows us to go forth and issue the significant safety recommendations that we send to industry, to the 50 states, and to other federal agencies and the DOT, including the FAA.

Constant review of data from accidents and normal operations, a curiosity to explain what happened when something goes wrong, and a willingness to question accepted theories and practices will yield new safety knowledge from fuel tank inerting and rudder redesign.

As we review the past and look to the next hundred years of flight, one constant remains the same, however, and must remain the same—the issue of safety. I do not believe that there is or can be a question of choice between safety OR security. In a post 9/11 world, we must find a way to accomplish both tasks without jeopardizing or negatively impacting the other. It must be safety AND security. There is a balance that will be achieved and must be achieved in order for peace and prosperity to continue. Let us remember that economic strength is one of the greatest weapons against terrorism.

The direct impact of the airline industry on gross domestic product in the United States is $306 billion. Internationally, the revenues of the top 150 airlines groups are estimated $300 billion, and we haven't even included the impact of related industries such as the travel and hospitality industries. Therefore it is critical that all partners in this industry, manufacturers, management, maintenance, the pilots, the flight attendants, the airports—internationally and nationally—work together to get this industry back in the sky. Our ultimate mission is to ensure public confidence in the national and international transportation system. As you know, the role of the NTSB is unique—I have had more than one person tell me that while they were delighted to meet me the first time, they hoped to never have to meet me again. I understand.

It's sometimes hard to determine how to frame one's words and thoughts when everything you say is based on the fact that an accident occurred and that lives were lost. But it is in tribute to them that the work of the NTSB is focused—that out of tragedy may come the promise of a safer future. May we learn in order to protect.

The NTSB is responsible, consistent with the U.S. Department of State requirements, to fulfill the obligations of the United States presented in Annex 13 to the Chicago Convention on International Civil Aviation. This means that for an accident or incident in a foreign state involving civil aircraft of a U.S. operator or of U.S. registry, manufacture, or design, while the State of occurrence is responsible for the investigation, the U.S. government participates in these investigations through an NTSB-appointed and accredited representative and a team of technical advisors named by the NTSB. The United States is also responsible to transmit information to maintain continued airworthiness and the safe operation of aircraft. Thus our role is to appropriately participate in foreign investigations and maintain the health of the U.S.-manufactured fleet.

As you know, the NTSB is a fiercely independent agency that must remain so in order to accomplish our mission of determining the probable cause irrespective of fault. Once that probable cause is determined, we issue our recommendations. W have issued more than 12,000 with 80+ percent acceptance rate; and while that is good on its face, when I came to this office in March we had 1,025 open recommendations.

Open recommendations mean that the safety loop is not closed. Open recommendations mean that our job is not done. The risks that have been identified still remain and action is yet to be completed. So a key aspect of my tenure at the Board will be to clean up the record of outstanding recommendations, and we are focused in each mode, with the states and with industry to accomplish this task. I fiercely believe that the NTSB's independence should not be interpreted as adversarial. We must be partners in achieving safety, our goals, our mission, and our dedication to protecting lives must be on parallel if not overlapping paths. Here are areas of interest to us as we continue these endeavors:

Runway incursions. We can't afford to wait for the perfect high-tech solution and must find and implement low-tech alternatives or phased-in approaches, focusing on the dozen or so of the airports with the highest risk. In the United States, the runway status lighting system to be installed at Dallas Fort Worth and the use of 24-hour runway guard lights at Las Vegas will hopefully provide immediate improvements and support a multilayered approach to safety. But as the tragedy in Taipei, Taiwan, on Oct. 31, 2000, and the accident in Milan, Italy, on Oct. 8, 2001, illustrated, the issue is not yet resolved.

Center Wing Fuel Tanks. The FAA must complete a rulemaking to prevent operators from flying transport-category aircraft with explosive fuel-air mixtures in fuel tanks. The FAA is currently working with Boeing to test a fuel tank inerting system designed to prevent fuel tank explosions, they have not set a deadline to certify the system. Sooner is better than later. We cannot forget the tragedy that occurred on March 3, 2001, in Bangkok, Thailand, with the center fuel tank explosion that occurred at the gate.

Icing. Icing is a continued serious problem. A thorough certification test program, including application of revised standards to airplanes currently certificated for flight in icing conditions, is merited. The NTSB recommends that the FAA ensure manufactures of turbine-engine aircraft clarify minimum safe operating speeds in both icing and non-icing conditions and that carriers publish the information in pilot training and operating manuals.

Human Fatigue. Operating any vehicle or vessel without adequate rest, in any mode of transportation, is dangerous. The laws, rules, and regulations governing this aspect of transportation safety are archaic. I hope that all modes will soon respond to this issue as illustrated the new hours of service rules recently completed by the Federal Motor Carrier Safety Administration.

As you know, recommendations that we have made to the FAA often affect the international community through standards and certification issues and can also have results that return. Last year an NTSB team assisted our colleagues in Germany with the investigations of a fatal midair collision between a Boeing 757 cargo flight and a Tupolev passenger airliner. Our investigations assisted the German authorities with examination of operational factors, air traffic control, traffic collision avoidance systems, and aircraft structures. This led to the Board's safety recommendation to the FAA to address potential safety issues in U.S. systems, and I am glad to note that the FAA has recently responded positively to the recommendation and is working to make improvements in the U.S. system.

We believe that safety is job one and will continue to work through the remaining open recommendations with each of the other DOT modes in this SWAT team approach to address all open NTSB recommendations and will continue to dog each and every one of them. Since March 24 we have closed 68 recommendations, and I want an upward slope on that graph.

Uniquely both FAA Administrator Blakey and I have both issued and received recommendations from the NTSB. We have the experience of shared moccasins, and I truly believe that under her management and the leadership of Transportation Secretary Mineta that the open NTSB recommendations in all modes will be addressed. Of course, as you know, the NTSB is not a regulator, we are a bully pulpit but I am holding daily services.

Performance and funding issues are also internal to the NTSB. We cannot make recommendations if we do not follow our own advice. As "CEO" of the Board, I am leading the staff in focusing on increased performance, fiscal management, and quality of product delivery. The Safety Board must improve our ability to deliver an accident investigation report that is soundly developed based on science, data, and facts and unswayed by guesswork, supposition, or desire. Our internal procedures are being reviewed to determine if there is a way to increase the timeliness of the reports. Yes, they must be thoroughly developed, and cannot be hurried for false or artificial deadlines. That being said, I am focused on internal review of processes to see if we can increase our efficiency without affecting the quality. In a perfect world, no major accident report would take longer than 2 years, and general aviation and others would be finished in one year or less. Now that's a perfect world, but it is a goal as well.

And we're seeing results. Since March, the NTSB has conducted 112 accident investigations, including Air Algerie, a Boeing 737 that crashed after takeoff with 102 fatalities; Sudan Airways, a Boeing 737 with 116 fatalities; Kenya, a Fairchild Metroliner with 14 fatalities, and the NTSB continues to support the investigation of the China Air Boeing 747 that crashed in the straits of Formosa. We have fielded more than 1,350 calls from the media or victims' families, and our law judges have closed 131 cases and held 40 hearings. We have saved more than $250,000 via procurement review and held eight meetings and public hearings that included the most-wanted list, 15 passenger vans, driver distraction, two rail accidents, and Emery Worldwide Flight 17. We have also issued 47 new recommendations, so the beat goes on.

A new beginning will be the opening of the NTSB Academy. This leased facility is located on the grounds of George Washington University in Ashburn, Va., and offers new opportunities for safety partnership. It will house the NTSB investigation and safety training programs, offer opportunities for safety symposia, roundtable discussions and forums, formulate safety partnerships for research, development and implementation of new technologies, and create a sanctuary for discussion of key safety issues and topics.

The National Transportation Safety Board relies on its partners in safety, and today is no different. We hope that the NTSB Academy will be the forum for international discussion on shared issues and interests, a place where shared knowledge and open debate will help grow the overall body of safety knowledge in industry, government, academia and in personnel. We are working on developing key issues that will be appropriate to this venue and I solicit your comments and support. With your help and the help of other industry and transportation leaders, this timely discussion can and will make a difference in achieving safer skies. ◆

The Practical Use of the Root Cause Analysis System (RCA) Using Reason[1]®: A Building Block for Accident/Incident Investigations

By Jean-Pierre Dagon, Director of Corporate Safety, AirTran Airways (CP0204)

***Jean-Pierre Dagon**, from June 2000 to present, is Director Corporate Safety—AirTran Airways—oversight of operational (including ASAP and FOQA), occupational safety, and emergency response. Oversight of the internal evaluation process. Captain B-717-200, rated on DC-9 (B-717), SF-340, and SA-2000. Native of Switzerland (Geneva). Member of AIAA, corporate members of ISASI and the Flight Safety Foundation. Participation in ACOSM (Air Carrier Oversight System Modeling) Working Group since 1999. May 1998 to June 2000: Northwest Airlines, Inc., Manager, Flight Operational Quality Assurance. Oversight and in charge of codeshare audit, safety audits of regional carriers; implemented ATOS at NWA. For a short period of time in charge of the Ops Specs (Part A, B, and C). May 1996 to May 1998: FlightSafety Texas, San Antonio Learning Center: Director of Pilot Standards—helped obtain first Part 142 certificate in the nation. In addition TCE (Training Center Evaluator) SF-340 and SA-2000 instructor. Prior to 1995: Crossair LTD, Basel, Switzerland; head of pilot training for one of the largest regional airlines in Europe, and launch customer for successful SF-340 and (not so successful) Saab 2000. Check airman, SF-340. Education: B.B.A., aviation management option, Boise State University (cum laude). Type rating: SF-340 SAS Flying Academy. SA-2000: FlightSafety International B-717-200: FlightSafety Boeing, Long Beach. NAIA, ASMEL, CFI&I College of Geneva (Switzerland). Sandia National Labs: System Safety for High Consequences Industries course. TSI: Safety Officer Course. George Washington University: Safety course in safety data analysis.*

The defense in-depth strategy is common to all safety prevention doctrine. Successive layers of protection, one behind the other, each guarding against the possible breakdown of the one in front, are commonly illustrated by the Swiss Cheese Theory. According to Prof. James Reason, each layer has weaknesses and gaps akin to a Swiss cheese. The Swiss Cheese metaphor is best represented by a moving picture, with each defensive layer coming in and out of the frame according to local conditions[2].

These holes are created by a combination of active and latent failures. The active failure consists of errors or violations committed at the sharp end of the system. A latent failure stems from poor design, a shortfall in training, inadequacy of tools and equipment, which are present for sometimes years before these conditions combine with local circumstances and active failures to penetrate the system's many defensive layers[3].

As such, the rare conjunction of a set of holes in successive defenses allows hazards to come into damaging contact with people and assets, according to James Reason®, as he defines the accident trajectory.

To date, however, accident/incident investigations point many times to causal factors (i.e., bringing forth the facts) but leave it up to the recipient of the report to determine root causes.

This approach offers an opportunity to examine root causes and brings forth some measurable indicators of the likelihood of reoccurrence. It may offer an avenue to the question: "What latent conditions led to the accident?"

Root cause analysis (RCA) is commonly used in engineering and reliability programs, but is not always emphasized in accident/incident investigations. RCA can lead to changes in procedures, processes, manuals, oversight, and training.

Basic elements of root cause analysis, using Reason®

In root cause analysis, one recognizes three basic elements that built causal patterns:

A change or changes: An action that triggered another step in a problem. The initial change comes from the problem statement. For example, aircraft ship number 123, Flt. 456's left wing collided with a parked fuel truck. This is a change—something happened that caused the end result, a collision.

A condition: A state of being that existed within the environment over some period of time, i.e., it was dark, the ramp was wet, the fuel truck was parked on the safety zone, the pilot's scan was poor.

An inaction: Anything that could have or should have occurred to prevent the next step in the problem, but did not. The inaction is akin to allowing the chain of events to continue unchallenged. For example, the pilot did not stop when confusing marshalling signals were present. The airplane was allowed to continue with a high rate of descent. The flight crew did not react to a GPWS pull-up command, and so forth.

A set of facts identifies all of the factors that are essential for one step to occur within one chain within the Reason® model. As you list the component factors that explain why a particular step in the event occurred, a set of factors is built. Each set must contain only factors that are necessary to explain the consequence of that set, and nothing more.

Certain rules have to be met in order for the system to work. A set is a group of factors that causally account for the next higher step (their consequent) in the model.

1. There can be only one change in a set (a group of answers that explains one cause, or one change for any level).
2. Change is produced by change.

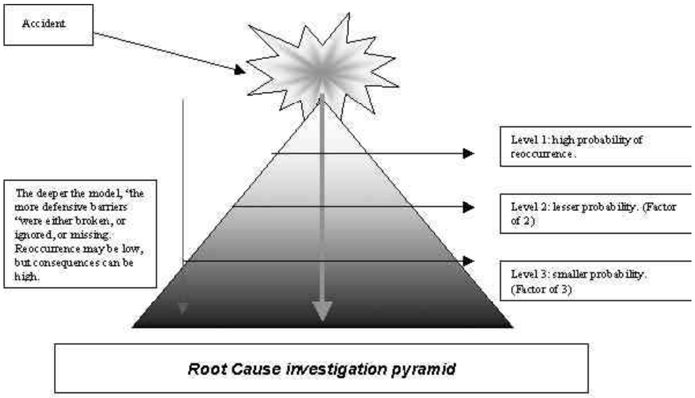
3. Inactions are always brought about by inactions; therefore, you cannot have a change answer in an inaction set. (Something didn't get done, or didn't happen, either due to a lack of plan, or the plan did not work.)
4. Conditions can occur in any set, but it is not necessary to have a condition in every set.

There are two types of conditions: those that are brought about by change, and those that are brought about by a lack of change. This software will ask you to designate with which type of condition you are dealing with before the advice area activates the questions for the set.

Note: The software stringently enforces these four rules.

Building steps for root cause analysis

The building steps start with a change (which may be a summary of the incident broken down in simple building blocks). That change is developed with a sets of factors that contributed to the initial event. This allows the investigator to retrace steps that came into effect to bring about the changes. In this process, one will find repeating patterns that can be looped and thus connected to one factor which accounts for several of these event sets leading to the accident. The process is basically structured around a pyramid:



Upstream risk analysis

Upstream (top of pyramid) accounts for critical steps prior to the event (the last chain of the event chain). As you move down, the values are becoming smaller; it lends a predominance of weight at the top of the model.

Downstream analysis

A longer chain of events, as analyzed downstream (or at the bottom of the pyramid), would indicate a bigger problem, for there were many opportunities to break the chain of events from unfolding, yet these opportunities were either ignored or unknown. It is likely that latent effects would be best described by downstream analysis, whereas active failures would more be consequential at the top of the pyramid.

If one assumes a single level of events caused the accident, than one has a typical active failure model (a virtual impossibility).

Engineering fixes versus organizational fixes

This approach offers an alternative to eventually costly engineering changes that may not be necessary given the propensity for the event to reoccur. Engineering safety brings forth a comprehensive and permanent fix; however, this can have alternative drawbacks.
[1] It can be impractical or hard to market for the industry at large. Example: Considering an initiative to equip passenger aircraft with aft-facing seats. Although used extensively in the military, a proposition for aft-facing passenger seats could be interesting if one considers the flying public's likely distaste for flying "backwards."[4]
[2] It can introduce new threats because of the fix in itself. Example in point is the automation introduced in modern jets, which is intended to alleviate the workload and monitor parameters. If the automation fails, it relies on intuitive knowledge by the pilot who is not cognizant at first of a failure in automation, or a failure in programming and could lead to a catastrophe. Example: the Air Inter A320 crash in Strasbourg, were a vertical speed of 3.3 (as in 3,300 fpm down) [VS/HDG combined mode] may have been left or erroneously selected by the PIC, in lieu of the track/flight plan angle mode or 3.3° [TRK/FPA mode] desired, leading into a controlled flight into terrain against the Mt. St. Odile.[5]
[3] It brings forth a bulldozer approach to level an ant hill. A disproportional fix to a single and remote possibility of a failure.

Root cause analysis is a process designed to discover both an engineering solution and organizational alternatives. In the Reason® system, these controls can be compared for effectiveness for prevention of a certain event. This effectiveness comparison coupled with an understanding of the propensity for the specific event to recur provides decision makers with important information to aid them in deciding whether engineered controls are preferred.

Root causes division[6]

A root cause can be categorized in the following hierarchy:

A. Management-level action required

Management principles must be first considered to ensure that a policy is in place, is enforced, and controls are established. Here are management-level statements:

- Management did not COMMUNICATE this requirement.
- Management did not DESIGNATE that this policy apply to this specific situation.
- Management did not establish a means to MONITOR compliance with this policy.
- Management did not COMMUNICATE how it was MONITORING for compliance.
- Management did not ENFORCE the policy when an infraction was found.
- Management did not ESTABLISH a policy to control this.

The point at which the statement can be affirmed as true is the point of breakdown in the organizational principles of control. If the statements are not applicable, the next step is analyzed.

B. Supervision-level action required

At this point, the software offers supervision principles to consider in each of the following statements:

- Supervision did not COMMUNICATE what was wanted.
- Supervision did not PROVIDE the things necessary in order to comply with policy.
- Supervision did not FOLLOW the policy in the past.
- Supervision did not ENFORCE the policy in the past.

The point at which a statement can be affirmed as true is the point of breakdown in the organizational principles of control. After looking at a failure at the management level, filtering down to the supervisory level, the individual performance may be examined.

C. Individual-level action required

- The individual's incorrect action is now acceptable and the policy can be changed.
- The individual's incorrect behavior can be MODIFIED.
- The individual's incorrect behavior cannot be changed, and he must be REMOVED from that particular environment.
- The software is diligent in giving this as a last-resort option stating: "Selecting an individual RC is a serious and rare decision. Using the RC wizard will help to avoid missing the systemic portion of a RC where the individual(s) share responsibility."

Often an organization will resort to disciplinary action at the expense of finding a systemic problem to an incident/accident going against the accepted proposition that individuals for the most part have an innate desire for self-preservation, and in a high consequence environments seldom create intentional accidents.

Application of RCA using Reason®

To illustrate the practical application of root cause analysis, let's take a real example of a simple ground damage.

Problem statement

Aircraft # 123 arrived at Destination as Flight 456 from Philadelphia on 14 June with 59 customers and a crew of five and was assigned to Gate C-3. The ramp crew was at another gate and not in position for an arrival at C-3, but ran to their positions when notified of the waiting aircraft. As the aircraft moved forward into the gate, it struck an unattended fuel hydrant truck left inside the containment zone, damaging the leading edge and underside of the left wing.

Figure 1: Leading edge slats 4 and 5 damaged.

Figure 2: Detailed view of the damage with fuel truck.

Narration obtained by the Reason® software

Because the fuel vendor's supervision did not enforce the policy of parking fuel trucks in designated areas only and the individual(s) did not comply on their own with the established business process, the fueler did not park the vehicle in a designated parking area.

Additionally, because the customer service organization did not establish a policy to advise fuel company personnel on the importance of safety zone lines, the fuel company did not stress the importance of not parking in safety zones. So, the fueler was not attentive when he parked the vehicle.

Also, because the fuel vendor did not establish a policy to park vehicles in designated parking spots only, the fuel company did not have a prohibition against parking in the safety zones for office business. Since the fueler was not attentive when he parked the vehicle, and because the fuel company did not have a prohibition against parking in the safety zones for office business, the fueler did not park outside of the safety zone line. Because the fueler parked the truck to deliver a bill to fuel vendor's office, and because the fueler did not park the vehicle in a designated parking area, and because the fueler did not park outside of the safety zone line, a fuel truck was parked in the safety zone.

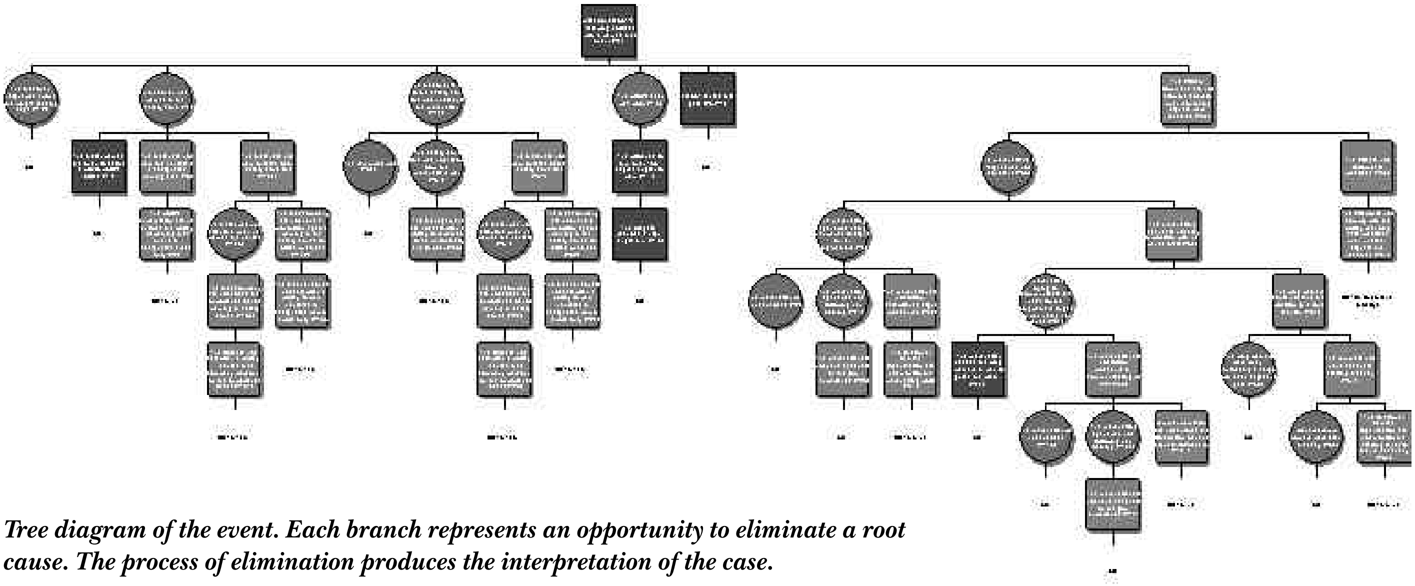
Moreover, because the management did not establish a policy to repaint the lines periodically due to wear, the safety zone line was not visible from the marshaller's position. As the ramp was wet, and since the safety zone line was not visible from the marshaller's position, and because the fueler did not park outside of the safety zone line, the fuel truck's position to the safety zone line was unclear to the marshaller.

In addition, because the 3-C gate required a high-angle turn, the pilot had to turn over a 135-degree angle to park. So the pilot's scan was poor.

Furthermore, because the marshaller did not have adequate on-the-job experience, the marshalling agent was not following her training.

Then, because the customer service organization did not monitor the marshalling policy and the individual(s) did not comply on their own with the established business process, the marshaller did not follow established signal procedures. As the marshaller was under stress, and since the marshalling agent was not following her training, and because the marshaller did not follow established signal procedures, the marshalling agent was using her wands to signal to her wingwalkers.

Meantime, as the marshaller was under stress, and the marshalling agent was not following her training, and ramp supervision did not enforce the illustration of hand signals (SP6720.3[7]) and the individual(s) did not comply on their own with the established business process, the marshaller did not follow procedure in communicating with wingwalkers. Then, because the marshaller needed the wingwalkers in position to guide the aircraft in, the



Tree diagram of the event. Each branch represents an opportunity to eliminate a root cause. The process of elimination produces the interpretation of the case.

marshaller was trying to communicate the need for the wingwalkers to get in position using her wands.

Additionally, as several ramp workers were sick that day, and the customer service organization did not monitor the staffing level to insure adequacy and the Individual(s) did not comply on their own with the established business process, the ramp did not have adequate staffing that day. Consequently, as the wing walkers were busy unloading a cargo bin at an adjacent gate, the wingwalkers could not take their position in a timely fashion. Since the marshaller was trying to communicate the need for the wingwalkers to get in position using her wands, and because the wingwalkers could not take their position in a timely fashion, the marshalling agent did not stay in position with her wands crossed. Since the marshalling agent was using her wands to signal to her wingwalkers, and because the marshalling agent did not stay in position with her wands crossed the marshaller's crossing signal was not constant.

Also, because the PIC would not comply with the policy requiring safe practices when unclear signals are received, the PIC did not follow safe practices. Since the marshaller's crossing signal was not constant, and because the PIC did not follow safe practices, the pilot in command did not stop the aircraft when confusing signals were received. As the fuel truck height was above the wing's leading edge, and since a fuel truck was parked in the safety zone, and since the fuel truck's position to the safety zone line was unclear to the marshaller, and since the pilot's scan was poor, and because Flt. 456 taxied into gate C-3, and because the pilot in command did not stop the aircraft, when confusing signals were received, aircraft 123, Flt. 456's left wing collided with a parked fuel truck.

Interpretation of the case

Analysis of this investigation shows that it is valid to compare the identified root causes to each other, given a calculated reliability of 100 percent. This event contains a typical mix of both conditions and actions.

The fuel vendor's supervision has the opportunity to enforce the policy of parking fuel trucks in designated areas only, and the individual(s) did not comply on their own with the established business process.

In terms of preventing this problem, this is the seventh best option, removing 9 percent of this model.

The customer service organization has the opportunity to establish a policy to advise fuel company personnel on the importance of safety zone lines.

This is the best prevention option. It eliminates 22 percent of this problem.

The fuel vendor has the opportunity to establish a policy to park vehicles in designated parking spots only.

Preventing this root cause is the second best option and will deal with 22 percent of the causes that produced this problem.

Management has the opportunity to establish a policy to repaint the lines periodically due to wear.

This action, the eighth best option, will remove 7 percent of this problem.

The customer service organization has the opportunity to monitor the marshalling policy, and the individual(s) did not comply on their own with the established business process.

This option is the fifth best available option. It will remove 13 percent of this problem.

Ramp supervision has the opportunity to enforce the illustration of hand signals (sp6720.3), and the individual(s) did not comply on their own with the established business process.

This prevention opportunity is the fourth best, eliminating 14 percent of the process that produced this problem.

The customer service organization has the opportunity to monitor the staffing level to ensure adequacy, and the individual(s) did not comply on their own with the established business process.

In terms of preventing this problem, this is the third best option, removing 15 percent of this model.

The PIC has the opportunity to comply with the policy requiring safe practices when unclear signals are received.

This is the sixth best prevention option. It eliminates 12 percent of this problem.

Brief explanation of the tree model

The tree model above illustrates a complete root cause analysis on the aforementioned example. Changes are dark squares. Conditions are grey circles. Inactions are grey rounded squares. It is not surprising that root causes often happen as a result of an inaction.

A level is best described as a collection of events occurring horizon-

LISTING OF SPECIFIC ROOT CAUSES

#	*Type*	*Cause*	*Cost*	*Policy*	*Department*	*Regulation*
9	RC - S4, I	The fuel vendor's supervision has the opportunity to enforce the policy of parking fuel trucks in designated areas only, and the individual(s) did not comply on their own with the established business process	$0.00			
131	RC - M1234	The customer service organization has the opportunity to establish a policy to advise fuel company personnel on the importance of safety zone lines	$0.00			
133	RC - M1234	The fuel vendor has the opportunity to establish a policy to park vehicles in designated parking spots only	$0.00			
85	RC - M1234	Management has the opportunity to establish a policy to repaint the lines periodically due to wear	S$3500	New policy to repaint safety zones	Customer service organization	
74	RC - M34, I	The customer service organization has the opportunity to monitor the marshalling policy, and the individual(s) did not comply on their own with the established business process	$0.00			
124	RC - S4, I	Ramp supervision has the opportunity to enforce the illustration of hand signals (SP6720.3), and the individual(s) did not comply on their own with the established business process	$0.00			
67	RC - M34, I	The customer service organization has the opportunity to monitor the staffing level to insure adequacy, and the individual(s) did not comply on their own with the established business process	$0.00			
54	RC - IM (Individual Modify)	The PIC has the opportunity to comply with the policy requiring safe practices when unclear signals are received	$0.00			

tally, henceforth a set notice that there is one change per level.

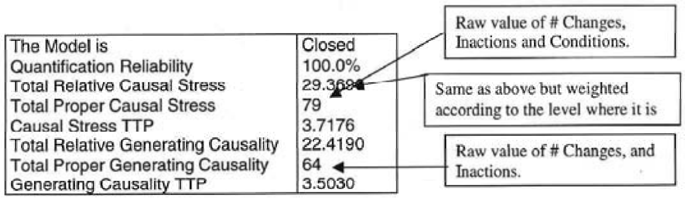
As the tree model builds up, consider the bottom as the flat portion of the pyramid. To understand how Reason® prioritizes actions (most effective action) to affect the outcome, one can look at the right identical branches of the second and third conditions (first level of the model) following the initial change.

As we eliminate one root cause, they are duplicated, i.e., the same root cause eliminates 22 percent of the model, henceforth the interpretation.

The customer service organization has the opportunity to establish a policy to advise fuel company personnel on the importance of safety zone lines.

This is the best prevention option. It eliminates 22 percent of this problem.

REASON SUMMARY SHEET CHART



The Model is	Closed
Quantification Reliability	100.0%
Total Relative Causal Stress	29.368
Total Proper Causal Stress	79
Causal Stress TTP	3.7176
Total Relative Generating Causality	22.4190
Total Proper Generating Causality	64
Generating Causality TTP	3.5030

Raw value of # Changes, Inactions and Conditions.

Same as above but weighted according to the level where it is

Raw value of # Changes, and Inactions.

However it also worth noticing that an active failure at the first level was an immediate contributor to the accident, looking at the far right-hand corner, first level: The pilot in command did not stop when signals where confusing (last line of defense). Hence this interpretation:

The PIC has the opportunity to comply with the policy requiring safe practices when unclear signals are received.

This is the sixth best prevention option. It eliminates 12 percent of this problem.

By removing him from the picture, we do not remove the conditions that exist, or could exist, for this accident to reoccur. Conditions are still present for another opportunity to damage an airplane.

In this example, we see a brief overview of a latent failure (systemic issue) and an active failure (individual failing to stop) as contributors to this event.

Interpretation of the summary sheet

Since the model contains no insufficient data, it is 100 percent reliable (according to our inputs). The raw numbers include proper causal stress: The value of each changes inactions and conditions. Proper generating causality: The value of all changes and inactions (we subtract the existing conditions).

Relative means the importance assigned depending on which level of the model these factors occur (the closer the event to the outcome, the heavier the weight). Proper means a equal number per level. Relative gives more importance and weight to factors occurring early in the model (i.e., top of the pyramid). The causal stress TTP (tendency toward process) is interpreted to mean the relative number of all factors (including conditions) divided by the proper numbers of factors (discounting the level at which it occurs). The generating causality TTP is interpreted to mean the same, but we discount the existing conditions.

Tendency toward process interpretation

The tendency toward process (TTP)[8] number is a metric calculated within the Reason® software that indicates the amount of "causal stress" present within a specific event model. Given that the discovered corrective actions are not put in place, TTP indicates how quickly and/or frequently the organization could anticipate a recurrence of the same event. In many ways it is a measure of the potentiality of recurrence.

TTP is charted in a numeric range of 0-10. TTP scores of around 3.0 are normal. This particular case had a 3.7 TTP, which is slightly elevated yet indicates that the event is not prone to recur quickly or frequently. In the Reason software, TTP indicates the degree of quickness and frequency related to an event's recurrence, and there are several reasons why it should be contemplated when prioritizing events for corrective action.

Often, after an organization experiences an incident with serious consequences, it proceeds into the decision-making phase of corrective action with a mindset that often defaults to putting in engineered controls, even if solutions dealing with the organizational system seem to be equally effective.

Engineered solutions are indeed often effective, yet they often are the most costly options available for dealing with an event. Engineered solutions are sometimes quick—you put them in place and if they are designed correctly, they provide instant protection. Yet if the TTP is low for an incident, the ***need*** for an expedient correction is not as great. Very often a discovered fix in the organizational system can be both more effective and more cost effective than the engineered solution.

Some unwanted events tend to happen over and over due to the repetitive nature of the specific business process associated with them. An example of this is the business process of boarding passengers on a plane, which is an extremely repetitive process. Due to the repetitive nature of this process, if any problems exist in the "boarding passenger business process" it can be expected that those problems would happen again and again. Such problem events tend to have high TTP scores in Reason®. Repetitious events such as these match well with the inherent advantages of engineered solutions in that they "dummy proof" those business processes so that they don't rely on people for correction. Relying on organizational systems and people to deal with voluminously repetitive problem issues is not going to be as consistent a control for these problems as an engineered solution.

But often the events we deal with (serious or otherwise) are the exceptional, infrequent events associated with business processes that are not as repetitive. These types of events tend to have low TTP numbers. Thus the TTP metric itself can serve as an indicator that assists a decision-maker in deciding between engineered solutions and/or fixes in the organizational system that often are as preventative and more cost effective.

In the "aircraft truck" case study, the TTP is 3.7, which is just slightly above normal. This score would tend to indicate that organizational fixes would be just as prudently chosen as any discovered engineered solutions.

Conclusions

The root cause approach to incident /accident investigation using Reason's® software offers an additional facet to the accident investigation. It may assist at looking at a systemic failure (organizationally) leading to an accident, it may help to answer the systemic "why" of an accident, complementing the "how" and "when." Hopefully this approach will provide additional weight in recommendations following investigations. In particular in can give an approach to risk analysis, offering an insight in the likelihood of reoccurrence of an event, and encourage sharing of "best practices" in the industry in terms of procedures, processes, and gained knowledge. This tool also affords a frame work for root cause analysis investigations. Finally it preempts the old-fashioned approach of removing the cause[9], and the problem ceases to exist.

Acknowledgements

I would like to acknowledge Paul W. Werner, Ph.D., principal member of technical staff System Surety Studies, Sandia National Laboratories, for introducing me to Reason and Decision Systems Inc., for bringing their expertise in this paper. ◆

References/Footnotes

[1] REASON® is a trademark of Decision Systems, Inc., company located in Longview, Tex., not to be confused with Dr. James Reason.

[2] *Managing the Risk of Organizational Accidents*, Dr. James Reason, Ashgate Publishing Company, 1997 reprinted 1999, p.9.

[3] *Managing the Risk of Organizational Accidents*, Dr. James Reason, Ashgate Publishing Company, 1997 reprinted 1999, pp.10-11.

[4] U.K. AAIB recommendations Aircraft Accident Report No: 4/90 (EW/C1095). Report on the accident to Boeing 737-400 - G-OBME near Kegworth, Leicestershire, on 8 January 1989. Recommendation 4.25: initiate and expedite a structured program of research with European authorities into passenger seat design, with emphasis on .2. Aft-facing passenger seats. (Made 30 March 1990).

[5] BEA, Bureau D'Enquêtes and D'Analyses pour la Sécurité de L'Aviation Civile. Report FED9202120, Accident occurred January 20, 1992 by the Mt. St. Odile (Lower Rhine), Airbus A-320, F-GGED, operated by Air Inter. Hypothesis of the accident, description at 21.58, para. 21.4, -1.

[6] The Management Principles, inquiry logic rules and causal patterns detailed in this paper are protected by DECISION Systems, Inc., © Copyright 1986-2003, and are included herein with approval of DII.

[7] SP6710.02, refers to AirTran's accepted Station Operations Manual, Standard Practice, concerning signals (Ground-Air).

[8] Courtesy of Scott Alan Jones, from Decision Systems, Inc., 802 N. High Street, Longview, TX 75601, website: www.rootcause.com.

[9] Removing the one who did it.

From the Wright Flyer to the Space Shuttle: A Historical Perspective of Aircraft Accident Investigation

By Jeff Guzzetti and Brian Nicklas

Jeff Guzzetti *(AO3317) (guzzetj@ntsb.gov) is the Deputy Director for Regional Operations at the NTSB's Office of Aviation Safety. Guzzetti has been with the NTSB for more than 11 years. Prior to his current position, he served as a regional air safety investigator, aerospace engineer, and major airline investigator-in-charge with the NTSB over the past 11 years. Prior to coming to the NTSB, he served in air safety positions with the Cessna Aircraft Company, the Naval Air Systems Command, and the Federal Aviation Administration. Guzzetti has investigated hundreds of general aviation accidents and is a long-time ISASI member. He graduated from Embry-Riddle Aeronautical University with a degree in aeronautical engineering and holds a commercial multiengine instrument rating.*

Brian Nicklas *(brian.nicklas@nasm.si.edu) is the Deputy Reference Chief for the Archives Division of the National Air and Space Museum (NASM). He is very knowledgeable about many subjects in aerospace history, but his special interests are flight testing and flight research. During his 15 years at NASM, he spent 1 year detailed to the NASA Langley Research Center working on a historical overview of that facility. He continues to write on, and photograph, current subjects in aviation, and he is a contributing editor to Air & Space magazine. Nicklas also served as a staff reporter and photographer for The Avion newspaper at Embry-Riddle Aeronautical University while attending college with Guzzetti, who also wrote for The Avion.*

As the world prepares to celebrate the 100th anniversary of the Wright brothers' historic first flight, it is only fitting that we, as air safety investigators, look back on the evolution of aircraft accident investigation in order to gain a perspective on how far we have come since that windy day at Kitty Hawk, and where we need to go from here. As we look back, the old adage "the more things change, the more they stay the same" continues to reveal itself through several landmark accidents that have redefined aviation safety.

Ancient history

Long before the Wright brothers, mankind was always fascinated with flight, and alarmed by its potential for tragedy. In the second century B.C., the ancient Greeks reported on an accident involving a father and son flying in formation from Greece, with a destination of Sicily, in order to escape prison. Both utilized wings that were constructed from feathers and held onto their bodies by wax. The father and son were, of course, Daedalus and Icarus. Since Icarus had flown too close to the sun, despite his father's recommendation against it, we can imagine the determination of probable cause stating that Icarus "exceeded his craft's thermal limits, inducing structural failure with subsequent loss of control."

About 1,200 years later, a Benedictine monk named Eilmer attempted to fly off of the west tower of his abbey in Europe by attaching wings to his hands and feet and diving off the tower. According to a historian, Brother Eilmer glided for a distance greater than 600 feet before falling hard onto the earth and breaking his legs. Brother Eilmer survived to investigate his own accident, and determined "that the cause of his failure was his forgetting to put a tail on the back part."

Accident prevention also appears in the writings of one Leonardo da Vinci, who stated: "In testing flying machines, do not fly too near the ground, for if you fall you will not have time to right your machine before hitting the ground."

About 800 years after the Eilmer mishap, in the year 1895, a German mechanical engineer named Otto Lilienthal crashed in one of his gliders and was injured due to his failure to install a device that he had designed to make the craft crashworthy. Lilienthal was first to recognize that flight testing was a hazardous business, and that "sacrifices must be made" (reportedly his last words, in fact) if progress in aviation was to be achieved. Still, to prevent serious injury during his flight testing, Lilienthal installed a curved, bow-like "rebounding hoop" to the front of his glider so that it would absorb impact forces in the event of an accident. The science of survival factors was born.

Later, as Lilienthal was testing one of his gliders, the glider stalled, flipped over, and dove into the ground, splintering the bow-like device. (The Wright brothers became aware of the accident and were influenced to place the horizontal stabilizer ahead of the wing on their aircraft, thus producing the "canard" configuration.) Lilienthal survived the crash, undoubtedly due to the bow-like device that shattered and absorbed the impact forces. Because of his survival, Lilienthal investigated and reported his own accident, and cited the rebounding hoop device as an improvement. Ironically, he had neglected to install the rebounding hoop on the later glider, an oversight he paid for with his life.

The Wright brothers and the first fatal accident

Influenced by the successes of Lilienthal gliders and his research into airfoils, the Wright brothers constructed a powered airplane and successfully flew it on Dec. 17, 1903. However, after the famous flight, as the airplane was being manually "taxied" back to the starting point for another flight, strong wind gusts grabbed hold of the aircraft and tumbled it onto the ground. The craft was destroyed and never flew again.

The Wrights then began to modify their aircraft design to meet Army specifications that were issued on Dec. 23, 1907. The fol-

First fatal accident.

lowing year, they delivered their product to the Signal Corps of the U.S. Army in Ft. Myer, Va., for official trials. On Sept. 17, 1908, the trials began. Orville Wright was on board the airplane in order to fly while First Lieutenant Thomas E. Selfridge of the First Field Artillery was on board to observe. (Wilbur was not present, as he was in France demonstrating a Wright machine near LeMans.) Selfridge was a qualified pilot of the Army's first dirigible airship and had a keen interest in and knowledge of aviation. He had been designated by the Signal Corps to participate in the trials.

At 5:14 p.m., the Wright Flyer, with Orville Wright and Lt. Selfridge on board, took off and circled the field four-and-a-half times. Suddenly, a piece of one of the propeller blades broke off, and the airplane plummeted to the ground from an altitude of about 75 feet. Lt. Selfridge suffered a severe head injury in the accident and died about 3 hours later; this was the first official aircraft accident fatality. Selfridge, age 26, was buried with full military honors in nearby Arlington Cemetery. Orville Wright somehow survived with serious injuries and was hospitalized for 6 weeks; he broke his left leg and several ribs in the crash.

Immediately after the accident, the Aeronautical Board of the Signal Corps, composed of Army officers and civilian experts who rode to the accident site on horses, conducted a thorough investigation and wrote a substantive report. The cause of the accident was reported as "…the accidental breaking of a propeller blade and a consequent unavoidable loss of control, which resulted in the machine falling to the ground…." The report explained that prior to the trials, Orville Wright replaced the 8-foot 8-inch propellers with ones that were nine feet long for the purpose of "tuning up the speed of his machine preparatory of making his official speed trial." Due to the vibration of the machine, the longer propeller caught a guy wire on the aircraft and broke the propeller. The guy wire pulled the rear rudder to its side, and the airplane lost control.

World War I and the Roaring 20s

The death of Lt. Selfridge was unfortunately the first of many in the early days of powered flight. On Sept. 12, 1912, 2nd Lt. Edward Hotchkiss and Lt. C.A. Bettington became the first British Royal Flying Corps officers to die in an aircraft accident when their Bristol-Coanda Monoplane crashed on takeoff next to the Thames River near Godstow, Oxfordshire, England. Within 3 weeks of their deaths, the British Secretary of State for War banned all military flights of monoplanes, stating that two wings were safer than one. The ban was lifted 5 months later.

World War I and the Roaring 20s.

World War I brought with it significant developments in aviation, and also significant numbers of aircraft accidents. The German military appears to have been the first to require photographic documentation of all accidents. In the United States, civilian aircraft accidents continued to occur, and the majority of them were investigated by the aircraft designers and surviving pilots.

Following the end of World War I, commercial aviation evolved out of the business of air mail. Many pilots, including Charles Lindbergh, frequently had to bail out of their single-engine airplanes due to poor visibility that prevented accurate navigation and a safe landing. The aircraft losses were staggering, but the sacrifices led to the impetus for commercial air routes, aerial marking systems, and the need for instrument flying.

During this time, many of the air mail crashes and other types of accidents were not officially investigated, or were only investigated by the aircraft designers or surviving pilots. This was most likely because aviation was still considered to be outside the mainstream of life; there was simply very little public interest in aviation at that time. Additionally, there were no real "experts" in aviation, other than the designers and pilots, available to investigate accidents.

With the birth of the U.S. National Advisory Committee for Aeronautics (NACA) in 1915, formal accident investigation methodologies began to coalesce. On Oct. 3, 1928, the NACA created the Committee on Aircraft Accidents. The Committee issued Technical Report No. 357 entitled "Aircraft Accidents: Method of Analysis." The report defined the terminology and classifications of accidents, and even included a one-page "NACA Aircraft Accident Analysis Form" that served as a checklist for analyzing the various aspects of an accident.

There were two more events that occurred during the 1920s that are worth noting. In 1926, the U.S. Congress enacted the Air Commerce Act, which gave the Commerce Department regulatory powers over aviation, although no formal accident investigation body had been established. Additionally, in 1929, not-yet-famous Air Force pilot Jimmy Doolittle invented instrument flight, thus allowing pilots to takeoff and land in fog and poor visibility.

Watershed accidents of the 1930s

The decade of the 1930s brought great advances in commercial aviation. In 1934, the number of passengers flown by U.S. carriers reached 461,743, up from a mere 5,782 in 1926. But it was on March 31, 1931, that a watershed aircraft accident occurred that changed commercial aviation and the way that accidents are investigated. In a pasture near the small Kansas town of Bazaar, a three-engine Fokker F-10A monoplane carrying seven passengers and two pilots plummeted to the ground and was destroyed. There was no fire. A wing section was found a quarter mile away from the main impact site. The flight was being operated as Transcontinental and Western Airways (TWA) Flight 99E bound for Wichita from Kansas City. One of the passengers killed was legendary football coach Knute Rockne of Notre Dame University. The nation was stunned.

No attempt was made to secure the accident site, and souvenir hunters carted away anything that could be carried by hand, including the propellers and fuselage. The airplane's designer, Anthony Fokker, and a handful of investigators from the Department of Commerce arrived the next day only to find two wings and three engines. Three days later, the Aeronautics Branch of the Commerce Department in Washington, D.C., issued a public statement that said the agency "assumed" pieces of propeller blade broke off and severed the wing. It also publicly speculated that a piece of ice had formed on one of the propeller hubs, broken loose, and struck the propeller blade. The statement ended with, "no blame can be attached to the pilots."

With the help of local authorities, several propeller blades were recovered, providing proof that the agency's first speculation as to the cause was in error. So, on April 7, 4 days after the release of the erroneous statement, another public statement was issued indicating that the cause of the accident was a coating of ice on the wings, causing the airplane to become uncontrollable, which led to an inflight separation of a wing during the excessive forces in the dive to the ground. Later, after more research, it was discovered that the F-10A had previous problems of flight control instability, stress fractures of the interior of the wooden wing (which could not be easily inspected), and deterioration of the glue that held the fabric onto the wing. The airplanes were temporarily grounded as a result of this research.

To this day, there seems to be inadequate evidence to determine the cause of the Knute Rockne crash with confidence. The poor investigation and lack of solid evidence spurred media speculation about the accident, such as the theory that a time bomb exploded about the airplane in order to kill a priest who witnessed the gangland execution of Jake Lingle in a Chicago subway.

The accident led to several advances in accident investigation methodology, such as enhanced authority to take charge of an accident scene and its wreckage; prohibitions regarding official public speculation of cause immediately following the accident; improved documentation of body recovery; accepted use of the NACA "Method of Analysis" for aircraft accidents; and the ability to ground a fleet of airplanes in the wake of an accident. The investigation also provided impetus for the aircraft industry to develop all-metal commercial airplanes, giving rise to such stalwarts as the Douglas DC-3.

Another watershed accident occurred 4 years later at Wright Field in Dayton, Ohio. The military was testing a Boeing B-17 bomber prototype. On Oct. 30, 1935, the prototype crashed on takeoff, destroying the airplane by fire and killing all aboard. The U.S. Army investigation revealed that the accident occurred due to the crew's failure to remove the gust locks prior to takeoff. The findings from this accident led to the concept of flight crew checklists.

About 2 years later, on May 6, 1937, the German airship *Hindenburg* exploded into flames and was destroyed. Twenty-two crewmembers and 13 passengers died in the accident, and many more were seriously injured. Again, the nation was stunned. This time, the Bureau of Air Commerce conducted an exhaustive investigation and issued a final report 3 months later. The 18-page report concluded that the cause of the accident was "…the ignition of a mixture of free hydrogen and air. Based upon the evidence, a leak at or in the vicinity of cells 4 and 5 caused a combustible mixture of hydrogen and air to form in the upper stern part of the ship in considerable quantity; the first appearance of an open flame was on the top of the ship and a relatively short distance forward of the upper vertical fin. The theory that a brush discharge ignited such mixture appears most probable."

Another accident involving a TWA Boeing 747 over the Atlantic Ocean would occur nearly 60 years later, resulting in a somewhat similar probable cause.

The decade of the 30s ended with the mysterious loss of Amelia Earhart and her navigator, Fred Noonan, somewhere over the Pacific Ocean during their attempt to fly around the world.

1930s B-17 prototype crash.

1930s **Hindenberg** *crash.*

World War II and the 1950s

In the United States, the Bureau of Air Commerce was formed from the Civil Aeronautics Branch in 1933. In 1940, the Civil Aeronautics Board (CAB) was created under the mandate of the Civil Aeronautics Act of 1938. A Bureau of Safety was created under the CAB to investigate aircraft accidents. Then, World War II began, bringing with it requirements for large four-engine military transports and bombers, and the need for speed. The British, having rescinded its ban on monoplanes, developed the highly successful Spitfire fighter. The Germans were the first to build operational jet aircraft, which ushered in a new era in aviation.

In the early 1950s, the British led the world in commercial jet design with the introduction of the de Havilland Comet, a sleek transport aircraft that could carry 36 passengers and fly at altitudes approaching 50,000 feet at speeds of 500 miles per hour. The Comet was powered by four jet engines and incorporated a pressurized cabin for flight at high altitudes. The Comet began to corner the market on commercial aircraft sales, since all other aircraft manufacturers were continuing to build slower propeller-driven transports.

On May 2, 1953, a Comet broke apart immediately after departure from Calcutta, India, while flying in the vicinity of a storm. The official cause reported by the Indian government was an encounter with severe weather, so the Comet received a clean bill of health. Then, on Jan. 10, 1954, another Comet broke apart in cruise flight about 24,000 feet on a flight from Rome to London, killing all six crewmembers and 29 passengers. The wreckage was strewn along the bottom of the Mediterranean Sea. All of the Comets were immediately grounded until some answers could be found. An investigation was conducted by the Royal Aircraft Establishment (RAE) in Farnborough, England (the current site of the British Air Accidents Investigation Branch). With a lack of evidence, there came speculation of a bomb, uncontained engine failure, and onboard fire. The RAE procured another Comet and began testing its fuselage for metal fatigue. After more than 2 months, with no findings yet from the fuselage testing, and no new evidence from the sunken wreckage, the Comets were allowed to fly again.

Two weeks after the grounding was lifted, in early April 1954, another Comet mysteriously broke apart while cruising at 35,000 feet from Rome to Cairo. A crew of seven and all 14 passengers died. An extensive wreckage-recovery effort began, and pieces began coming into the RAE at Farnborough for a wreckage reconstruction. The reconstruction revealed that the fuselage had blown apart, but no initiating site for the structural failure had been found. Meanwhile, the ongoing pressure testing of the other Comet suddenly revealed a flaw. A stress crack from the sharp edge of an antenna hole began to form and eventually cracked open the fuselage. A similar piece was then recovered from the accident Comet and revealed a crack in the same place. The accident was solved, and the need for fatigue-tolerant aircraft structure was recognized. Unfortunately, the older Comets remained grounded, and the new Comets began competing unsuccessfully with other manufacturers of new jet transports.

Another watershed accident occurred in the United States a few years later on June 30, 1956. On that day, a United Airlines DC-7 collided in flight with a TWA Lockheed Super Constellation about 21,000 feet above the Grand Canyon. A total of 128 people lost their lives. Investigators with the CAB's Bureau of Air Safety spent many grueling weeks recovering, identifying, and analyzing pieces of wreckage from both airliners that were strewn along the steep slopes of Temple Butte in the Grand Canyon. The hard work paid off. The wreckage signatures painted a picture of how the airplanes came together. Additional evidence and research revealed that the air traffic control system at the time was not adequate enough to ensure safe separation of commercial airlines.

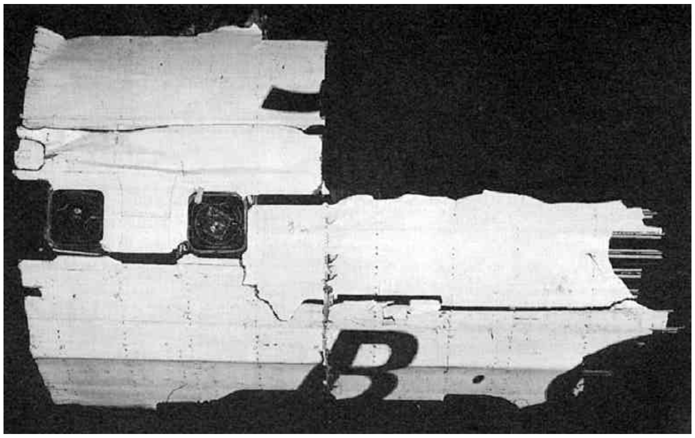
As a result of this horrific accident, pressure was brought to bear to increase aviation safety. On May 21, 1958, a bill was introduced to create the Federal Aviation Agency (FAA) to control use of the navigable airspace and develop and operate air navigation facilities and air traffic control; however, the Bureau of Air Safety within the CAB would remain in charge of civil aircraft accident investigation.

Rock and Roll Hall of Famers Buddy Holly, the Big Bopper, and Ritchie Valens perished in a Beech Bonanza accident on Feb. 3, 1959, known as "the day the music died." The airplane took off into a stormy winter night and crashed near Clear Lake, Iowa, a classic case of a weather-related accident.

The end of the 1950s brought about the beginning of arguably the most important advance in aviation accident investigation…the flight recorder.

The 1960s: a decade of changes

In the early 1960s, the CAB's Bureau of Air Safety continued to investigate U.S. civil accidents with a cadre of mostly tough-talking aviation combat pilots from World War II and Korea. These investigators were typically all men who were mostly high-time military and airline pilots and mechanics. Their vast operational



1970s Tenerife ground collision.

experience outweighed any formal education that they may have had. One of these investigators was a man named Richard Rodriguez, who has been investigating accidents for the CAB, and now the NTSB, for more than 40 years. Another investigator who came along later was Ron Schleede, the current vice-president of ISASI.

On Oct. 1, 1966, Rodriguez was assigned to investigate (along with a "Go Team") the first fatal accident involving a DC-9. The West Coast Airlines flight smacked the eastern slope of the 4,090-foot-tall Salmon Mountain near Mount Hood in Oregon. The cause of the accident was determined to be the inexperienced crew's failure to comply with vectors from air traffic control during descent.

Rodriguez was also involved in what would be another watershed accident. On March 30, 1967, a Delta Air Lines DC-8 crashed into a hotel near New Orleans, La., while on a training flight during which a dual-engine failure on the same side was simulated. Five crewmembers and one FAA inspector died on the airplane, along with 13 people on the ground. After the accident, the FAA required that airline training for such emergencies be conducted in simulators instead of an actual airplane. One interesting note about this accident was that when Rodriguez and his peers launched on the accident, they did so as CAB investigators. After completing the on-scene portion, they came back to Washington, D.C., as employees of the newly created National Transportation Safety Board. The NTSB opened its doors on April 1, 1967. Although it was an independent agency, it relied on the U.S. Department of Transportation (DOT) for funding and administrative support.

During these times, air safety investigators were paid salaries that were barely able to support their families. Investigators received very little per diem on accident launches. They often doubled up on hotel rooms or bunked in the local YMCA or military base. When they were on call, they had no pagers or cell phones; they had to wait at home during their duty for their rotary-dial phones to ring with news of an accident. Public hearings were held in small conference rooms with a few tables and very little news media (by design, there wasn't much room for them anyway). Traveling across country in those days was not nearly as easy as it is today.

Also during this decade, the FAA required airlines to install flight data recorders. These recorders were somewhat crude (only five parameters written onto a ribbon of foil) compared to today's solid-state electronics that can store data for hundreds of parameters. Crude or not, the flight recorders helped NTSB investigators quickly solve major airline accidents and, therefore, assisted in preventing more accidents of the same nature.

The 1960s also brought with it the untimely deaths of rock singer Otis Redding and country singer Patsy Cline (who died in a Piper Comanche with a very low-time private pilot on board); both were classic weather-related accidents in small airplanes. History continued to repeat itself with weather-related accidents.

The 1970s: the deadliest decade, and true independence

The beginning of the 1970s began with the investigation of an American Airlines DC-10 accident on June 11, 1972. At the time, no one realized the lasting effect that this accident would have. During climbout over Windsor, Ontario, from its takeoff in Detroit, a partially secured aft baggage cargo door suddenly blew out due to an excessive pressure differential between the cabin and the thin air. The explosive decompression buckled the cabin floor, causing several flight control cables to be severed. The crew was fortunately able to nurse the crippled airplane safely back to Detroit (although a casket was blown out of the cargo compartment, which caused intense media attention). Even though no one was hurt, the NTSB initiated a thorough investigation and made several recommendations about the inadequate design of the DC-10 cargo door to its sister agency, the FAA. However, the FAA did not require Douglas to correct the door design. Two years later, on March 3, 1974, a Turkish Airlines DC-10 experienced the exact same scenario while climbing out from Paris. This time, however, all of the flight controls were severed, and the airplane slammed into the Ermenonville Forest northeast of Paris, killing all 346 people on board.

At the time, political scandals were erupting throughout the Nixon Administration, and it was suggested that because of its reliance on the DOT, the NTSB might not be objective and impartial in its conclusions and recommendations. Fueled by these controversies, Congress passed the Independent Safety Board Act of 1974, which severed all organizational and financial ties between the Safety Board and the DOT, including the FAA. The NTSB no longer had any "sister" agencies and now reported directly to Congress.

That same year, a Boeing 727 slammed into a hill near Berryville, Va., initiating another significant safety change. On Dec. 1, 1974, TWA Flight 514 was descending to land at Washington's Dulles International Airport on an instrument approach. The investigation later determined that there were inadequacies and a lack of clarity in air traffic control's procedures, and that the crew improperly decided to descend to a minimum altitude prior to the approach segment in which that altitude applied. As a result of the investigation, the FAA required that all air carrier aircraft be equipped with ground proximity warning systems (GPWS), arguably one of the most significant developments in the prevention of the all-too-frequent accidents involving controlled flight into terrain (CFIT).

As if these incredibly tragic accidents weren't enough for one decade, another landmark accident occurred at the Los Rodeas Airport on the Spanish resort island of Tenerife on March 27, 1977. After taxiing on a fog-shrouded taxiway, the very experienced captain of a KLM Boeing 747 thought he had been given clearance to take off, due in part to language difficulties with air traffic controllers and the failure of his copilot to speak up. Meanwhile, on the other end of the runway, the crew of a Pan Am World Airways 747, who were talking to a different controller, was back-taxiing on the active runway for takeoff. The KLM airplane, during its takeoff roll, slammed into the Pan Am 747, causing a horrific fireball. All 248 on board the KLM 747 lost their lives. Only 61 passengers survived out of the 396 people on the Pan Am 747. The final death toll was 583. It stands today as the deadliest aviation disaster in world history.

One year later, on Dec. 28, 1978, the crew of a United Airlines DC-8, Flight 173, allowed the airplane to run out of fuel and crash six miles southeast of Portland, Ore. Eight passengers and one flight attendant were killed. The investigation revealed a lack of assertiveness by the flight engineer, who knew the airplane was running low on fuel. This accident, along with Tenerife, was the impetus for the concept of crew resource management, or CRM. Experienced captains and their lesser crewmembers were being taught to work as a team in the cockpit.

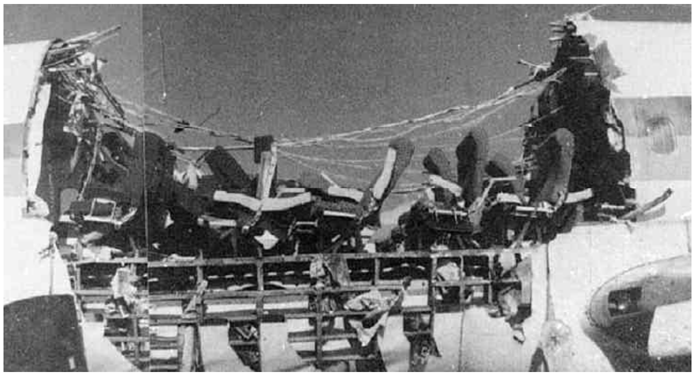
The decade ended with the deadliest aircraft accident in U.S. history, when an American Airlines DC-10 (Flight 191) crashed right after takeoff from Chicago's O'Hare Airport on May 25, 1979. All 273 people were killed. The accident was due to a failure of the left engine's support pylon as a result of improper maintenance, which led to the left engine separating from its wing, a retraction of the slats, and an aerodynamic stall. The FAA grounded all DC-10s for over a month as a result.

In addition to these major airline disasters, in the seventies aircraft accidents also killed all-star New York Mets catcher Thurman Munson, House Majority leader Hale Boggs, rock singer Jim Croce, U2 pilot Francis Gary Powers, World War II hero and actor Audie Murphy, oceanographer Phillipe Cousteau, and baseball great Roberto Clemente.

The 1980s: deregulation, aircraft aging, and the space shuttle

The decade of the 80s began with the ripple effects of the Air Line Deregulation Act of 1978. The Act allowed airlines to compete for routes against each other, rather than have the federal government determine routing and ticket prices. As a result, the airlines began to operate with a keen eye on profits and economics. Some critics declared that some airlines would be tempted to "cut corners" in order to become more competitive. For example, there were fears that some airlines would contract out their maintenance parties, hire less-experienced pilots for lower salaries, and decrease the amount of training that their pilots received.

On the frigid afternoon of Jan. 13, 1982, the voices of these critics echoed throughout the country. On that afternoon, Air Florida Flight 90 began its takeoff roll from Washington National Airport. About 1 minute later, it impacted the Fourteenth Street Bridge and landed in the partially frozen Potomac River. Seventy-four people lost their lives. Only five survived. In a 141-page report released on Aug. 10, 1982, the NTSB determined that "...the probable cause of this accident was the flight crew's failure to use engine anti-ice during ground operation and takeoff, their decision to take off with snow/ice on the airfoil surfaces of the aircraft, and the captain's failure to reject the takeoff during the early stage when his attention was called to anomalous engine instrument readings. Contributing to the accident were (1) the prolonged ground delay between de-icing and the receipt of an air traffic control takeoff clearance during which the airplane was exposed to continual precipitation, (2) the known inherent pitch-up characteristics of the B-737 aircraft when the leading edge is contaminated with even small amounts of snow or ice, and (3) the limited experience of the flight crew in jet transport winter operations." (Rudy Kapustin, long-time member of ISASI, was the investigator-in-charge of this accident.)


1980s Aloha Airlines 737.

Air Florida marked the beginning of a string of takeoff accidents in the 1980s involving ice-contaminated wings. These accidents included an Airborne Express DC-9 in Philadelphia, a Continental DC-9 in Denver, a Ryan Air DC-9 in Cleveland, and USAir Flight 405, a Fokker F-28, at La Guardia Airport in New York. (Veteran investigator Richard Rodriguez served as the Operations Group Chairman on all of these accidents.) As a result of these investigations, revolutionary changes in the way the airlines deice their airplanes were initiated and are still in force today.

As college students, these authors were eyewitnesses to another significant accident of the 1980s. The space shuttle *Challenger* exploded less than a minute after launch on a cold Florida morning in late January 1986. The nation mourned the deaths of seven astronauts, including the first "teacher in space" Christa McAulliffe. The shuttle program had been running smoothly for 5 years, and NASA and the public seemed to take space travel for granted. Then, the *Challenger* horror shocked the nation.

After the accident, NASA initially shared very little with the public, and the public didn't like it. Realizing that NASA couldn't really investigate itself with public credibility, President Reagan formed the independent Roger's Commission on the accident. Less than 5 months after the accident, the Commission submitted its report and cited, among other items, that the accident was caused by a failure of an o-ring in a joint of the right solid rocket booster. Underlying factors that were cited, however, addressed NASA management failures to address problems that it had been aware of, but did not take adequate action to correct. Additionally, the Rogers Commission cited a reduction in funding and emphasis on safety. Ironically, 17 years later, another space shuttle, along with another crew of seven astronauts, would perish due to some of the same concerns. Aviation, including space travel, is unforgiving.

Yet another watershed accident occurred on April 28, 1988, when an "island hopping" Boeing 737, operated by Aloha Airlines, suddenly had the top of its fuselage rip away while cruising at 19,000 feet. A flight attendant was ejected during the rapid decompression. Miraculously, she was the only person who was killed. The airplane landed safely and an intense investigation convened. The cause involved fatigue damage that led to the failure of a fuselage skin lap joint. The investigation gave rise to a vast program, know as the Aircraft Aging Program, that required frequent detailed inspections of airplanes for corrosion damage and fatigue.

Other notable accidents in the eighties included the mid-air collision of a DC-9 with a small airplane over Cerritos, Calif., which provided the impetus for the traffic alert and collision avoidance system (TCAS), and the United Airlines DC-10 uncontained engine failure and loss of control in Sioux City, Iowa, which changed the way airplanes and engines are certified.

Celebrities who perished in aircraft accidents during this decade included actor Vic Morrow, who died when a helicopter blade struck him during the filming of *The Twilight Zone* movie, and rock singer Ricky Nelson, who perished in a DC-3 accident involving an electrical fire.

The 1990s: Icing, rudders, JFK, Jr., and TWA 800

The 1990s began with a rash of commercial airline accidents, but the most notable and controversial of these was United Airlines Flight 535 in Colorado Springs, Colo., and USAir Flight 427 near Pittsburgh, Pa. Both accidents involved the Boeing 737, and both involved catastrophic movements of the rudder. After lengthy periods of time due to the lack of information from the older flight data recorders, the investigations gave rise to a rudder package retrofit of the most popular jetliner in the world. Accidents such as these were extremely complex and required more and more specialists with formal education, and more time for exhaustive research and testing.

The 90s also ushered in another important aspect in commercial aviation safety: Icing research. On Oct, 31, 1994, an ATR 72, operating as American Eagle Flight 4184**,** crashed over Roselawn, Ind., while in a holding pattern to land in Chicago. Icing conditions prevailed, and the airplane suddenly experienced an aileron hinge moment reversal due to aerodynamic and autopilot effects that resulted from ice contamination on the wings. The accident would have been extremely difficult to solve if it were not for the new expanded parameter flight recorder on board, something that the 737 rudder accidents did not possess. In stark contrast to the 737 accidents, the Roselawn ATR 72 crash was solved within days of the accident. Newer solid-state flight data recorders were proving to be exponentially more valuable than their crude "foil" and magnetic tape predecessors

A few years later, on Jan. 9, 1997, an Embraer EMB-120 turboprop, operating as Comair Flight 3272, crashed for some of the same reasons as the Roselawn ATR 72 while on approach to Detroit. Richard Rodriguez, as the IIC, needed the help of younger scientists at the NTSB, and also at NASA, who had never piloted an airplane, but had the educational background to research the complexities of aerodynamic penalties due to icing. This second accident further underscored the need to review aircraft icing certification.

Of course, no historical perspective of aircraft accidents would be complete without mentioning TWA Flight 800, a Boeing 747 that exploded while climbing out after takeoff from New York's JFK Airport in July 1996. After arguably the most arduous accident investigation in U.S. history, the NTSB determined that the cause of the accident was similar to that of the *Hindenburg* disaster 60 years previous…that a volatile mixture of fuel and air was ignited by an unknown ignition source. Specifically, the Board concluded that probable cause of the TWA Flight 800 accident was "an explosion of the center wing fuel tank (CWT), resulting from ignition of the flammable fuel/air mixture in the tank. The source of ignition energy for the explosion could not be determined with certainty, but, of the sources evaluated by the investigation, the most likely was a short circuit outside of the CWT that allowed excessive voltage to enter it through electrical wiring associated with the fuel quantity indication system." To this day, some people believe that the airplane was downed by a missile or a bomb, reminiscent of the theories that abounded at the time of the *Hindenburg* and Knute Rockne case, proving that conspiracy theories are as tenacious today as they were decades ago. Distrust and cynicism, it seems, are timeless traits of the human species.

Another interesting change in aircraft accident investigation was the length of reports. For example, the entire final CAB report of a United Airlines DC-6 crash in Bryce Canyon, Utah, on Oct. 26, 1947, was *four pages long* and was adopted 4 months after the accident. The accident killed all 46 passengers and a crew of six, and involved a mechanical malfunction that affected the fleet of DC-6 aircraft across the world. The American Airlines DC-10 crash at Chicago's O'Hare Airport in 1979 gave rise to a final report in less than 7 months, and was 98 pages in length, including appendices. The TWA Flight 800 final report came out 4 years after the 1996 accident and was 425 pages in length. The phenomenon of larger and larger reports can be attributed to the proliferation of litigation and the news media (i.e., need for more and more proof to defend against other theories and law suits), the complexities of technologically advanced aircraft and their accident causation, and the high financial and political stakes of aviation.

The decade ended with the death of John F. Kennedy, Jr., his wife, and sister-in-law, in a Piper Saratoga off the coast of Martha's Vineyard, Mass. One of the authors was involved in airworthiness aspects of the investigation, and none were found. Instead, the final probable cause reflected yet another accident involving a VFR-rated pilot who became spatially disoriented. Again, conspiracy theories about murder abounded.

Other celebrities who perished in general aviation and commercial aircraft accidents during the 90s included pop singer John Denver, golfer Payne Stewart, blues guitarist Stevie Ray Vaughan, Sen. John Tower, Sen. John Heinz, NASCAR driver Davey Allison, the band of country singer Reba McEntire, and 7-year-old Jessica Dubroff.

A new century

The dawn of the new century began with the fatal plunge of Alaska Airlines Flight 261 into the Pacific Ocean in January 2000. (The investigation was led by Richard Rodriguez; it was his fifth decade of accident investigation.) The investigation again showcased the continuing trend toward conducting extensive scientific re-

A new century American Airlines 587.

search programs as part of accident investigations. In the case of Flight 261, one topic that was studied extensively was the effect of lubricating grease. In the end, the Safety Board ruled that the cause of the accident was the failure of the horizontal stabilizer's actuating mechanism as a result of excessive wear caused by the airline's inadequate lubrication during maintenance. Once again, as was the case in Aloha Airlines and the Chicago O'Hare DC-10 accident, a maintenance deficiency had reared its ugly head.

In November of 2001, another deadly accident, the second deadliest in U.S. history in fact, occurred right after takeoff from New York's JFK Airport. American Airlines Flight 587, and Airbus A300, crashed into a residential area after its composite vertical stabilizer separated in flight. A total of 260 persons on the airplane and five on the ground were killed. The use of composite materials in aviation components suddenly took the spot light. The accident is still under investigation. It is interesting to note that the first fatality in U.S. history, that of Lt. Selfridge, also involved a "composite" airplane (the Wright Flyer), which plummeted to the ground as a result of its vertical stabilizer/rudder becoming partially separated from the aircraft.

The *Columbia* space shuttle

After the space shuttle *Challenger* accident of 1986, it seemed that the U.S. space program was safely and quietly progressing under the radar of public scrutiny due to nearly a hundred more successful missions. But suddenly, 17 years after the *Challenger* disaster, on February 1 of this year, the space shuttle *Columbia* disintegrated in the atmosphere during its return to Kennedy Space Center. Seven more astronauts lost their lives. Remembering the public response from the *Challenger* accident, NASA immediately was forthright and candid in divulging information regarding the accident. Another independent commission was formed, similar to the Rogers Commission, and was called the *Columbia* Accident Investigation Board (CAIB). It is being led by Retired Admiral Harold W. Gehman, Jr., and includes 14 experts in physics, space sciences, military and civilian accident investigation, and other disciplines Their report is expected to be released this month.

One of the authors participated as an advisor to the CAIB for a short period of time. The CAIB members used somewhat unorthodox accident investigation methodologies, but they appear to have been serving them well. Rather than first breaking up into numerous groups and generating field notes/group factual reports for a variety of disciplines, the Board basically developed several "working scenarios" by reviewing telemetry data, examining wreckage, interviewing key persons, and listening to detailed briefings given to them by NASA and their own staff. The Board then attempted to fit the developing facts into the scenarios to prove or disprove each, all the while making frequent public appearances to expound on their thoughts. In the end, they declared that the most probable working scenario involved the damage of the *Columbia's* left wing's leading edge due to impact with a piece of foam that came off the shuttle's external fuel tank during launch. The damaged leading edge allowed extreme heat to penetrate the *Columbia's* structure and initiate its disintegration during reentry.

The CAIB was also stunned to learn that NASA management had been aware of the potential hazards of external tank foam debris, but did not take adequate action to correct them. Additionally, CAIB members have cited a reduction in funding and emphasis on safety in NASA's shuttle program. These underlying factors were very similar to the Rogers Commission on *Challenger*. History repeated itself.

The more things change…

After a hundred years of aviation accidents, many things have changed in the methodologies and hardware of accident investigation. The magnifying glass has given way to the scanning electron microscope. Rotary-dial telephones have been replaced by satellite cell phones and text pagers. Paper archives have been replaced by the Internet and digital storage. Wool coats and black ties have given way to biohazard suits. Pencil and paper documentation of wreckage is being overtaken by 3-D scanning and software for reconstruction. Topographical maps and compasses are being superseded by hand-held global positioning satellite (GPS) receivers. The negatives of a 35 mm film have been replaced by digital photography. Needle impressions from "steam gage" cockpit indicators have been replaced by non-volatile memory chips. The typewriter has given way to the laptop.

By the same token, things have remained very much the same over the past 100 years. The news media and the public continue to speculate in the wake of a crash investigation. General aviation pilots continue to die in the same types of weather-related accidents. New technological advances in aviation continue to prove deadly when misunderstood or misused. Management complacency and ignorance of safety continue to be unforgiving. Inde-

Space shuttle reconstruction layout.

pendent, objective, and thorough investigations continue to save lives through lessons learned. Most importantly, what has remained the same despite all of the changes in aviation is the air safety investigator's dedication to prevent accidents through investigation.

Where do we go from here? If we are smart, we will learn from history and not be "doomed to repeat it." We must constantly improve. It has been said that if we remain satisfied with the current airline accident rate, then, in a few years, the world will experience one airline hull loss per week due to the proliferation of the flying population. This is a challenge to us. Perhaps advances such as cockpit video recorders, enhanced GPWS, real-time download and analysis of flight parameters, and increased training and stature for mechanics will help ameliorate the current accident rate.

In the end, however, it will be the air safety investigator's iron will to make aviation safer. Accident investigation must remain, as it has for the last 100 years, a noble mission to save lives through knowledge and recommendations to prevent future accidents. ◆

References

Adair, Bill. *The Mystery of Flight 427: Inside a Crash Investigation*, Smithsonian Institution Press: Washington, D.C., 2002.

Bureau of Air Commerce, "Report of Airship 'Hindenburg' Accident Investigation." Bureau of Air Commerce, Air Commerce Bulletin, August 15, 1937, Washington, D.C.

Civil Aeronautics Board. "Accident Investigation Report: United Air Lines, Inc., Bryce Canyon, Utah, October, 1947" Civil Aeronautics Board. File No. 1-0097-47. February 3, 1948.

Columbia Accident Investigation Board Press Release PA 27-03. "*Columbia* Accident Investigation Board Releases Working Scenario." May 6, 2003.

Crouch, Tom D., *The Bishop's Boys: A Life of Wilbur and Orville Wright*, W.W. Norton: New York, 1989.

Crouch, Tom D., Jakab, Peter L., *The Wright Brothers and the Invention of the Aerial Age*, National Geographic: Washington, D.C., 2003.

Eckert, William G., MD. "The Rockne Crash: American Commercial Air Crash Investigation in the Early Years," *American Journal of Forensic Medicine and Pathology*, Volume 3, Number 1, March 1982.

Guzzetti, Jeffrey, Interview with Richard Rodriguez. National Transportation Safety Board Senior Air Safety Investigator. Washington, D.C., June 4, 2003.

Hallion, Richard P. *Test Pilots*, University of Washington Press, 1981.

Hallion, Richard P. *Legacy of Flight*, University of Washington Press, 1977.

Hallion, Richard P., *The Wright Brothers: Heirs of Prometheus*, Smithsonian Institution Press: Washington, D.C., 1978.

Jakab, Peter L. and Young, Rick, (eds.) *The Published Writings of Wilbur and Orville Wright*, Smithsonian Institution Press: Washington, D.C., 2002.

Lahm, Frank P., 1st LT, U.S. Army Signal Corps. "Report of the Accident to the Wright Aeroplane at Ft. Myer, Virginia, on September 17, 1908." 1908.

Mallan, Lloyd, *Great Air Disasters*, Fawcett Publications, Inc.: Greenwich, Connecticut. Book No. 517, 1962.

Nance, John J., *Blind Trust*. William Morrow and Company, Inc.: New York, New York, 1986.

National Advisory Committee for Aeronautics, "Aircraft Accidents: Method of Analysis" Report No. 357. Prepared by the Committee on Aircraft Accidents, NACA, Washington, D.C., January 28, 1930.

National Transportation Safety Board Aircraft Accident Report. "Trans World Airlines, Inc. Boeing 727-231, N54328, Berryville, Virginia, December 1, 1974." Report Number AAR-75-16.

Oliver, David. *British Military Aircraft Accidents: The Last 25 Years,* Ian Allen Ltd.: Shepperton, Surrey, 1990.

Owen, David. *Air Accident Investigation*, Haynes Publishing: Somerset, United Kingdom. 1998.

Quinn, John. "JFK Jr.'s Final Flight Blasted out of the Sky," www.freeworldalliance.com 1999.

"Report of the Presidential Commission on the Space Shuttle *Challenger* Accident," June 6, 1986.

"Rockne Died Gangsters' Victims." *Washington Times,* January 6, 1933.

Strauch, Barry, and Frank Richey. "Training Facility will Prepare Safety Experts for Increasingly Complex Investigations," Journal of the International Civil Aviation Organization. Number 4, 2003.

Wald, Mathew L. and Schwartz, John. "Board Criticizes Shuttle Oversight," the *New York Times,* July 12, 2003.

The Emergency and Abnormal Situations Project

By Barbara K. Burian, Ph.D., SJSUF / NASA Ames Research Center; R. Key Dismukes, Ph.D., NASA Ames Research Center; and Immanuel Barshi, Ph.D., NASA Ames Research Center

__Dr. Barbara Burian__ is the Emergency and Abnormal Situations (EAS) Project Director, working through San Jose State University at the NASA Ames Research Center. The EAS Project is a large, multiyear project that examines a variety of issues and factors that affect the ways in which flight crews and others respond to emergency and abnormal situations on the flight deck. Burian is also involved in work and research related to pilot weather training and knowledge and the influence emotion has upon pilot decision making. She has a bachelor's degree in education from Ohio State University and master's and doctoral degrees in psychology from Southern Illinois University in Carbondale. She completed a predoctoral internship and post-doctoral residency at the University of Florida and the University of Miami Medical Center, respectively. She was awarded Stanford/San Jose State University/NASA/ASEE Faculty Fellowships in 1999 and 2000. She left academia and 10 years of clinical practice, with a specialty in Post Traumatic Stress Disorder, to work at the NASA Ames Research Center full-time in August 2000. She is a certificated private pilot and plans to complete her instrument rating "any day now."

This paper reviews the objectives, goals, and issues being addressed in the Emergency and Abnormal Situations (EAS) Project currently under way in the Human Factors Research and Technology Division of the NASA Ames Research Center.[1] Examples of various issues being covered in the project that are evident in recent aviation accidents are provided.

Introduction and overview

Emergency and abnormal situations represent unique challenges in air carrier operations. They are often time critical and complex, and the nature of the underlying problem is sometimes ambiguous. Almost by definition they involve high-stress and high-workload conditions that require exceptionally high levels of coordination inside and outside of the airplane. Executing emergency and abnormal procedures depends on cognitive processes that are fragile under the combination of high workload, time pressure, and stress. Some procedures are confusing or difficult to complete, and many procedures focus on responding to malfunctioning aircraft systems rather than guiding crews to manage the situation as a whole. Although these procedures must be executed correctly and efficiently when needed in line operations, crews have infrequent opportunity to practice them.

The aviation industry lacks substantive human performance guidelines for designing, validating, certifying, and training procedures for emergency and abnormal situations. It is tremendously challenging to design procedures that are robust in the face of real-world ambiguities, workload demands, and time constraints and that are well matched to human cognitive processes and limitations. Pilot initial and recurrent training currently provides limited opportunity to practice emergency and abnormal procedures in the context of real-word demands (e.g., coordinating with ATC, dispatch, maintenance, and cabin crew; avoiding other traffic; responding to emergencies in deteriorating weather conditions).

The Emergency and Abnormal Situations (EAS) Project was undertaken to address these and related concerns, which are discussed in greater detail below. Our overriding goal for this Project is to develop guidance for procedure and checklist development and certification, training, crew coordination, and situation management based on knowledge of the operational environment, human performance limitations and capabilities, and cognitive vulnerabilities in real-world emergency and abnormal situations.

We are working toward this goal through several focused studies in close collaboration and consultation with partners from the aviation community. Ultimately we will produce a series of field guides that will summarize what we learn and provide guidelines for best practices targeted to the specific needs of various populations within the aviation industry. Although the project is largely oriented around the flight crew, to understand the issues affecting crews' ability to manage non-normal situations we must also consider their interaction with other players in the aviation system who help manage these situations, especially cabin crew, controllers, dispatchers, and mechanics.[2] We are also concerned with the roles of manufacturers, regulatory agencies, and air carriers in developing equipment, procedures, checklists, written guidance, and training for use in non-normal situations.

Table 1: EAS Project Taxonomy of the Domain

Broad Overarching Issues
- Philosophies, Policies, and Practices of Dealing with Emergencies and Abnormal Situations
- Economic and Regulatory Pressures
- Definitions and Perspectives

Issues Related to Checklists and Procedures
- Development of Checklists and Procedures
- Checklist Structure and Design
- Checklist Type and Availability

Issues Related to Humans
- Crew Coordination and Response
- Checklist Use
- Human Performance
- Personnel Issues
- Roles of Others

Issues Related to Training
- Flight and Cabin Crew Emergency Training

Issues Related to the Aircraft
- Critical Aircraft Systems
- Automation Issues

Emergency Equipment and Evacuations
- Selected Emergency Equipment and Evacuation Issues

EAS Project—taxonomy of the domain

This Project addresses many diverse issues and concerns. We have sorted these into 15 categories, grouped in six larger areas, which we refer to as the "Taxonomy of the Domain" (Table 1). This taxonomy helps guide our work in the focused studies. In this paper, organized around our taxonomy, we sketch out the issues and illustrate them with examples from airline accidents.[3]

Broad, overarching issues

Three categories in the taxonomy relate to rather broad, overarching issues. The first involves **philosophies, policies, and practices of dealing with emergencies and abnormal situations.** Here, we are concerned with how the philosophies, policies, and practices of manufacturers, regulatory agencies, and air carriers shape the materials and guidance they provide flight and cabin crews, air traffic controllers, and others who must directly respond to emergency and abnormal situations. We are also interested in how the perceptions, attitudes, and practices of those directly involved in these situations influence their performance. For example, checklists from different organizations vary in the degree to which they focus on troubleshooting a problem versus simply isolating the problem to allow continued flight in a non-normal condition. The extent of explanatory or annotated information included in checklists also varies. Both of these issues are driven by checklist designers' philosophies regarding the desired role of flight crews when responding to non-normal situations and the degree of knowledge that crews are expected to have, and be able to readily retrieve from memory, during situations that often challenge human information processing capabilities.

We are also interested in the ways that **economic and regulatory pressures** influence how the various players involved in non-normal situations respond to the demands of those situations. Several issues revolve around **definitions and perspectives**, which is a third category in our taxonomy. For example, what is the difference between an emergency and an abnormal situation? Does such a distinction matter, and if so, when, or under what circumstances? How do procedures and checklists differ? And, what are the objectives and goals of emergency and abnormal checklists and the steps that comprise them? The answers to these questions have great relevance for checklist and procedure development and design and for the best ways to manage non-normal situations.

Examples from recent accidents

Following the inflight fire and subsequent crash of a MD-11 off the coast of Nova Scotia, Canada, on Sept. 2, 1998, the Transportation Safety Board (TSB) of Canada studied 15 inflight fires that occurred over 31 years (TSB, 2003). The Board determined that the average amount of time between the detection of an onboard fire and the point at which the aircraft ditched, conducted a forced landing, or crashed was 17 minutes. Seventeen minutes is not a lot of time to complete a diversion from cruise altitude, and half of these flights had less than that amount of time.

Examination of the smoke-related checklists available to the crew of this MD-11 reveals a series of checklist steps designed to isolate the origin of the smoke, followed by a list of system limitations and consequences related to the identified inoperative system (TSB, 2003). The final step at the bottom of the second checklist the crew would have likely accessed states: "If smoke/fumes are not eliminated, land at nearest suitable airport." The ELECTRICAL SMOKE OR FIRE checklist available to the crew of a DC-9 that crashed in the Florida Everglades on May 11, 1996, (National Transportation Safety Board (NTSB), 1997) also contains numerous steps designed to isolate the source of the smoke. Unlike the second MD-11 checklist, however, this checklist contained no item regarding diverting to a nearby airport. In these two accidents, because of the speed with which the fires on board spread, it is unlikely that the crashes could have been avoided even if the crews had diverted to make emergency landings as soon as the fires were discovered (TSB, 2003; NTSB, 1997). However, in other accidents a prompt decision to conduct an emergency descent and landing might mean the difference between life and death. Thus, it is important to evaluate the underlying philosophies illustrated by the design of these checklists.

When are crews to consider that their problem may be so serious that a diversion is required? Only after attempts at isolation have failed? If the isolation or elimination of smoke is not attempted, will the crews become so incapacitated that a diversion is not possible? How often are crews able to successfully isolate and eliminate smoke or extinguish a fire and continue their flights to their planned destinations? If this happens in the vast majority of these situations, then, perhaps, placing a checklist step related to diverting at the end of a checklist would not seem unreasonable. Conversely, however, if even one catastrophic accident might be averted by a crew making a diversion at the first sign of trouble, then perhaps "Divert to the nearest airport" should be at or near the top of a smoke or fire checklist, even if it means that many flights are diverted unnecessarily. This of course is a policy decision involving cost-benefit tradeoffs. This clearly illustrates how philosophy and economic issues may influence checklist design.

Another accident illustrates the ways different job responsibilities of individuals involved in managing inflight emergencies can influence their perspectives and actions. Below are four excerpts from the cockpit voice recorder (CVR) transcript of an MD-83 that crashed off the coast of California on Jan. 31, 2000 (NTSB, 2002). This first was an exchange between the captain (CA) and a company dispatcher (DIS) over the radio:

DIS: …If uh you want to land at LA of course for safety reasons we will do that uh wu we'll uh tell you though that if we land in LA uh we'll be looking at probably an hour to an hour and a half we have a major flow program going right now uh that's for ATC back in San Francisco.

CA: Well uh yu you eh huh…boy you put me in a spot here um….

CA: I really didn't want to hear about the flow being the reason you're calling us cause I'm concerned about overflying suitable airports.

DIS: Well we wanna do what's safe so if that's what you feel is uh safe we just wanna make sure you have all of the uh…all the info.

CA: Yea we we kinda assumed that we had…what's the uh the wind again there in San Francisco?

Soon after this exchange, the captain was recorded saying to someone on the flight deck (most likely a flight attendant):

CA: …just…drives me nuts…not that I wanna go on about it you know, it just blows me away they think we're gonna land, they're gonna fix it, now they're worried about the flow. I'm sorry this airplane's idn't gonna go anywhere for a while….

The dispatcher was concerned about the movement of aircraft and adherence to a schedule—central aspects of a dispatcher's job. It is not clear from this transcript that the dispatcher was aware how serious the problem faced by the captain was. However, the captain by this time was clearly aware that their situation was serious, based upon the other recorded comment and his concern in the first exchange about over-flying airports suitable for an emergency landing. (His concern about "overflying suitable airports" may have also been motivated by a desire to not violate legal requirements included in the federal aviation regulations.)

The captain decided to continue toward San Francisco until landing data could be obtained at which time they would turn back and begin their decent for a landing at Los Angeles International Airport (LAX). Soon thereafter, in a conversation with an operations agent (OPS) in Los Angeles, the following exchange was recorded:

OPS: Ok also uh….just be advised uh because you're an international arrival we have to get landing rights. I don't know how long that's gonna take me…but uh I have to clear it all through Customs first.

CA: Ok I unders…I remember this is complicated. Yea well. Better start that now cause we're comin to you.

Following this exchange, the captain talked with an individual from maintenance (MX. It appears that the crew had also consulted with maintenance prior to the beginning of the CVR transcript):

MX: Yea did you try the suitcase handles and the pickle switches, right?

CA: Yea we tried everything together, uh…we've run just about everything….

MX: um yea I just wanted to know if you tried the pickles switches and the suitcase handles to see if it was movin in with any of the uh other switches other than the uh suitcase handles alone or nothing.

CA: Yea we tried just about every iteration.

MX: And alternate's inop too huh?

CA: Yup, its just it appears to be jammed the uh the whole thing it spikes out when we use the primary. We got AC load that tells me the motor's tryin to run but the brake won't move it when we use the alternate. Nothing happens.

In the conversation with the operations agent, the captain was frustrated. He knew he had a serious problem on his hands but the operations agent was concerned with making sure all logistics were in order. The maintenance technician was trying to help the crew troubleshoot their problem. Taking care of logistics and fixing things that are broken on airplanes is what operations agents and maintenance personnel do. Both were trying to do their jobs as they normally do them. It can be very difficult for individuals to set aside the mindset for their normal mode of operation—be it scheduling airplanes, taking care of landing logistics, troubleshooting systems problems, or flying an aircraft from point A to B— to recognize and communicate the severity of a situation and to put all other considerations aside in order to get the airplane safely on the ground. Cognitive research has demonstrated that individuals are slow to revise an established mindset even when aware of circumstances that should compel revision. (Klein, 1998).

Issues related to checklists and procedures

The issues grouped in the next three categories in the EAS project taxonomy of the domain pertain to the checklists and procedures used in emergency and abnormal situations. In the **Development of Checklists and Procedures** category, we are concerned with what checklists and procedures are developed and by whom. What types of situations warrant the development of a checklist? When and how are changes to checklists made and recorded? How is regulatory approval obtained for checklists and procedures? What guidance exists for developers and regulatory agencies regarding checklist development and design? How well do checklists and procedures reflect the realities of the operational environment and to what degree, if any, can they be standardized across different aircraft fleets?

The **Checklist Structure and Design** category includes many important issues that influence the degree to which checklists are useful to the crews, including which items are placed on checklists and where, missing or incorrect items, the length of time required to complete a checklist, and the inclusion (or exclusion) of memory or recall items. We are concerned with how well crews are able navigate within a checklist (to find the actions appropriate for their specific situation) and what features help crews locate the proper checklist in the first place (e.g., organization, indexing, nomenclature, etc.). We are interested in whether or not normal checklist steps are integrated with non-normal checklists and the consistency of the checklists and procedures used by the flight crews with those used by cabin crews, with the MELs, and with other material the flight crews may reference. Of course, we are also interested in style guide, formatting, and layout considerations.

In the **Checklist Type and Availability** category, we are concerned with issues related to the modality used for the presentation of checklists (i.e., paper, mechanical, integrated electronic, non-integrated electronic, etc.) and the ways that crews must physically access the checklists. Issues related to computerized prioritization schemes that determine which integrated electronic checklists are displayed first are also considered under this category.

Examples from recent accidents

On Jan. 7, 1996, the crew of a DC-9 had difficulty raising the landing gear on their departure climbout (NTSB, 1996). They used the UNABLE TO RAISE GEAR LEVER procedure that was included in their quick reference handbook (QRH). Although this allowed them to resolve their gear problem, a few minutes later they realized that the cabin pressurization and takeoff warning systems were still in the ground mode. As directed by the same checklist, the crew pulled the ground control relay circuit breakers to place the systems in the flight mode.

In a later portion of the UNABLE TO RAISE GEAR LEVER checklist, under a heading entitled "Approach and landing," was a checklist step directing the crews to reset the circuit breakers.

The crew did this while on final approach into Nashville, approximately 100 feet (30.5 meters) above the ground. Upon doing this, however, related systems immediately went into the ground mode causing the ground spoilers to deploy. The aircraft lost lift, hit the ground very hard, and the nosewheel separated from the aircraft. The aircraft bounced into the air and the crew was able to complete a successful go-around procedure and landed on a different runway.

Other than including the item instructing the crew to reset the ground control relay circuit breakers in an "Approach and landing" section of the QRH checklist, no further guidance was given to the crew about specifically when or how this step was to be completed. However, in the expanded or annotated checklists that appear in the aircraft operating manual (AOM), such guidance was given: "Reset Ground Control Relay circuit breakers during taxi and verify that circuits are in the ground mode." Yet according to interviews with the accident flight crew and other pilots employed by the same air carrier, they were trained to refer only to the QRH when handling an emergency or abnormal situation. Some people may argue that the accident crew should have been able to reason out that these circuit breakers should only be reset once on the ground. We believe that crews should have all information necessary for the proper completion of checklist steps in the primary resource referenced (in this case, the QRH) so that such reasoning is not required when time may be limited and workload and stress may be high.

Another example of a checklist- or procedure-related issue can be found in the accident of a C21A (a U.S. military version of a Learjet 35A) that occurred in Alexander City, Ala., on April 17, 1995 (Fuel Imbalance Cited, 2000). During the flight, unknown to the crew, the right standby fuel pump continued to operate uncommanded after engine start because of two bonded contacts on the fuel control panel. This prevented fuel from being transferred to the right wing during normal fuel transfer procedures and resulted in a severe fuel imbalance as fuel was pumped from the right to the left wing tank. The crew incorrectly believed that the fuel in the left wing had become "trapped" and that both engines were using fuel from the right wing. Fearing an imminent dual-engine flameout, the crew attempted an emergency landing but lost control and all eight individuals on board perished.

The crew's flight manual did not contain a checklist for correcting a fuel imbalance that occurs during the transfer of fuel. Such a checklist was available from the manufacturer at the time of the accident, however, but the operator did not contract for flight manual updates from the manufacturer after purchasing the aircraft.

Issues related to humans

Until the day that commercial transport-category aircraft fly without pilots, cabin crew, dispatchers, and air traffic controllers, the human element will continue to be crucial in the response to emergency and abnormal situations. In the EAS Project, issues specifically related to humans in these situations comprise five taxonomy categories.

Issues such as the distribution of workload and tasks, decision making, prioritization of tasks, and accurate assessment of the nature of the threat and the degree of risk are considered under the **Crew Coordination and Response** category. Issues related to communication, coordination, and crew resource management (CRM) within and between flight and cabin crews are also considered. We are also concerned with the ways in which vulnerability to confusion, fixation, distraction, and overload may affect how well crews are able to manage non-normal situations.

Under **Checklist Use** we are interested in errors made by crews such as inadvertently skipping checklist items, misunderstanding directions, or completing the wrong conditional branch for the specific situation. We are examining situations in which checklists or procedures were not used at all or in which they were accessed but not complied with. We are also considering the amount of "blind faith" crews place in checklists or procedures for dealing with emergency or abnormal situations.

As research psychologists, we are particularly interested in **Human Performance** under high-stress and high-workload conditions. We are examining the effects of stress and time pressure on attention, retrieval from memory, and problem solving. We are interested in the conditions, factors, and cues that affect pilots' ability to recall procedural and declarative knowledge under stress and heavy workload. Flight crews' emotional or affective response to stress is also being considered within this category.

Under the **Personnel Issues** category we are examining the influence that background, previous experiences, initial training, and experience levels may have on pilots' response to non-normal situations. We are interested in the effect that flight crew size (two-person crews, three-person crews) and cabin crew size has on situation response and the influence that company mergers can have on working relations, communication, and how non-normal situations are handled.

We are not just considering the response of flight and cabin crews to these situations but also the **Roles of Others** involved in the situations. Air traffic controllers, dispatchers, maintenance personnel, airport rescue and firefighting personnel, MedLink, and even passengers each play important parts in how these situations are resolved. A high degree of communication and coordination between these various groups is essential for the successful outcome of emergency and abnormal situations. The degree to which the procedures and checklists of different parties are consistent with and compliment each other is particularly important.

Examples from recent accidents

On May 12, 1996, a B-727 experienced a rapid decompression and performed an emergency landing at Indianapolis, Ind. (NTSB, 1998a). While showing the flight engineer how to silence a cabin altitude warning that sounded right before reaching their cruise altitude of 33,000 ft. (10058.4 meters), the captain noticed that the second pack was off. The captain instructed the flight engineer to reinstate it. The flight engineer stated that he turned the right pack on and then "went to manual AC and closed the outflow valve." When taking these actions the flight engineer did not refer to the PACK REINSTATEMENT FOLLOWING AUTO PACK TRIP checklist, which is fairly lengthy. Also, instead of closing the outflow valve, the flight engineer actually opened it and the aircraft rapidly lost pressurization.

During this event, the captain, flight engineer, and lead flight attendant, who had been on the flight deck at the time, briefly lost consciousness. The first officer, who was the pilot flying and was still on his initial operating experience in the B-727, performed an emergency descent and they landed without further incident. However, the captain did not call for and the crew did not complete any emergency checklists, including the decompression checklist or the emergency descent checklist. The captain did not put his oxygen mask on immediately when the altitude warning sounded, as required by procedures—fortunately, the first officer did immediately don his mask.

An accident involving a DC-10 near Newburgh, N.Y., on Sept. 5, 1996 (NTSB, 1998b), provides several good examples of issues related to human performance under stress. During cruise at 33,000 ft. (10058.4 meters) the cabin/cargo smoke warning light illuminated and the crew very quickly realized that they had a real fire on their hands. The flight engineer announced, and the crew completed, the memory items from the SMOKE AND FIRE checklist and then the flight engineer accessed the printed checklist and continued to execute it. However, without input from the captain, the flight engineer chose to complete the conditional branch on the checklist for "If Descent is NOT Required." The captain did command an emergency descent and diversion to the closest airport but only somewhat later—three-and-one-half minutes after the warning light had first illuminated. Prior to this he was preoccupied with the warning indicators, testing the fire-detection system, and other cockpit duties.

The flight engineer missed two steps on the CABIN/CARGO SMOKE LIGHT ILLUMINATED checklist, which was the next checklist he conducted. The captain was busy monitoring the progress of the fire and coordinating the diversion with ATC and the first officer, who remained the pilot flying throughout the flight. The captain did not notice the flight engineer's errors and did not call for any checklists, although required by company procedures to do so. The emergency descent checklist and the evacuation checklists were never accessed or completed. While the flight engineer was attempting to complete the two emergency checklists he did access, he was also trying to complete the normal approach and landing checklists and obtain data needed for figuring the landing speeds. Upon landing, the missed checklist items and uncompleted checklists resulted in the aircraft remaining partially pressurized, which impeded and delayed the crew's evacuation.

This was a very serious emergency, and the crew and two jumpseat riders barely escaped the burning aircraft. The influence of the great stress and overload the crew was experiencing was evident in many ways. The captain delayed making the decision to divert and land and never called for any checklists to be completed. He did not adequately monitor the flight engineer's completion of the checklists and mistakenly transmitted his remarks to the crew over the ATC frequency on several occasions. The flight engineer missed checklist items, did not adequately monitor the status of the aircraft pressurization on descent, and five times over the span of 6 minutes, he asked for the three-letter identifier of the airport they were diverting to so he could obtain landing data from an onboard computer. Although he was told the identifier at least twice, he apparently never heard it. During an interview following the incident, the flight engineer reported that he had felt very overloaded.

Issues related to training

The **Training** that flight and cabin crews receive regarding emergency and abnormal situations is also an important area we are examining. We are looking at various training technologies and approaches used for dealing with these situations during both initial and recurrent training. We are interested in issues related to skill acquisition and retention, especially of procedures that are rarely practiced or even discussed. We are particularly interested in training to help prepare crews to deal with "non-standard" or ambiguous problems and how to respond to situations in which multiple problems occur concurrently

Examples from recent accidents

A particularly tragic example of some of these training issues can be found in the crash of a BAe Jetstream 32 that lost control on approach to the airport at Raleigh Durham, N.C., on Dec. 13, 1994 (Commuter captain, 1996). At the final approach fix descending through 2,100 ft. (640 meters), with the power levers at flight idle, an illuminated ignition light led the captain to believe that the left engine had flamed out. The captain, who was the pilot flying, did not feather the propeller, secure the engine, or undertake any abnormal or emergency procedures associated with an engine failure. During a missed approach procedure, the captain lost control of the aircraft and it struck terrain. Three passengers survived the accident.

The illuminated ignition light was actually a "minor transient anomaly" (Commuter captain, 1996, p. 8) and it was later determined that both engines had functioned normally throughout the flight until impact. However, in the accident investigation it was discovered that the company had incorrectly trained their flight crews to always associate an illuminated ignition light with an engine failure. During the accident investigation, it was also determined that training provided by the company did not adequately address the recognition of an engine failure at low power and company records did not provide enough evidence that training performance was properly monitored and managed.

Issues related to the aircraft

We are also looking at issues related to the aircraft that influence the outcome of non-normal situations. In a category we have named **Critical Aircraft Systems,** we are interested in the role that systems with flight protection envelopes might play in how these situations are handled. We are also interested in how cockpit warnings and warning systems may facilitate or impede a crew's response.

Automation Issues are also important to consider in these situations. We are interested in learning what level and types of automation are most appropriate to use and under what conditions. We are exploring the degree to which uncritical acceptance of automation may lead crews to misdiagnose or respond incorrectly to a non-normal situation. We are also interested in comparing procedures for emergency and abnormal situations between highly automated aircraft and less automated aircraft. Issues involving reverting to manual flying and degradation of hand-flying skills are also being considered.

Examples from recent accidents

Two recent accidents provide examples of how aircraft and automation issues factor in the resolution of emergency and abnormal situations. One accident occurred on Dec. 27, 1991, at Gottrora, Sweden, and involved an MD-81 that experienced a dual-engine failure shortly after departure from Stockholm (Martensson, 1995). The day was snowy and windy, with temperatures hovering around freezing. On lift off, clear ice broke off the wings and was ingested by the engines, damaging the fan stages. This damage caused the engines to surge—the right one began to surge 25 seconds after lift off, the left one 39 seconds later. At 3,194 ft. (973.5 meters) both engines lost power. Grey smoked filled the cockpit and the electronic flight instrument system (EFIS) went blank, forcing the crew to attempt an emergency landing using only back-up instruments. Despite the aircraft breaking into three pieces on landing, all 129 on board survived.

On climbout the crew did not notice that engine power was increased automatically by the automatic thrust restoration (ATR) feature. This increase in engine power increased the intensity of the surging and contributed to the failure of the engines. During the accident investigation, it was discovered that the airline company had no knowledge of the ATR feature.

Issues related to automation and warning systems are illustrated by an accident involving a B-757 that lost control off the coast of the Dominican Republic on Feb. 2, 1996 (Walters & Sumwalt, 2000). During the takeoff roll, the captain indicated that his airspeed indicator was not working. It appeared to start working once the aircraft began to climb but significant discrepancies appeared between the captain's, first officer's, and alternate airspeed indicators. A few seconds later two advisory messages appeared on the engine indicating and crew alerting system (EICAS) display: RUDDER RATIO and MACH/SPD TRIM.

By this time, the captain's airspeed indicator showed a very high speed and the overspeed warning clacker sounded. Additionally, the center autopilot commanded an 18-degree nose-up attitude and the autothrottles moved to a very low power setting in an attempt to bring the speed down. Adding to the crew's bewilderment, the stall warning "stickshaker" activated and the autopilot and autothrottles automatically disengaged. As the crew tried to sort out the true nature of their problem, they applied power and then removed it more than once. The first officer selected Altitude Hold on the mode control panel in an attempt to level off and to stabilize the aircraft. However, the throttles were at too low of a power setting to maintain altitude so the selection of Altitude Hold was ineffectual. The aircraft crashed into the ocean a short time later and all lives on board were lost.

Investigators later determined that the pitot tube providing information to the left air data computer (ADC) had most likely been completely blocked and consequently the information provided by the left ADC to the captain's airspeed indicator and the center autopilot was erroneous. The crew did not attempt to clarify the RUDDER RATIO or MACH/SPD TRIM advisories; however, it is unlikely that they had time to do so or that the related checklists would have proved useful to them. The relation of these two particular messages to the difference in the captain's and first officer's indicated airspeeds is far from intuitive and is not information generally included in checklists related to these messages. There was no specific airspeed discrepancy warning on the B-757.

Although the crew agreed that the alternate airspeed indictor was displaying correct airspeed information, they were distracted by and continued to try to use (and be confused by) airspeed information on the primary flight displays. The contradictory warnings and indicators were greatly confusing to the crew, and the center autopilot and autothrottles contributed greatly to their problems, at least initially. Additionally, the crew did not try to fly the aircraft manually; they continued to try use automation (i.e., Altitude Hold) in ways that did not help them. During normal operations the use of automation can be confusing for crews; under non-normal conditions, these problems are likely exacerbated.

Selected issues related to emergency equipment and evacuations

Finally, the EAS project is addressing a selected subset of issues involving **Emergency Equipment and Evacuations.** Some equipment provided to flight and cabin crews for emergency or abnormal situations can be problematic to use, for example, smoke goggles that do not fit over eyeglasses. Another issue is whether crews receive adequate training and practice to be proficient in use of emergency equipment. We are also interested in whether differences in emergency equipment among different aircraft configurations and types create vulnerability to confusion and error by flight attendants. Although the EAS Project is not addressing the full range of evacuation issues, we are concerned with issues such as the decision whether to evacuate and communication between the cabin and the cockpit.

Examples from recent accidents

There have been many accidents in which problems with emergency equipment impeded a flight or cabin crew's response to an emergency. One such accident occurred in Maui, Hawaii, on April 28, 1988, when an 18 ft. section of fuselage separated from a B-727-200 as it was leveling out at a cruise altitude of 24,000 ft. (7315.2 meters), causing an explosive decompression (NTSB, 1989). Although the crew was able to land at Maui 13 minutes after the event occurred, the first officer had to hold the oxygen mask on her head and to her face because it was so large that it kept sliding around and communication was very difficult through the oxygen mask microphone.

Problems with communication between the cabin and flight crews likely influenced the evacuation of a flight on March 26, 2003 in Flushing, N.Y. (NTSB, 2003; preliminary report). Nearing the final approach fix, the engine and alert display (EAD) of a B-717-200 indicated that the left generator had failed. The display units and standby instruments went dark and then began flashing randomly. The flight crew noticed a burning smell in the cockpit. The forward flight attendants also noticed a burning smell in the cabin and determined that the handset used to make announcements and contact the cockpit was inoperative. After landing, the lead flight attendant tried to get the attention of the flight crew by banging on the cockpit door and speaking loudly. The flight crew reported that they heard neither the banging nor the loud talking through the door. This incident is currently under investigation so it is still unknown if the flight crew did not hear the flight attendant because they were preoccupied with other duties or if the reinforced security door precluded communication.

Conclusion

Fortunately, serious accidents, such as the ones we have reviewed, are infrequent in airline operations. However, emergency and abnormal situations occur on flights across the world everyday. These situations are inherently challenging and require highly skilled performance by flight crews and close coordination among all those assisting them. Many issues are involved in this large domain, more than can be answered definitely by any one project. By identifying latent vulnerabilities and delineating issues, the

EAS Project will lay a foundation for establishing best practices. In this way, we hope to help prevent emergency and abnormal situations from becoming accidents. ◆

Footnotes

[1] The Emergency and Abnormal Situations Project is funded through the Training Element of NASA's Aviation Safety and Security Program.

[2] For simplicity, the term "non-normal situations" will occasionally be used to refer to both emergency and abnormal situations.

[3] All accident-related information included in this paper has been taken from the reports of the investigative bodies involved.

References

Commuter Captain Fails to Follow Emergency Procedures After Suspected Engine Failure, Loses Control of the Aircraft During Instrument Approach. (1996). *Flight Safety Foundation—Accident Prevention, 53(4).*

Fuel Imbalance Cited in Learjet 35A Control Loss. (2000). *Flight Safety Foundation—Accident Prevention, 57(2).*

Klein, G. A. (1998). *Sources of power: How people make decisions.* Cambridge, MA: MIT Press.

Martensson, L. (1995). The Aircraft Crash at Gottrora: Experiences of the Cockpit Crew. *The International Journal of Aviation Psychology, 5(3) 305-326.*

National Transportation Safety Board. (1989). *Aloha Airlines Flight 243, Boeing 737-200, N73711, Near Maui, Hawaii, April 28, 1988.* Washington, D.C.: Author (NTIS No. PB89-910404).

National Transportation Safety Board. (1996). *Ground Spoiler Activation in Flight/Hard Landing, ValuJet Airlines Flight 558, Douglas DC-9-32, N922W, Nashville, Tennessee, January 7,1996.* Washington, D.C.: Author (NTIS No. PB96-910407).

National Transportation Safety Board. (1997). *In-flight Fire and Impact with Terrain, ValuJet Airlines, Flight 592, Douglas DC-9-32, N904VJ, Everglades, Near Miami Florida, May 11, 1996.* Washington, D.C.: Author (NTIS No. PB97-910406).

National Transportation Safety Board. (1998a). *American Trans Air Flight 406, Boeing 727-290, N775AT, Indianapolis, IN, May 12, 1996 (NTSB ID No. CHI96IA157).* Abstract Retrieved July 16, 2003, from http://www.ntsb.gov/ntsb/brief.asp?ev_id=20001208X05709&key=1.

National Transportation Safety Board. (1998b). *In-Flight Fire/Emergency Landing, Federal Express Flight 1406, Douglas DC-10-10, N68055, Newburgh, New York, September 5, 1996.* Washington, D.C.: Author (NTIS No. PB98-910403).

National Transportation Safety Board. (2002). *Loss of Control and Impact with Pacific Ocean, Alaska Airlines Flight 261, McDonnell Douglas MD-83, N963AS, About 2.7 Miles North of Anacapa Island, California, January 31, 2000*. Washington, D.C: Author. (NTIS No. PB-2002-910401).

National Transportation Safety Board. (2003). *Air Tran Airways Flight 356, B717-200, N957AT, Flushing, NY, March 26, 2003 (NTSB ID No. NYC03FA067).* Preliminary Report Retrieved July 16, 2003 from http://www.ntsb.gov/ntsb/brief.asp?ev_id=20030409X00464&key=1.

Transportation Safety Board of Canada. (2003). *In-Flight Fire Leading to Collision with Water. Swissair Transport Limited, McDonnell Douglas MD-11 HB-IWF, Peggy's Cove, Nova Scotia 5 nm SW, 2 September 1998 (TSB Report No. A98H0003).* Gatineau, Quebec: Author.

Walters, J.M., & Sumwalt, R.L., III. (2000). *Aircraft Accident Analysis: Final Reports*. Chap. 4, pp. 75-87. New York: McGraw-Hill.

Acknowledgements

Richard Geven, Todd Kowalski, and Sean Belcher, members of the EAS Project Team, assisted in locating information used in the preparation of this paper. Appreciation is extended to Ben Berman and Tom Chidester who provided thoughtful and helpful comments in their review of an earlier draft of this paper.

SESSION II

Accident Reconstruction—The Decision Process

By John W. Purvis (MO3002), Partner, Safety Services International

***John Purvis** is an internationally recognized expert in large aircraft accident investigations. For 41 years, he worked at the Boeing Company, leading Boeing's commercial airplane investigative team for 17 years. When he retired at the end of 1998, he and his partner, Kevin Darcy, formed an aviation safety consulting business, Safety Services International (SSI). He is currently instructing at the Southern California Safety Institute and is a member of its Advisory Board. In 2001, he earned ISASI's prestigious Jerome F. Lederer Award for outstanding contributions to the industry.*

During my more than two decades of accident investigation experience, several issues have increasingly gnawed at the back of my mind. One of those is what I perceive as the seemingly haphazard industry process for deciding when to reconstruct wreckage as part of an accident investigation. In my quest for information, I approached many of the world's leading investigators and discovered, not to my surprise, that the decision process for reconstruction **is** very loose and poorly documented. Sometime mockups or reconstructions just seem to happen.

There seemed to be general agreement that the system could, and should, be improved. This paper examines the current practices and the various levels of accident reconstruction—from a simple, minor parts layout up through complex 2-D and 3-D mockups of major portions of an airplane. In addition, it will suggest certain steps the investigator can take to ensure there is value in doing a reconstruction. Finally, it will look to the future for new ideas.

Before we get into the details, let's define what we are talking about. In my correspondence, I have used the words *mockup* and *reconstruction* interchangeably. In my mind they are one in the same. They are part of the system of collecting physical wreckage from land or under water, sorting it, usually by airplane section, and after a period of investigation, laying it out in some organized fashion.

This paper will discuss the mockup and its decision process—what happens after the parts are recovered—it will not talk about the actual recovery process of the physical wreckage, or even the initial sorting process.

Why do a reconstruction in the first place? Clearly, a reconstruction is an excellent investigative tool when used properly. It can be the key for determining the existence of clues leading to the causes of the event. It can eliminate certain ideas as well. Some of the things you may be looking for can include

- structural inflight breakup—breakup patterns, sequence, loss of parts, etc.
- progress and effects of fire, smoke, and heat—fire or smoke patterns
- missile or gun projectile, meteor hits, space debris, etc.
- mid-air collision
- overpressure, such as from a bomb or other explosion
- chemical residue of an explosive device
- missing pieces
- interactions between different airplane systems

No doubt more items could be added to this list, but this covers the majority.

Sometimes there are other ways to get the information needed to establish causes. For example, if you believe that an explosion occurred in a lavatory, recovering just the portions of that lavatory, without doing a major mockup, may be possible. One could take chemical swabs from the lavatory components and have them analyzed. On the other hand, one may wish to at least build a mini-mockup of the lavatory area and nearby surrounding structure to more exactly determine the effects of an explosion.

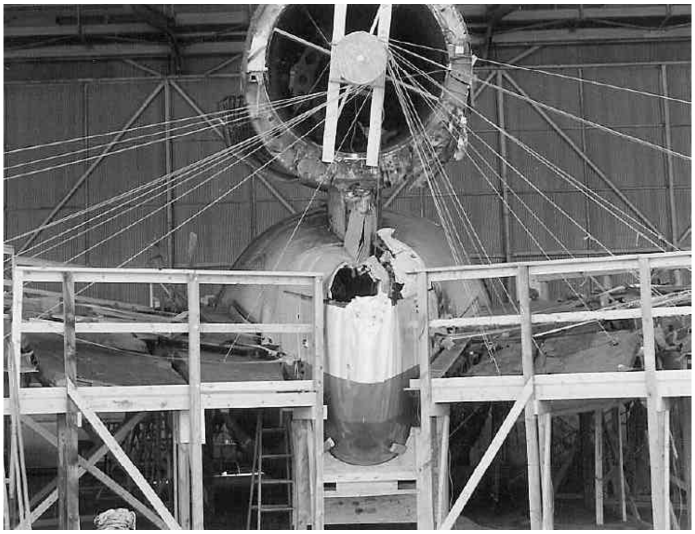
Let's look at the technical issues that may support a need for reconstruction.

- Evidence from full body X-rays and autopsies, burns, and smoke inhalation
- Search for explosives
- Evidence of fire and smoke on the structures and systems—the need to determine origin and progress patterns
- Parts found some distance from the wreckage sites
- Major missing parts
- Evidence from other systems analysis
- Evidence derived from a basic, simple layout

Even if the causes of the accident have already been established, the mockup can play an important role in preventing a similar situation. For example, if you suspect there was a bomb in a cargo hold, the mockup may lead you to look at a breakup sequence and help you determine where to make changes to the airplane or its operating procedures to control venting so that the overpressure won't cause catastrophic structural damage. Or you could develop stronger cargo containers or other means to control the overpressure.

What kind of mockups are we talking about? There are several, each having increased complexity. The reconstruction can be as simple as a reassembly of just a few significant pieces of wreckage. This would typically be done on a hangar floor to examine a limited area of the airplane. It's a basic 2-D layout, done flat on the hangar floor, or even a simple 3-D construction such as the lavatory we just mentioned. Graduating from there would be a more complex 2-D layout where more of the airplane is laid out on the floor. Finally, there is the complex 3-D mockup, either of a limited section or system of the airplane or a rebuild of an entire section. Let's examine these one by one.

Basic, simple layout—The decision process is likewise simple. The mockup might be done as, say, a structural group activity, with the group chairman making the decision. The cost of such a layout can be very low since it could be accomplished with exist-



Limited 3-D mockup applying to a specific area in question (UAL DC-10, Souix City).

Aft pressure bulkhead 3-D mockup (JAL B-747, 1985).

ing personnel and in existing space. Some sort of a layout like this is done in most accidents. Potentially, this can be as basic as laying out a few pieces to visualize their relationships, to look for witness marks or to examine burn or smoke patterns. In many cases, this may be all that is necessary to assist the investigator in determining probable cause. The simple layout is often the starting point for a more formal decision to go further. All mockups have the added benefit of providing a visual inventory of the wreckage recovered.

Comprehensive 2-D mockup—These are also commonly done and can be extensive but still quite cost effective. The tools to make a larger 2-D mockup can be a tape measure, masking tape, some chalk, a clean floor, and basic technical information. It can be indoors or outdoors. The need for a roof would be driven by the expected length of the investigation and the weather. For technical information, you'll need a diagram, probably from the manufacturer, of the area under study.

For example, in the Air Florida 737 accident in 1982, where the airplane ended up in the Potomac River near Washington, D.C., we had an entire hangar floor available and were able to lay out the parts of the airplane as they were recovered from the River. As this developed, we were able to visualize what we had, what was missing, and where the basic parts of the airplane had separated. Eventually, other information from the investigation such as the recorders began to supercede the need for a layout and this effort was halted. However, given the high profile of the accident and the unknown situation in the early days of the investigation, it was a prudent first step to take. The decision to proceed was made by the IIC after consulting with his group chairmen.

Once the tape measure and chalk have been used to mark the outline of the area to be mocked up, putting down masking tape will help with the visualization. Another trick would be to "scale up" the area being looked at. Scaling-up means providing additional space between the pieces by enlarging the space allotted for the layout by up to 20 percent. This allows you to walk between the pieces to visualize/examine them as well as facilitate moving the parts into position. It will also ensure that torn edges will not rub one another and damage the fracture surfaces or remove other evidence. Further, it will provide extra space for laying out the upper and lower surfaces in the same area, although for detailed layouts separate areas would be used for the two surfaces. A 2-D mockup can eventually be converted to a 3-D mockup, if needed.

3-D mockups—These can be the ultimate in physical reconstruction, depending on their extent. However, going to a 3-D mockup is not for the feint of heart, and it comes with political overtones. The costs rise astronomically because of the demands for space and manpower. The physical facilities will be in use longer because of the length of time the mockup will be under construction and preserved. Some large 3-D mockups may require the formation of a separate "reconstruction group" to staff and manage the process. Further, significant effort will be expended on a database to track the parts being hung on the frame. On a major reconstruction, the frame alone can cost tens of thousands of dollars. The overall cost for a major mockup can run into several millions of dollars.

On the positive side, a 3-D mockup has distinct advantages that no other investigative tool offers. It can show the presence or absence of causes, such as penetration or missile impact. It will create sightlines that could provide other clues. These may help reduce or eliminate outside pet theories. On the other hand, it may allow an insight that didn't exist before. It may eliminate or confirm potential criminal activity. It can give a good visualization of missing pieces. Three-dimensional relationships are easier to visualize, especially those involving fire or smoke patterns or curling and bending of parts.

However, not all areas of the world are created equal. Some poorer States may not have the technical capabilities to accomplish a major reconstruction. More importantly, they may not have the financial resources to pay for such an unusual effort.

What is the answer to this costs and resources dilemma? Some years ago (ISASI Boston 1999), I presented a paper entitled "Who Should Bear the Burden for Extraordinary Investigative Costs?" The same ideas that were outlined to assist with recovery costs could be applied to mockups, since they could also be considered extraordinary. These solutions might include worldwide insurance or a fund supported by governments or a service tax. Indeed, the NTSB has proposed to ICAO that means be found to help with costs of extraordinary investigations. I expect this issue will once again surface at the next ICAO AIG meeting.

One fact stands out loud and clear in my data collecting. In my search for inputs, I found that large 3-D mockups often do not add much to the technical understanding, and it is difficult to keep them simple, safe, and uncluttered. My experts seem to think that an extensive mockup is rarely required for a technical investigation. Rather they are important for show and tell. It is "sexy" from the media standpoint and makes excellent fodder for the media and politicians. It can provide both public and political support for the investigative agency in a quest for recognition, budget, or manpower. This is important to understand and appreciate—there can be good and valid reasons and demands, besides technical, that may sway a decision for a mockup. More about this later.

Along with this, it seems that once a major mockup gets started, it is difficult to stop the momentum, even if the thrust of the investigation changes. The decision process of where to stop and how much of the airplane you REALLY need should be determined ahead of time by the right people involved in the investigation. At the same time, there must be flexibility and understanding if the plan needs to be altered or reversed.

Quite often, the floor space occupied by a 3-D mockup could be more productive for other uses. Cost, space, and manpower are only part of the consideration. What will you do with this expensive edifice once the investigation is no longer necessary? As one of my experts said, "They are hell to dust."

Below is a list of some accidents that involved 3-D reconstructions. It is far from a comprehensive list but rather presented as examples where large mockups were used.

- Swissair 111, MD-11 (forward fuselage)
- Air France, Concorde (fuel tanks and wings)
- TWA 800, 747 (center fuselage/center wing tank)
- United Sioux City, DC-10 (center engine/tail)
- Pan Am Lockerbie, 747 (center fuselage)
- ValuJet, DC-9 (cargo compartment)

Virtual mockups—As computer power grows and methods of digitizing objects improves, there is a growing interest in the virtual mockup, along the line of computer-aided design (CAD programs) currently used to design parts or manufacturing processes. Much of the software is still being developed, but investigators need to understand what is waiting in the wings. At this time, a virtual mockup is typically being done after the 3-D mockup is in place. It is good for cataloguing the rescued pieces and determining what may be missing. It provides another option for the investigator, but its cost and pros and cons are still to be determined.

One of the possible downsides of this new technology is the ability to manipulate digitized data and the need for systems that ensure absolute data security.

During this conference you will hear an excellent paper prepared by people from the Aviation Safety Council (ASC) of Taiwan. It will cover the use of their impressive Three Dimensional Software Reconstruction and Presentation System (3D-SWRPS) in the CI611 747 accident. It will also discuss the capabilities of integrating several sets of data to accomplish other tasks such as simulating the inflight breakup sequence. Play close attention to their paper; this is exciting stuff. The ASC has done an amazing job—because of their effort the future is here, right now.

Eventually, it will be possible to jump directly to a virtual mockup, bypassing the need for a physical 2-D or 3-D mockup. Consider this: we take our digitizing devices to the accident site and digitize the wreckage through a photographic or laser process by taking multiple views of each piece of wreckage. These are then manipulated onto a 3-D view of each part and applied to a virtual frame. The technique will first become common with land-based accidents because the pieces can be easily accessed and digitized. Eventually, the technology may allow us to go under water using remotely operated vehicles, digitizing parts in place, thus eliminating the need of bringing them to the surface. Further it may be possible to do very close up digitizing of fracture surfaces, burn patterns, and other features and apply them to the frame separately.

Jig/frame for Swissair MD-11 3-D mockup (photo courtesy TSB Canada).

Let's not fool ourselves. As mentioned previously, there are many non-technical reasons for building some form of mockup, especially a 3-D mockup. As investigators, we probably don't like to hear that the process can be driven by anything but the need for technical information, but it seems to be true. Politics and pressures from the public, families, and media all play roles in whether to build a mockup and how far to take it. There seems to be a desire on the part of the investigative agencies to show off their work. It has PR value. The grand 3-D mockup has value in obtaining budget, and it could even play a role in personal image building. These are major driving factors and usually underestimated by investigative teams.

All of these may be valid reasons—if they are accepted by the investigative team as priorities during the planning stages. The time, cost, and manpower need to be understood and a determination made that there are no better ways to use these resources. Let's summarize some of the resources required.

- Additional parts may be needed
- Hangar space and roofing needs
- Money, and lots of it
- Labor
- Consider an "expanded" mockup—where you make the layout larger than the original design to allow room for interiors, visualization, analysis, and access
- Time
- Management support
- A safe physical frame (3D) designed for the job and with space for adding interiors, carpets, seats, systems, etc., if necessary
- Knowledgeable, professional help (say to build a good frame)
- Multiple mockups (2D or 3D) to cover separate systems or areas of the airplane

- Know where the mockup's final resting place will be—and have a design that allows it to be relocated

So, where are we? In the ideal world, the decision process would be technically based and made primarily by the technical team of investigators. Economics would not play a role. Politics and public pressures would be minimal. The decision to move ahead with a simple, 2-D or 3-D mockup would prove to be wise and produce valuable results. (It would "solve" the accident.) The decision to halt the process would be acceptable at any point without retribution.

But we live in a real world. Mockups may not be as valuable as hoped, especially 3-D mockups, when considering the time, money, and effort spent to create them and the space they occupy. I was surprised to discover in my research that there are no well-thought-out, formal plans for the full process. Once a decision has been made to construct a mockup, it is difficult to stop or change direction. The extent of the reconstructions often exceeds technical needs. Finally, when the mockups are complete, they can take on lives of their own beyond the consideration of technical value. No one has thought about "what are we going to do with it?" It can become a monument, a museum piece, or an expensive white elephant looking for a home.

Summary

The decision process for constructing a mockup is just a small part of the overall management of an investigation. Typically, project management oversight includes the resources and their allocation, the people and their assignments, budget, travel, and research. This should also include, as a distinct and separate item, the reconstruction decision process. In my search, I could not find any organization with an existing formal process setting out the ground rules and decision process leading to a "go" or "no go" of a reconstruction. Mostly, I found it was a "seat of the pants" decision process, handed down informally over the years and accomplished somewhat haphazardly in the heat of the battle. As mentioned earlier, sometimes mockups seem to—just happen.

To improve the process, consider the following:

- It is a major decision; act accordingly.
- Think about what you have, what you need (and what of that you can reasonably expect to get), and what you are trying to accomplish
- Consider delaying the mockup decision process while other facets of the investigation proceed; it may turn out you don't need one
- Involve all the interested parties in the decision process
- Attempt to minimize the effects of politics, cost, time, and space requirements or, at least, understand them
- Proceed up the chain, starting with a basic, 2-D construction and do it in a logical, well-planned way
- Avoid making it an open-ended research project
- Have a plan and stick with it
- Have an end point in mind

The bottom line is the same: Have a process and follow it.

The preceding discussion has been a distillation of my thoughts garnered over 45 years of aviation experience and supplemented by generous inputs from numerous expert investigators from all over the world. It should not be taken as the ultimate word on the reconstruction decision process but rather as one step in an attempt to get investigators to think about where they are going before launching off on an expensive and time-consuming project that ultimately may be unnecessary. As the ASC presentation demonstrates, this is a rapidly changing world progressing far more quickly than we can track individually. Thanks to venues like this ISASI seminar, we can learn from each other. ◆

CI611 and GE791 Wreckage Recovery Operations—Comparisons And Lessons Learned

By David Lee*[1], Steven Su *[2], and Kay Yong **, Aviation Safety Council, Taiwan, ROC

David Lee is an Aviation Safety Investigator, ASC, Taiwan, and the Wreckage Recovery Group Chairman of CI611 Accident Investigation.

Abstract

On May 25, 2002, approximately 1507 Taipei local time (UTC 2307), China Airlines Flight CI611, a Boeing 747-200 aircraft, with 209 passengers and 16 crewmembers on board, vanished from the ATC radar screen. The CI611 departed from Taipei enroute to Hong Kong. It was later found that the aircraft had an inflight breakup and crashed into the Taiwan Strait near Penghu Islands. The crashed site, located approximately 15 nm northwest from Makung on Penghu proper, covered an area 30 square nautical miles with an average ocean depth of about 70 meters (230 ft). All 225 people on board Flight CI611 perished. On Dec. 21, 2002, approximately 0137 Taipei local time (UTC 0937), TransAsia Flight GE791, an ATR 72 cargo aircraft, with two crewmembers on board, crashed into the ocean located approximately 10 nm southwest of Makung, Penghu Island. Both crewmembers perished from the accident. The wreckages were distributed within an area of 160 meters by 260 meters with the depth of approximately 60 meters. Both accident aircraft were equipped with a flight data recorder and cockpit voice recorder.

The Aviation Safety Council, an independent government investigation agency of the ROC, is the investigation authority of the two accidents. In the case of CI611, the U.S. NTSB is the accredited representative with Boeing and Pratt and Whitney as the supporting parties to the NTSB. In the case of GE791 accident investigation, BEA of France is the accredited representative with ATR of France as the supporting party. At the time of this writing, investigations of those two accidents are still under way and no probable causal factors are identified. Although both accidents occurred around the same proximity of the Penghu Islands, wreckage recovery operations and environmental conditions, including the recovery of recorders, were quite different. This paper presents the wreckage and recorder recovery operations for both accidents, as well as lessons learned from those two operations. Since the underwater wreckage recovery operation often is far more complex than the land operation in the accident investigation process, the associated costs are also higher than the land operation; both issues will be discussed in this paper.

I. Introduction

Accident sites could be anywhere, inside an airport, on a mountain, or at sea. ASC has investigated 25 occurrences in 5 years of existence. There are 21 accident sites on land and four accident sites on water, which include two helicopter accidents in rivers and two Part 121 aircraft accidents in Taiwan Strait. These two accidents are the CI611 accident on May 25, 2002, and the GE791 accident on Dec. 21, 2002. The time between these two accidents is about seven months, one in summer and the other one in winter. The aircraft size, breakup situation, weather, and marine meteorology are quite different.

II. Underwater recovery

2.1 Weather and marine meteorology

CI611: The CI611 accident occurred on May 25, 2002. In May the weather in Taiwan is getting hot. The weather and marine meteorology at Taiwan Strait in summer is usually good, except for the visiting typhoon. During the CI611 wreckage recovery period, the wind speed varied from 8-21 knots, gusts to 40 knots. The underwater recovery team also encountered two typhoons. Each typhoon's visit interrupted the recovery operation for about 4 days, but it did not seriously affect the operation. The current speed varied from 2 to 5 knots. The depth of the water is from 50 meters to 70 meters. The seabed is sandy and flat. Generally speaking, the environment in summer and fall at Taiwan Strait is friendly to underwater recovery operation.

GE791: The GE791 accident occurred on Dec. 21, 2002. The accident site is about 62 kilometers from the CI611 accident site. From October to February, the Taiwan Strait is usually very windy; the weather and marine meteorology are poor. During the GE791 wreckage recovery period, the wind speed varied from 13 to 33 knots, gusts to 55 knots. The current speed varied from 3 to 7 knots. The depth of the water is about 60 meters. There are many coral reefs on the seabed. The wave height varied from 2 meters to 6 meters. Generally, the environment in winter at Taiwan Strait is adverse to an underwater recovery operation.

2.2 Factors of underwater recovery planning

CI611 was the first accident ASC dealt with regarding underwater recovery in the ocean. This was also the first time Taiwan had undergone a search-and-rescue operation for more than 200 people in the water. We have limited knowledge and almost no experience for this kind of accident. Initially the Coast Guard started to rescue the floating victims and recovered floating wreckage debris. ASC called the State of the aircraft manufacturer, the NTSB, Taiwan's CAA, and the operator, China Airlines, to be part of the investigation team. When the accident happened, the radar data from Taipei Area Control Center and floating debris positions from Taiwan's Coast Guard were available. The most important thing at that time was the planning of the underwater recovery. We calculated the radar track and estimated the possible wreckage distribution pattern. The last transponder position obtained from the secondary radar data was used as a primary reference point, and we continued to develop the flight recorders and wreckage recovery plan. The following factors were considered during the planning process:

Radar data: Radar data are the most useful record for the search of missing aircraft. The contents of radar data include time, latitude, longitude, mode-C altitude, ground speed, and track angle. In fact, the raw radar data could be the primary or secondary signal returns (sometimes they are denoted as PSR and SSR). Only the SSR could track the aircraft with transponder code, Mode-C altitude, and position. SSR data were used to compute the azimuth angle and slant range to determine the position of target; these targets could be the inflight breakup clues or irrelevant signal in the sky. The most important factors in processing the primary radar data are to obtain the position, magnetic deviation, and altitude of radar station. In order to calculate the radar track precisely, the WGS-84 coordinate system was selected, for the integration of the radar data, salvage position, and flight data into a master map. In additional, the doppler weather radar was also used to detect the airborne debris.

Floating debris and oil trail: After the accident happened, it was not difficult to find the floating debris and oil trail, which was affected by the current and tide. We considered the current speed and direction at the time of accident when we wanted to use the position of floating debris. The position of floating objects would become less and less effective for reference when time passed by. Updated sonar/ROV data: As the underwater wreckage was found, the search plan was modified accordingly.

Equipment: Side-scan sonar was used to depict the picture of the seabed. Depending on the equipment and survey method, this technology could survey a large area with low resolution or small area with high resolution. Multi-beam sonar detection was also used to check the depth of the water with high resolution. A remote operated vehicle (ROV) is necessary for underwater recovery. An ROV with high-intensity light and color video camera can help to verify the wreckage.

Weather and marine meteorology: Weather and marine meteorology always affect underwater recovery. Usually the survey equipment and vessel can be operated only when the weather conditions are favorable. Bad weather or meteorology conditions usually requires more powerful vessels and equipment, therefore adding cost to the recovery operation.

2.3 Recorder search and recovery

Recorder search requires proper detection equipment and supporting vessels. The underwater locate beacon (ULB or pinger) is installed with the flight recorder. The pinger would transmit 37.5khz supersonic sonar every second as the pinger was immersed in the water. The signal is conductive in water, but not in sand or soil. Usually the standard output is about 160db? Pa@1m. However, if the pinger was in the sand or part of the pinger was in sand, the output would be attenuated. The ULB signal can be detected by the pinger receiver. A good receiver may detect the pinger signal from 1 nm away. The distance depends on the sensitivity of the receiver, output of the pinger, the conducting media, and the environmental condition. We may not know the effective distance of the pinger receiver in hand. The pinger receiver should be tested with a pinger in similar water condition for planning. The supporting vessel should not to be too big. Under good marine meteorology conditions, a small boat is easy to move and to start and shut down the engine.

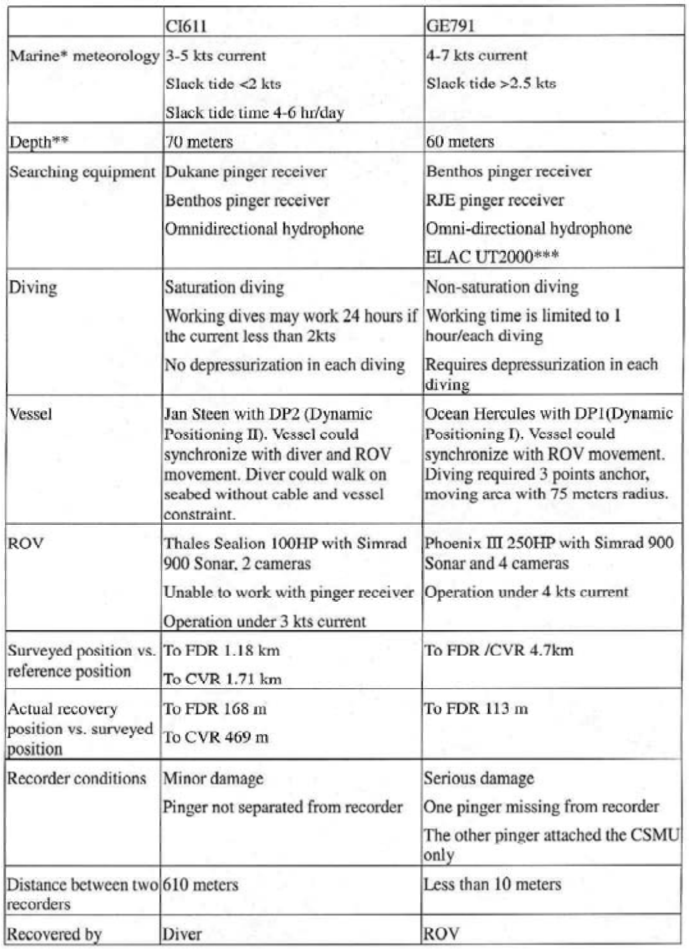
The approach in searching for the pinger signal could be simplified into five steps.

1. Equipment test: Use a pinger to test the function and distance of the pinger receiver or detection equipment.
2. Select reference point: Usually the position of the last transponder return is a good reference.
3. Plan search area: Once we have the distance of the pinger receiver and reference point, we could make the reference position as the center in the grid. The search area may be set about 10 km X 10 km. Sometimes we may consider the radar track, wind, and current to shift the grid related to the reference point. Depending on the marine meteorology; the supporting vessel should go with or against the current, rather than across the current.
4. Water surface search: The common pinger receiver is used to detect the signal by human hearing. Experience in detection operation is essential. Because the signal is detected by human hearing, the environmental noise should be as low as possible. If possible, the engine should be shut down to reduce the environmental noise.
5. Underwater searching: When several positions of the pinger signal are detected, we can use the triangulation method to locate the pinger as close as we can. Usually the pinger is within a few hundreds meters of the probable position with water surface searching. When the water is less than 50 meters deep, it's not difficult to find the pinger with non-saturation diving. If the water is deeper than 50 meters, saturation diving and a working vessel with dynamic positing system are vital to the operation.

If the impact force was high, the pinger may separate from the recorder. We should understand finding the pinger does not equal finding the recorder. However, there is a higher probability of finding the recorder at the vicinity of the pinger.

The major differences between the CI611 and GE791 recorder search operation were experience and marine meteorology. In CI611, ASC had no underwater recovery experience. We encountered not only technical problems but also resource coordination difficulties. Although we were not familiar with underwater technology, we had great assistance from our national resources and international investigation parties. Fortunately, from May to September, the weather and marine meteorology was general favorable. We recovered both recorders 25 days after the accident. The GE791 crashed in Taiwan Strait on December 21. The weather and marine meteorology were very bad almost everyday. In bad environmental conditions, the common pinger receivers were not very useful. Usually the sonar drum of the pinger receiver was submerged in water about 1-2 meters deep. In bad marine meteorology, the 4-meter-high wave moved the boat up and down and therefore moved the sonar drum out of water frequently. That induced noise on the pinger receiver. To reduce the noise, we shut down the boat engine. The boat was then moved by the rocky current, and the workers on board became very uncomfortable. The wind noise directly interfered with human hearing. Since it was very difficult to use the pinger on water surface, we tried to detect the signal by diving 10 meters under the water's surface. Although the noise effect was much better, it took longer time for every dive. It was also unreliable, because the divers were moved by the current and could not stay at a fixed location (the current would move the divers 1 nm from initial location after 20 minutes in water). To solve this difficulty, the search team tried to use the underwater communication system to find the pinger. The underwater communication system is built in the research vessel, which has multiple-functions, including side-scan sonar, multi-beam sonar, ROV, and a dynamic positioning system. We adjusted the carrier frequency of underwater communication system to 37.5 khz. With this approach, we isolated the outside noise and gained a precise position of the detection point. Eventually the pinger signal was found and then confirmed by the pinger receiver. After 20 days of searching, we found only one pinger signal by water surface searching. Table 1 shows the comparison between the CI611 and the GE791 recorder search.

Table 1: CI611and GE791 Recorder Searching and Recovery Comparisons.



	CI611	GE791
Marine* meteorology	3-5 kts current Slack tide <2 kts Slack tide time 4-6 hr/day	4-7 kts current Slack tide >2.5 kts
Depth**	70 meters	60 meters
Searching equipment	Dukane pinger receiver Benthos pinger receiver Omnidirectional hydrophone	Benthos pinger receiver RJE pinger receiver Omni-directional hydrophone ELAC UT2000***
Diving	Saturation diving Working dives may work 24 hours if the current less than 2kts No depressurization in each diving	Non-saturation diving Working time is limited to 1 hour/each diving Requires depressurization in each diving
Vessel	Jan Steen with DP2 (Dynamic Positioning II). Vessel could synchronize with diver and ROV movement. Diver could walk on seabed without cable and vessel constraint.	Ocean Hercules with DP1(Dynamic Positioning I). Vessel could synchronize with ROV movement. Diving required 3 points anchor, moving area with 75 meters radius.
ROV	Thales Sealion 100HP with Simrad 900 Sonar, 2 cameras Unable to work with pinger receiver Operation under 3 kts current	Phoenix III 250HP with Simrad 900 Sonar and 4 cameras Operation under 4 kts current
Surveyed position vs. reference position	To FDR 1.18 km To CVR 1.71 km	To FDR /CVR 4.7km
Actual recovery position vs. surveyed position	To FDR 168 m To CVR 469 m	To FDR 113 m
Recorder conditions	Minor damage Pinger not separated from recorder	Serious damage One pinger missing from recorder The other pinger attached the CSMU only
Distance between two recorders	610 meters	Less than 10 meters
Recovered by	Diver	ROV

*Diving requires current less than 2 knots.
**Fifty meters is a threshold for diving, all divers, procedure, and equipment required stringent control.
*** ELAC UT2000 is a underwater communication system.
****Diving never launched due to high current in GE791 recorder recovery

2.4 Wreckage survey and recovery

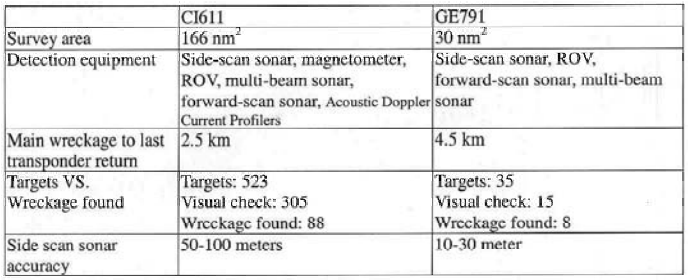
Underwater site survey: Underwater wreckage search primarily relies on sonar detection. Detection equipment transmits the sonar and receives the reflection from target. Targets with different size and material reflect different intensity. Comparing the difference to background, a sonar specialist could identify the suspect wreckage. The common sonar tools used to survey the seabed contour include side-scan sonar, multi-beam sonar, and forward scan sonar. The side-scan sonar system is commonly used for large area site survey.

Wreckage search could be simplified into five steps.

1. Select reference point: Initially we used the position of last transponder return as the reference point. Depending on the positions from primary radar data, oil trail, and wreckages detected/recovered, we could select many points for planning reference.
2. Plan survey area: Consider the scan range, scan resolution and scan speed of the detection equipment. We should assign the higher resolution equipment in the most probable accident area.
3. Coarse scanning: Use low-resolution and wide-range side-scan sonar to cover a large area in short time.
4. Fine scanning: After the highest concentration of the wreckage is found, we may use the highest resolution side-scan sonar in this area. Sometimes the multi-beam sonar could be used to depict the seabed contour in 1-meter resolution, but we need to know the position of the wreckage higher accuracy.
5. Visual check using underwater camera: Usually the cameras are installed on an ROV. Due to low visibility in deeper water, the high-intensity, color camera is required. Structure engineers from manufacturer and operator are required to identify the piece of wreckage from the monitor.

Table 2 shows the wreckage site survey comparison between CI611 and GE791.

Table 2: Wreckage Site Survey Comparison Between CI611 and GE791.



	CI611	GE791
Survey area	166 nm^2	30 nm^2
Detection equipment	Side-scan sonar, magnetometer, ROV, multi-beam sonar, forward-scan sonar, Acoustic Doppler Current Profilers	Side-scan sonar, ROV, forward-scan sonar, multi-beam sonar
Main wreckage to last transponder return	2.5 km	4.5 km
Targets VS. Wreckage found	Targets: 523 Visual check: 305 Wreckage found: 88	Targets: 35 Visual check: 15 Wreckage found: 8
Side scan sonar accuracy	50-100 meters	10-30 meter

Wreckage recovery: After checking wreckage visually, divers or an ROV may pickup the smaller wreckages. The large wreckage pieces require a crane. Before moving any wreckage, the wreckage needs to be documented by video thoroughly. Some important positions such as the lock, latch, and jackscrew need to be confirmed before moving. The engineers from manufactures are required to assist the diver to check positions of wreckage and how to wrap up large wreckage pieces. All wreckage needs to be transported to a temporary area or hangar for further inspection. During the transportation, especially from ship to ship, it is very easy to damage the wreckage again. The process is also dangerous to the worker; pay attention to the wind and current and make proper planning to reduce any risk.

Trawling operation: When all found wreckage is recovered, there may still be some wreckage to be recovered. The small pieces of wreckage can be picked up by trawling. The cost is much less than ROVs and divers. The disadvantages of a trawling operation are the lack of a precise wreckage position and a lack of a visual check before recovery. The trawling operation may also cause secondary damage. The limitations of a trawling operation include limited wreckage size, trawling net size, and wreckage transfer, etc. When the trawling net becomes stuck in the seabed rock, the net must be cut and left behind. Usually the trawling net is about 10 meters wide. There are many wreckages of the CI611 accident larger than 10 meters. It is impossible to recover large wreckage pieces with a trawling operation. The wreckage of the GE791 accident are in smaller pieces. The trawling operation was useful. Most of the underwater wreckage recovery of GE791 was by trawling operation. Only the engines were difficult to recover. The coverage rate of trawling is difficult to control. To increase the coverage rate, cross trawling in direction can be employed. However, the marine meteorology in Taiwan Strait during December, January, and February did not allow the cross operation; the trawling ships could operate only with current or against current. The planning of a trawling operation at least includes trawling area planning, selecting trawling ships, positioning system of ships, ships position tracking system, trawling area tracking system, and trawling tool selection. Table 3 shows the trawling operation comparison of CI611 and GE791 wreckage recovery.

Table 3: Trawling Operation Comparison of CI611 and GE791 Wreckage Recovery.

	CI611	GE791
Working period	09/10~10/21, 2002	02/15~02/21, 2003
Trawling area	19.5 nm^2	400mX250m (0.029 nm^2)
Trawling ships	5 (30-100 tons)	2 (30 tons and 50 tons)
Trawling net	10-meter-wide nylon net	10-meter-wide nylon net 5-meter-wide steel net
Ship position and tracking system	Integrated Navigation and Position Reporting System	Integrated Navigation and Position Reporting

2.5 Comparison between the two accidents

Wreckage distribution was the result from the aircraft breakup sequence, wind, current, altitude, and speed. If the wreckage was widely distributed, it may result from inflight breakup. If the wreckage distribution is very dense, it may result from impact breakup. The wreckage distribution would seriously be affected by wind, last altitude, and speed if it were an inflight breakup. While the aircraft impacts water, the distribution could be affected by current and contour of the seabed. Table 4 shows the comparison of the CI611 and GE791 accidents. From the wreckage distribution pattern, the CI611 was an inflight breakup case, and the GE791 was an impact breakup case.

III. Results and discussion

3.1 Conclusions

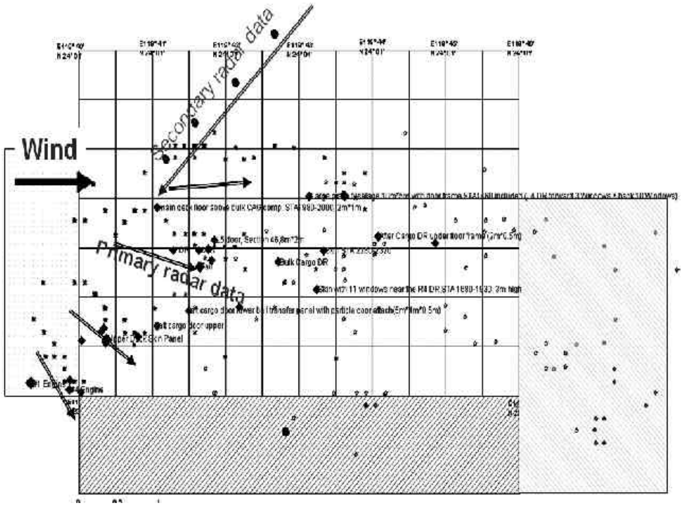
From the underwater recovery point of view, we concluded these two accidents as the following.

The wreckage distribution of the CI611 accident spread widely. This case is an inflight breakup accident. The resources required for wreckage and recorder recovery of this accident are huge and costly. Fortunately, the weather and marine meteorology were good for a long period time after the accident. However, the positioning system of side-scan sonar system was not accurate enough, which resulted in low efficiency of wreckage visual check by an ROV.

Table 4: Comparison of CI611 and GE791 accidents.

	CI611	GE791	Remarks
Aircraft length	70.7 m	27.17 m	
Wing span	59.6 m	27.05 m	
Cruise altitude	35,000ft	18,000ft	Prior to accident
Heading	234	240	Prior to accident
Derived grounds speed from radar data	429.9 knots	99.87 knots	Horizontal speed
Last recorded altitude from secondary radar data	34,900 ft	1,500 ft	
Last altitude recorded from FDR	34,573ft	< 3,027 ft	
Derived vertical speed from secondary radar data	3,272 fpm	-37,200 fpm	Estimated last vertical speed with aircraft powered
Last airspeed recorded from FDR	287 knots	433 knots	
Distance from cockpit to tail	1.474 km	Estimated less than 280 m	Only recovered part of GE791 wreckage
Distance between two wings	56 m	Estimated less than 280 m	Only recovered part of GE791 wreckage
Wreckage distribution pattern	From west to east 11.9 km From south to north 4.2 km (See Figure 1)	From northwest to southeast 280 m From northeast to southwest 90m (See Figure2)	While CI611 accident happened wind direction at 270 While GE791 accident happened, tidal current direction at 315

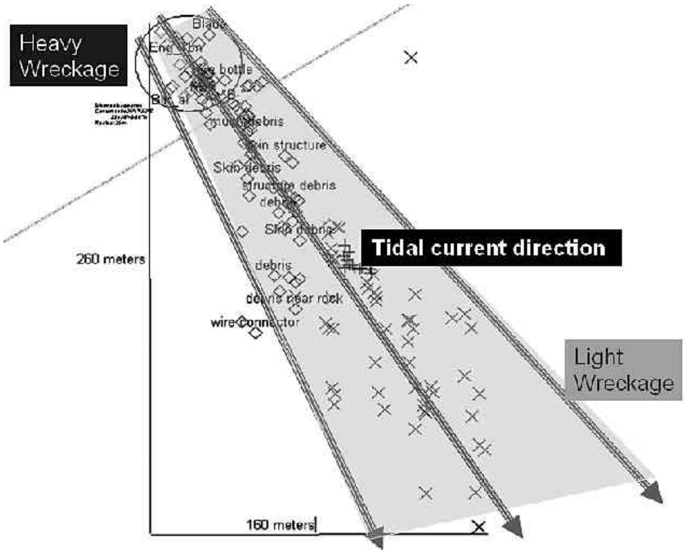
Figure 1: CI611 radar data and wreckage distribution pattern.



The wreckage distribution of GE791 was very dense. All wreckage was quite small except engines and landing gears. This case is an impact breakup accident. The weather and marine meteorology was bad and not suitable for wreckage recovery. The positioning system of side scan sonar was improved, which increased the efficiency of visual check by an ROV.

Underwater recovery is costly. Who shall be responsible for the expense of wreckage recovery is still an issue. There is no law to prescribe government, operator, owner, or anyone to pay in Taiwan. If the operator was not willing to pay for the recovery cost, that would adversely affect the accident investigation. ASC is currently proposing a special law for aviation accident investi-

Figure 2: GE791 wreckage distribution pattern.



gation that the expenses of underwater recovery shall be the responsibility of the government.

3.2 Lessons learned

Through the CI611 and GE791 accident underwater recovery process, we have learned the following lessons:

- Weather and marine meteorology are the primary factors for underwater recovery.
- Good planning is a must.
- Accuracy of radar track plays a major role in planning initial reference points.
- Adequate equipment is vital.
- Site survey before recovery is vital but may not be accurate.
- Floating wreckage has less significance in underwater wreckage recovery.
- Wreckage distribution pattern can be affected by in-air-breakup, impact breakup, flight path, impact speed, wind, and current.
- Positioning system of SSS, ROV, diving, and vessels affects the efficiency of recovery.
- Contour of seabed affects the recognition of wreckage by sonar.

3.3 Recommendations

To any agency that may take part in aviation accident underwater recovery, we have the following recommendations:

In search of recorders

- Use small and quiet boat with pinger receiver for surface survey.
- Use large vessel with equipment similar to UT2000 for surface survey, if weather is bad.
- Pinger receiver with bone conduction phone and compass is more user friendly to divers.
- Use pinger receiver with an ROV when diving is not allowed.

In wreckage recovery

- Precise side-scan sonar survey is required (towfish with beacon or IRS).
- Powerful ROV is required if current is high.
- For large wreckage recovery, skillful divers with proper equipment are a must. ◆

Footnotes

*1 Investigator
*2 Investigation Lab /Chief
** Managing Director

Application of the 3-D Software Wreckage Reconstruction Technology At the Aircraft Accident Investigation

Prepared by Wen-Lin, Guan *1 , Victor Liang *2 , Phil Tai *3 , and Kay Yong **,
Aviation Safety Council. Presented by Victor Liang.

Victor Liang is an engineer in the investigation laboratory, ASC, Taiwan, and Recorders & Performance Group member, CI611 Accident Investigation.

Abstract

The purpose of this paper is to present a methodology and application of a three-dimensional-software-reconstruction and presentation system (3D-SWRPS). This system was developed to support the investigation of China Airlines Flight CI611 inflight breakup accident that occurred on May 25, 2002. The accident aircraft was a B-747-200 carrying 19 crewmembers and 206 passengers. The accident occurred near Penghu Island in the Taiwan Strait. All 225 people onboard the aircraft perished in this accident. The Aviation Safety Council, an independent government organization responsible for all civil aircraft accident and serious incident investigation, has been investigating the accident. At the moment of this writing, this investigation is still ongoing, and probable causes of this accident have not yet been determined. The 3D-SWRPS utilizes a combination of the computer 3-D-graphic techniques, laser scanning of wreckages recovered, structure frame of a Boeing 747-200 cargo aircraft, and a generic CATIA engineering model of the same type of aircraft. It can provide sub-centimeter accuracy in the reconstruction process, and can be used to determine fracture behavior and propagation of stress of breakup. In addition, the 3D-SWRPS can combine radar return signal, wreckage salvage data, and a ballistic simulation program to assist in the analysis of the breakup sequence. It is believed that this technology would play an important role in supporting future accident investigation.

I. Introduction

When an aircraft accident happens, investigation begins on scene: searching for and subsequent readout of the flight recorders, gathering relevant factual data, drafting analytical topics, finding out probable causes, and proposing safety recommendations, etc.

The above work process is familiar to everyone in this field; however, for an inflight breakup accident such as Pan American Flight 103 (PA103, 747-100) [1], Trans World Airlines Flight 800 (TWA800, 747-141) [2], or Swissair Flight 111 (SR111, MD-11) [3], wreckage reconstruction becomes an important method to help factual evidence collection and the following task of analysis.

There are several relevant applications associated with wreckage reconstruction: finite element analysis (FEA), for the research of structure stress and metal fatigue; computational fluid dynamics (CFD), for verification of flow fields; evaluation of human-mechanics interface and flight controls by engineering flight simulators. For example, in hard landing investigations for a MD-11 and EMB-145, FEA was used to examine the stress of landing gears and support structures [4][5].

After the Air France Concorde accident in 2000, academic researches at the University of Leeds applied CFD to analyze the Concorde's phenomenon of combustible stabilization [6] .

Thanks to the advanced technology, the application of 3-D surveying technology provides an even better way to promote the efficiency and cost savings of wreckage reconstruction. This so-called 3-D surveying technology aims the precise 3-D laser scanner at an object to measure its tangent planes, then aligns these planes with selected reference points of alignment to assemble them into complete a 3-D model.

The methodology and application of 3D-SWRPS presented here can also be used for future accident investigation in the areas of three-dimensional site survey, in secluded mountain area, or inside an airport, to determine the distributional relationship of wreckage and terrain.

II. Aviation accident investigation and wreckage reconstruction

2.1 Characteristics of aviation accident investigation

Aviation accident investigation integrates the technologies of aerospace, avionics, human factor, flight operation, weather, underwater recovery, spatial remote sensing (global position system, geographic information system, remote sensing), etc. ICAO Annex 13 generally dictates the investigation procedures for the determination of causal factors, and for proposing safety recommendations for the prevention of similar occurrences from happening again.

The investigation of an aviation accident as a whole contains six phases: on-scene investigation, factual data collection, factual verification, analysis, findings, and safety recommendations.

Size of the investigation team depends on the nature and severity of the occurrence. A typical investigation team should include groups of flight operations, flight recorders, air traffic control, weather, airport, maintenance, survival factors, human factors, systems, and logistics.

The most difficult accident investigation in terms of budget and logistic is an over water investigation, which requires underwater recovery of the recorders and wreckages. For an inflight breakup accident, wreckage reconstruction becomes very informational helpful in the determination of causal factors. In the past decade, the aviation accident investigation agencies were aggressively seeking for an efficient method of wreckage reconstruction but without significant development. In the last 15 years there were six inflight breakup accidents: PA103, AA811, TWA800, SR111, Air France's Concorde, and China Airlines CI611. As summarized in Table 1, wreckage reconstructions were conducted for the determination of their probable causes.

2.2 Methods of wreckage reconstruction

Irrespective of whether an aircraft crashed on land or into the sea, after salvaging the wreckage, investigators need to identify and examine the wreckage pieces one by one. When the source of force and destructive direction of structure could not be determined, then reconstruction using the wreckage collected is a viable method. In general, to evaluate probable causes, determination of the failure sequence is required. However, not all accidents need wreckage reconstruction. For example, in the case of Singapore Airlines Flight 006 (SQ006), which crashed on the runway at Chiang Kai-Shek International Airport in Taiwan on Oct. 31, 2000, its structure failure sequence could be determined by ground collision marks and wreckage distribution, and hence did not require reconstruction of the wreckages.

Wreckage reconstruction serves three purposes: first, to find out source of structure failure; second, to judge the endurance of condition of forces; and third, to study the propagation of stress or force between main structures.

Several preparation considerations are required prior to the wreckage reconstruction: 1) Evaluation of the reconstruction site; 2) Identification and tagging of wreckages; 3) Partial or whole wreckage reconstruction; 4) 2-D wreckage layout or 3-D wreckage reconstruction; 5) Design of frame or mockup; 6) Wreckage cut up and crane operation; 7) Accessibility to the mockup; and 8) Safety concerns of personnel at work, etc.

The determination of whether to undertake a partial or whole wreckage reconstruction is an important issue. A decision should be made according to clues and factual information collected during the on-scene investigation phase. These clues can usually be radar tracks, flight recorder data, related testimonies, and characteristics of salvaged wreckages. Those characteristics include failure conditions at different sections of the fuselage, burning conditions, and fracture surfaces, etc.

For example, after the inflight breakup of TWA800, the primary radar data display indicated that wreckages followed the flight path spread along the downwind side. In interviews, testimonies such as "fireball and descending" appeared. There was abnormality and high-energy sound waves recorded in the cockpit voice recorder. Therefore, wreckage reconstruction of TWA800 emphasized finding the source of explosion; hence, the reconstruction was focused on the fuselage and central fuel tanks sections.

Furthermore, after the inflight breakup of SR111, primary radar data indicated that wreckages followed the flight path and spread along the downwind side. Before the cockpit voice recorder stopped recording, flight crews were discussing "cabin smoke problem." Therefore, wreckage reconstruction of SR111 emphasized finding the source of spark and smoke; reconstruction sections were then focused on the fuselage, flight deck, and electrical wiring. In contrast to past aircraft wreckage hardware reconstruction, the TSB of Canada was the first to produce panoramic images of the flight deck, which provide wreckage inspection technology similar to "virtual reality." In conjunction with wreckage sketches, 3-D CAD models, and relevant power wiring diagrams, TSB was able to demonstrate evidence of wire burning during the breakup sequence. The 3-D CAD model used to establish SR111 wreckage reconstruction is an improved method from the traditional hardware reconstruction.

Figure 1: Architecture of 3-D software wreckage reconstruction and presentation system.

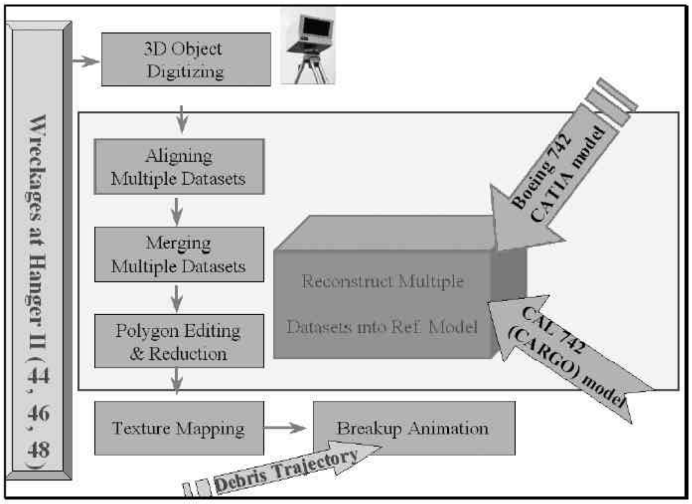
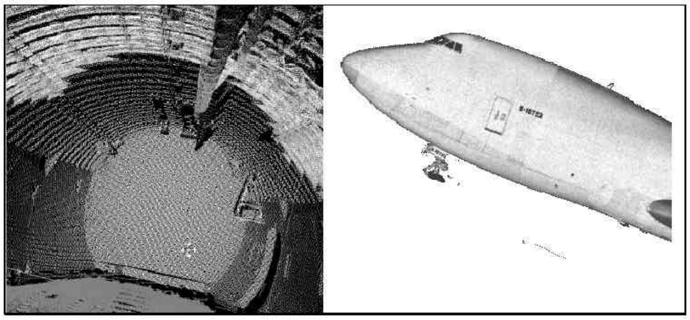


Figure 2: 3-D scan model of B-747-200 cargo aircraft, (a) inner model of rear area, (b) outer model of front fuselage.



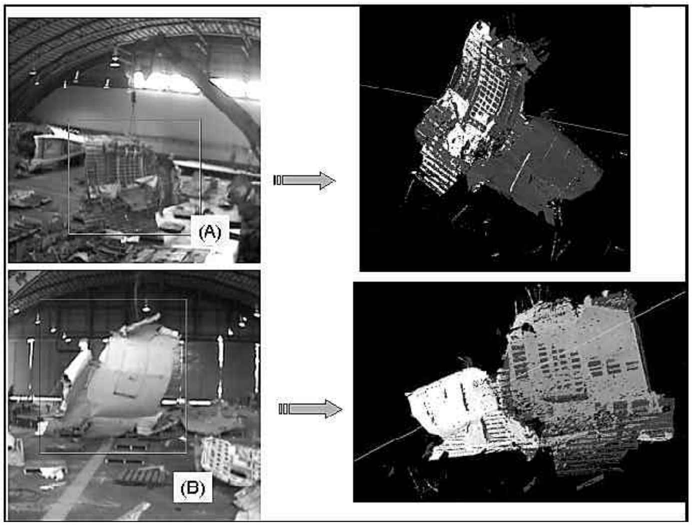
From the experience of using 3-D CAD model developed by TSB in SR111 investigation, ASC went on to develop the 3-D software wreckage reconstruction and presentation system (3D-SWRPS).

2.3 Architectures of 3D-SWRPS

The 3D-SWRPS utilizes a combination of computer 3-D-graphic techniques, laser scanning of wreckages recovered, the structure frame of an identical B-747-200 aircraft, and a generic CATIA engineering model of the same type of aircraft. It provides sub-centimeter accuracy in the reconstruction process. It can also be used to determine fracture behavior and propagation of stress of the breakup. In addition, the 3D-SWRPS can combine radar return signal, wreckage salvage data, and ballistic simulation program to assist analyzing the breakup sequence.

The 3D-SWRPS project uses long-range and precise 3-D laser scanner. Table 2 summarizes the functions of 3-D laser scanners OPTECH (model ILRIS) and RIEGL (model LMS Z420). Based on the reliable operational safety of a laser, it can achieve preci-

Figure 3: Crane operational photo of item 640 and side view of 3-D model. Marks of (A) and (B) are present as inner and outer side view of 3-D model.



sion to 3 mm with maximum range of 2 km. In order to align the 3-D wreckage model onto the "reference model," two models were collected, a Boeing 747-200 CATIA model and a scanned model of a China Airlines B-747-200 cargo aircraft. ASC selected the ILRIS to do the job. The 3-D scanning was done to the whole aircraft's inner and outer body.

Sections 44, 46, and 48 of the CI611 wreckage were 3-D scanned and modeled at Hangar II of Tao Yuan Air Force Base (TAFB), Taiwan. In total, 161 pieces of wreckage were digitized and modeled into 3D-SWRPS; among them, 50 wreckage pieces needed crane handling to be scanned. Wreckages less than 1m in size or smaller cargo floor beam pieces were ignored. The 3-D scanning and modeling process took nearly 1 month.

3D-SWRPS represents a different processing method for the aircraft wreckage reconstruction through following:

- 3-D object digitizing: Once the laser scanner scanned each individual piece, the piece was then digitized. It processes organized point clouds, as produced by most plane-of-light laser scanner and optical systems.
- Aligning multiple datasets: During digitizing process, investigators need either to rotate the wreckage or move the 3-D laser scanner in order to measure all wreckage surfaces. As a result, the digitizing process produced several 3-D scans expressed in a different 3-dimensional coordinate system. This step consists of bringing these scans into the same coordinate.
- Merging multiple datasets: A 3-D-graphic virtual reconstruction allows investigators to automatically merge a set of aligned 3-D scans of wreckage into a reference model, which was obtained from the same type of aircraft and Boeing's CATIA model. This procedure reduces the noise in the original 3-D data by averaging overlapped measurements.
- Polygon editing and reduction: In order to control the computer's memory allocation, this step uses the polygon reduction tool to reduce the 3-D model's size.
- Manually edit surfaces: Especially with uneven surfaces that may cause data loss.
- Texture mapping: Investigators can create texture-mapped models from the digitized color 3-D data.
- Breakup animation: A major function of this module is to simulate the inflight breakup sequence by combining radar data, ballistic trajectory, wind profile data, and wreckage 3-D model data in time history.

The 3D-SWRPS consists of six stand-alone programs: ballistic trajectory, polywork, multigen creator, polytrans, rational reduction, and the recovery analysis and presentation system (RAPS). The U.S. NTSB developed the ballistic trajectory program. The TSB of Canada developed RAPS. The Investigation Laboratory of ASC Taiwan developed other programs and integrated the whole as 3D-SWRPS. Figure 1 shows the detailed architectures of 3D-SWRPS.

After all 161 pieces of wreckage were scanned and modeled, ASC investigators spent 3 months to align and attach 62 pieces onto the reference model, based upon their frame station and stringer number of the original aircraft.

The result gives the investigators the capability to interact with the 3D-SWRPS to view the inner and outer side of the fuselage in different angles, to further examine the fracture conditions of neighboring wreckage pieces, metal fatigue and stress propagation of structures. In addition, the 3-D wreckage model also links to the database of the Systems Group, where investigators could access wreckage attributes through a secured Intranet. These attributes include size, station, section, damage photos, 3-D model, etc.

III. Results and discussion

3.1 Results of cargo aircraft 3-D model

The reference model of a B-747-200 cargo aircraft includes nose, fuselage, horizontal and vertical tails, inner frame, duct, aft pressure bulkhead, and door frames.

During a D-check of the cargo aircraft, the heat insulation blanket was removed. ASC spent 30 hours scanning the inner portion of the model. Figure 2 illustrates the 3-D model of a B-747-200 cargo aircraft's inner left aft fuselage, including frame segments of section 46, floor, duct, and installation platform for flight recorders. The right side of Figure 2 indicates the outer portion of the fuselage model, including registration number, nosewheel, flight deck, and L1-door frame, etc.

3.2 Results of CI611 wreckage 3-D model

ASC spent 2 months scanning and modeling 161 pieces of wreckage. Each piece requires three to eight scans depending on its shape. The basic element of a 3-D model is composed of polygons. According to the conditions of the crooked and fractured wreckage, each 3-D model consists of polygons ranging from 30 to 70,000 in numbers, and from 3 MB to 120 MB in file size. The data processing platform is a PC-based hi-level graphics workstation, equipped with a 1024 MB memory, AGP 4x graphics card, and 80 GB hard drive.

Figure 3 shows the crane operation and side view of item 640. Figure 3(A) is an inner view of the 3-D model of item 640; Figure 3(B) is the outer view of the 3-D model of item 640. The size of item 640 is 260"x 200," station number between 1920 and 2180, stringer number between S-24L and S-50R. Figure 4 illustrates the crane operation and side view of item 2136. The reference number of stations and stringers are between 1960 and 2100, and between S-07L and S-11R, respectively.

Figure 4: Crane operation photo of item 2136 and side view of 3-D model.

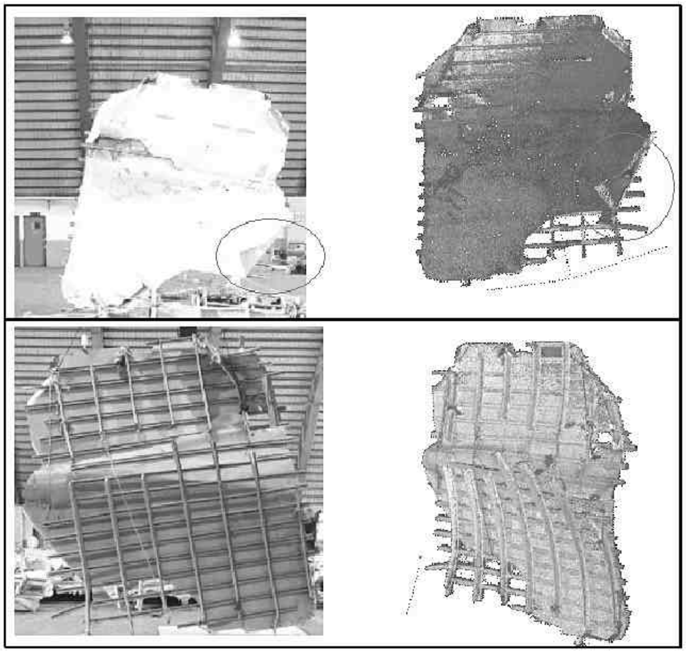
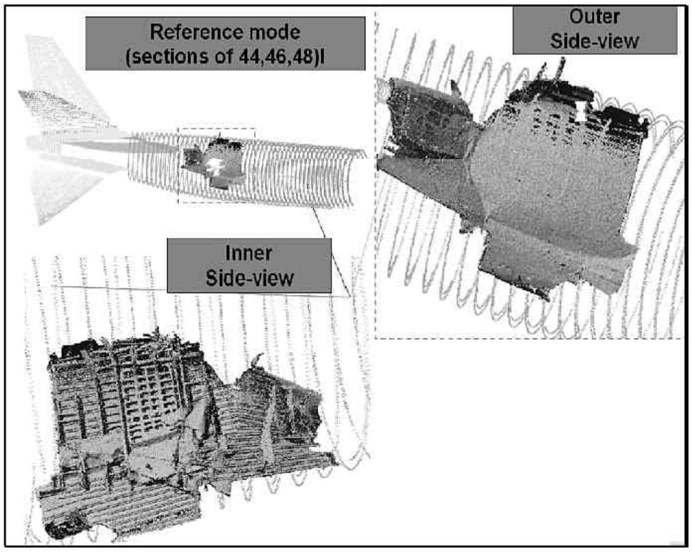


Figure 5: 3-D model of item 640 and reference frame model.



3.3 Results of 3-D software reconstruction

The entire 3-D wreckage model is aligned with reference coordinates of stations and stringers. Wreckages with the least-deformed fracture surfaces were selected first as the reference point of alignment and aligning surfaces. The greatest difficulty in 3-D software reconstruction is the computer's memory allocation and the appropriate selection of reference point of alignment. An uneven selection of the reference point of alignment could cause gaps in the connecting surfaces of wreckages, or the alignment could not be done just as in actual hardware reconstruction.

By using the reference coordinates of item 640, when manually aligning this piece onto the reference model of a B-747-200, it shows that the item belongs to section 46 of the right aft fuselage structure. Figure 5 indicates that the severe damage of the

Figure 6: Wreckage photo of item 640 and relevant station numbers.

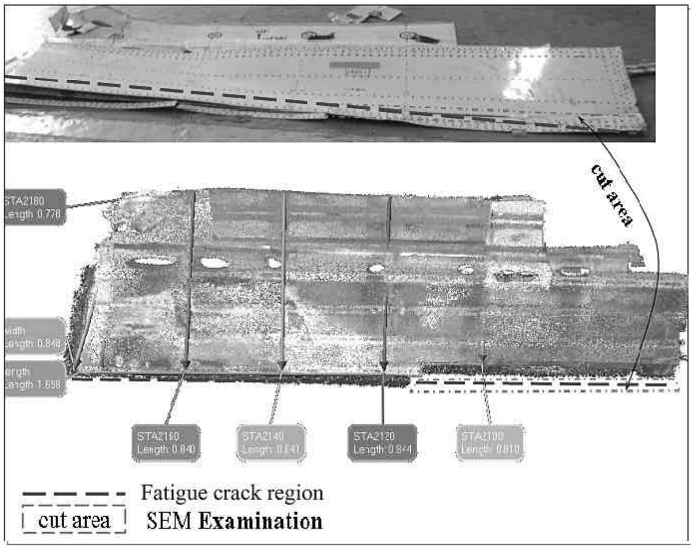
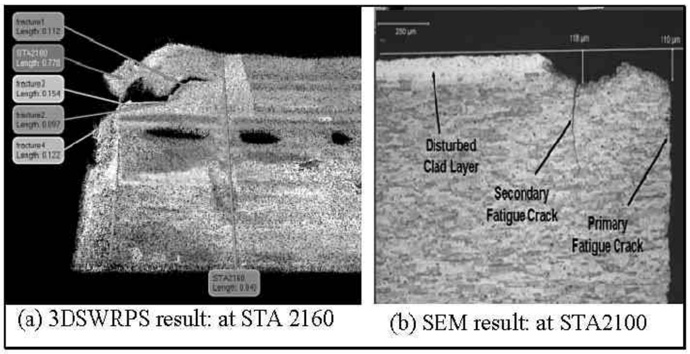
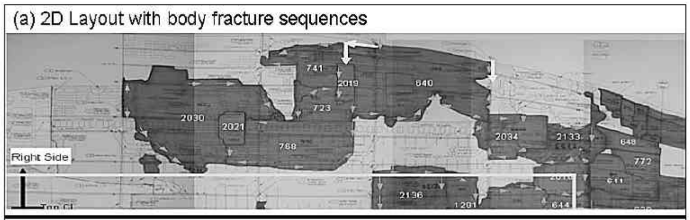


Figure 7: (A) "N" shape crack of item 640 located at station of 2160 (12.5 cm); (B) SEM results of metal fatigue located at station 2100.


(a) 3DSWRPS result: at STA 2160

(b) SEM result: at STA2100

Figure 8: Comparison of 2-D layout and 3-D software reconstruction at section 46 and aft pressure bulkhead (upside-down view from the right).


(a) 2D Layout with body fracture sequences

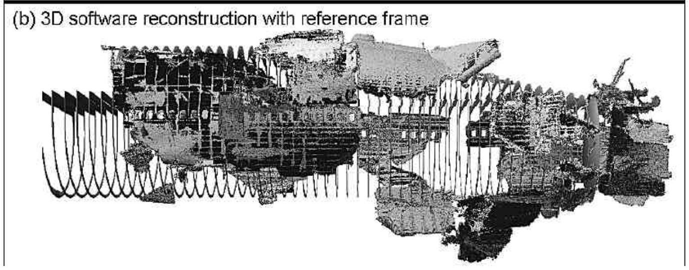

(b) 3D software reconstruction with reference frame

Table 1: Aircraft Wreckage Reconstruction for Inflight Breakup Investigations in Recent 15 Years.

	PA103	UAL811	TW800	SR111	F-BTSC	CAL611
Accident Date	1988.12.21	1989.02.24	1996.07.17	1998.09.02	2000.07.25	2002.05.25
Report No.	AAIB/2/90	NTSB/AAR-92/02	NTSB/AAR-00/03			
Possible Cause	In-Flight Breakup	In-Flight Breakup	In-Flight Breakup	In-Flight Fire	during takeoff In-Flight Fire	In-Flight Breakup
	High explosive Device	Explosive Decompression	Center Tank Explosion	fire in the ceiling area	Debris throw the lower wing tank	
Reconstruction Area	Full Fuselage and Tail plane	Foreword Fuselage with Cargo Door	Foreword Fuselage and Center Wing Tank	Cockpit and Foreword Fuselage	Wing Structure and Tanks	AFT Fuselage Sect 44, 46 and 48
3D Mockup	Yes	Yes	Yes	Yes	2D Layout	Yes
3D SWRPS	No	No	No	No	No	Yes
Finite Element Analysis	Yes		Yes	?	Yes	Yes

Table 2: Comparison of Long-Range and Precision 3-D Laser Scanners.

Manufacturer	**OPTECH (ILRIS-3D)**	**RIEGL (LMS Z420)**
Range	30 m ~ 2000 m	~ 800 m
Accuracy	3 mm	5 mm
Speed	2000 points/sec	3000 points/sec
Spot spacing	At 100 m < 2.6 mm	?
Controller	PDA (serial, IR)	PC / Laptop
Weight	12.0 KG	14.5 kg
Eye Safety	Class I Laser	Class IIIR

outer blend is located at stations 2060 and 2180, and a large "V" shaped fracture existed at station 2180. Figure 5 also shows the inner view of item 640; the aft cargo-door frame is slightly deformed but intact with relevant frames of the fuselage. Figure 5 also illustrates significant fracture conditions between stations 1920 and 1980. Beside the lower left of Figure 5 with a rectangular cut is a sample of metal fatigue examination. (Detail shown on Figure 6.)

Upper Figure 6 shows the repair doubler of item 640. Lower Figure 6 shows the 3-D models of the fuselage and doubler. The blue-dotted line is the area where SEM examination was conducted. In fact, it is very useful to adopt the 3D-SWRPS to evaluate or measure fracture behaviors. It could easily measure the arc distance, including curve angles on the surface of wreckages, then to mark or compare the differences between the wreckage and reference model. Figure 7(A) indicates the "N" shaped 12.5 cm crack at station 2160. Figure 7(B) shows the electron microscopic examination of item 640, which shows metal fatigue crack around station 2100.

Totally, 1442 pieces of wreckage had been salvaged from the Taiwan Strait, which were then identified and placed at the Air Force base hangar for hardware reconstruction. After finish tagging, sketching, and initial examination, all wreckages were arranged on the hangar floor according to their respective fuselage station and stringer numbers. For the time being, there are 62 pieces of wreckage aligned on the reference CATIA model. Figure 8 shows the 2-D layout and 3-D software reconstruction at section 46 and the aft pressure bulkhead view from the outer right side.

3.4 Comparison of 3-D hardware and software reconstruction

The utilization of 3D-SWRPS is generally better than 3-D hardware reconstruction. In fact, manpower, budget, and space required for 3D-SWRPS is much less than for 3-D hardware reconstruction. 3D-SWRPS has great advantages in reusability, ballistic trajectory analysis and simulation, and in conjunction with finite element analysis.

The cost of 3-D hardware reconstruction for CI611 was US$143,000, only for section 46. The cost of 3D-SWRPS for CI611 was US$91,500, including crane operation, rental of a 3-D scanner, and labor cost of two engineers. Use of 2-D wreckage layout together with 3-D software reconstruction might be the best choice if 3-D hardware reconstruction is not really that necessary from the investigation point of view.

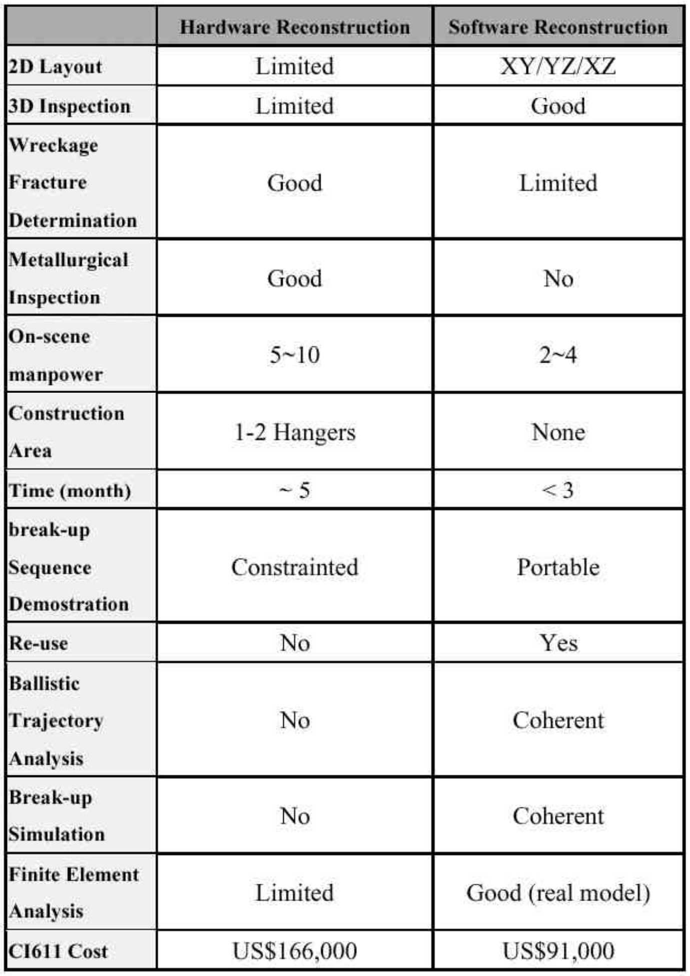
Table 3 (page 48) summarizes and makes the comparison between 3-D hardware and software reconstruction of CI611.

IV. Conclusions

3D-SWRPS was developed by utilizing a combination of computer 3-D-graphic techniques, laser scanning of wreckage pieces, plus generic engineering model of the same type of aircraft. It can provide sub-centimeter accuracy scan quality, and can be used to determine fracture behavior and aircraft breakup propagation.

Advantages of the 3D-SWRPS are a) no wreckage disposal problem; b) reusability, once developed, the methodology can be used for other accident investigation; c) only one-half of the cost as compared to hardware reconstruction; d) flexibility in combining with simulation program for better analysis support. ◆

Table 3: Functional comparison between 3-D Hardware and Software Reconstruction.



	Hardware Reconstruction	Software Reconstruction
2D Layout	Limited	XY/YZ/XZ
3D Inspection	Limited	Good
Wreckage Fracture Determination	Good	Limited
Metallurgical Inspection	Good	No
On-scene manpower	5~10	2~4
Construction Area	1-2 Hangers	None
Time (month)	~ 5	< 3
break-up Sequence Demostration	Constrainted	Portable
Re-use	No	Yes
Ballistic Trajectory Analysis	No	Coherent
Break-up Simulation	No	Coherent
Finite Element Analysis	Limited	Good (real model)
CI611 Cost	US$166,000	US$91,000

References

[1] Aviation Accident Report, “Boeing 747-121, N739PA at Lockerbie, Dumfriesshire, Scotland on 21 December 1988.” AAIB Report Number: 2/90 (EW/C1094), 1990.

[2] Aviation Accident Report, “ inflight Breakup Over the Atlantic Ocean Trans World Airlines Flight 800 Boeing 747-141, N93119 near East Moriches, New York July 17, 1996.” NTSB Report Number: AAR-00-03, 2000.

[3] “Aviation Safety Recommendations Material Flammability Standards Investigation Into the Swissair Flight 111 Accident.” TSB Occurrence Number: A98H0003, 2001.

[4] Har, J., “MD-11 Composite Spoiler Analysis Using MSC/NASTRAN & PATRAN PLUS,” Korea Institute of Aeronautical Technology (KIAT), KIAT-RR-90-011, 1990.

[5] Francisco K. Arakaki, etl. “EMB-145 Nose Landing Gear Door Stress Analysis,” Empresa Brasileira de Aeronautica, Structural Analysis Department, 12227-901 Sao Jose dos Campos—SP—Brazil, 1996.

[6] J.T., QinetiQ, “Fatal Concorde Fire Explained,” Leeds University (CFD Center), Leeds, Yorkshire, Hampshire, UK., 2001.

[7] Vittorio Casella, “Accuracy Assessment Of Laser Scanning Data: A Case Study,” University Of Pavia, Department of Building and Territorial Engineering, Via Ferrata, Pavia, Italy, 2001.

[8] Aviation Accident Report, “Explosive Decompression—Loss of Cargo Door in Flight United Airlines Flight 811 Boeing 747-122, N4713U HONOLULU, HAWAII February 24, 1989.” NTSB Report Number: AAR-92-02.

*1 Investigation Lab/Deputy Chief
*2 Investigation Lab/Engineer
*3 Investigator
** Managing Director

CVR Recordings of Explosions and Structural Failure Decompressions

By Stuart Dyne (MO4779), Manager, ISVR Consulting, Institute of Sound and Vibration Research,
University of Southampton, UK

__Stuart Dyne__ is manager of ISVR Consulting, the consultancy division of the Institute of Sound and Vibration Research at the University of Southampton in the UK. He has a B.A. in engineering science from the University of Oxford and works in acoustics, shock and vibration, and signal processing. Formerly a university lecturer, he also continues to teach undergraduates, post-graduates, and professional development courses. He first became involved in air safety by leading the research activity at ISVR arising out of a recommendation in the AAIB report on the Pan Am Lockerbie accident in 1988. In addition to his ISASI membership, he is a member of the Royal Aeronautical Society, Fellow of the Institute of Acoustics, and a Chartered Engineer. Dyne is married to Helen and has two children, Georgina (4) and Imogen (2).

Abstract

Rapid identification of the cause of failure is a high priority in the immediate aftermath of a major civil aircraft accident. Attention is often focused on the two recorders, the cockpit voice recorder (CVR) and flight data recorder. In the event of sudden, catastrophic loss of an aircraft through explosions or structural failure decompressions, the recordings are seen as even more important. Yet these recorders are not designed to record such events with great fidelity, and the ability of accident investigators to interpret such recordings has been severely tested in several major accidents in the past 30 years. Comparisons between accident recordings have not been able to produce conclusive results. This paper reports on a program investigating CVR recordings of explosions and rapid decompressions on a variety of aircraft from trials in several countries. In particular we show that CVR recordings are generally unable to discriminate between explosions and structural failure decompressions, and we explain why this is so. We shall also put forward practical suggestions for systems that may be able to record these events with greater fidelity and that would provide investigators in the future with tools to locate the seat of the failure.

Introduction

The AAIB report [1] on the Pan Am Lockerbie accident in December 1998 identified a loud sound lasting 170 ms on the cockpit area microphone (CAM) track at the end of the recording. The sound occurred while the crew was copying their transatlantic clearance from Shanwick ATC. A very large volume of forensic material arising out of Lockerbie indicated that detonation of an improvised explosive device led directly to the destruction of the aircraft. While it is reasonably inferred that the "loud sound" is related in some way to the detonation of the explosive device, the official report into the accident conceded "analysis of the flight recorders…did not reveal positive evidence of the explosion event." Moreover a safety recommendation arising out of the investigation was that "a method should be devised of recording positive and negative pressure pulses, preferably utilising the aircraft's flight recorder systems." Since the publication of this report, a study into the CVR/CAM response to explosions and structural failure rapid decompressions has taken place and has been reported widely to working groups, such as ISASI WG50, EUROCAE ED-56, at conferences [2, 3] and to an ISASI seminar [4]. More recently a loud sound at the end of the TWA 800 recording was subject to detailed and meticulous analysis by the NTSB but did not reveal the cause of the accident and was therefore of little diagnostic value. This aim of this paper is to explain why these recordings do not lead to useful forensic evidence and to consider what systems would be necessary to discriminate between explosions and structural failure decompressions and to locate the seat of the hull loss.

CAM/CVR recordings of explosions

Figure 1 (reproduced from reference [4]) shows the CVR and instrumentation signatures for an explosion event conducted on the ground in an ex-service BAe Trident aircraft. The plot shows the CAM channel of each of three tape-based CVR systems together with an accelerometer (vibration sensor) and a microphone (pressure sensor) installed close to the CAM for the trials. All sensors were in close proximity to each other in the cockpit and the explosion was approximately 9.4 m aft of the sensor position. Time zero is the time of detonation of the explosive device—obviously this reference would not be available on an accident recording but is helpful here in the determination of the cause of epochs within the recording.

Several features are striking about this Figure. First, the three CAM signatures have some similar features but are certainly not identical. The features that they share include a response commencing before 0.01s with a low amplitude and low frequency range (the graph is fairly smooth). All of them change character at around 0.025s increasing in amplitude and frequency range (the graph becomes more spiky). Interestingly, the vibration record is similar although the vibration response amplitude falls soon after 0.035s whereas the record for CVR system 1 remains at a high level until 0.06s and high for the whole of the record for CVR 2, suggesting a possible saturation of the tape dynamic range. The pressure record differs from the others in that it only commences at 0.025s.

Similar results have been obtained from very many trials with explosive devices at many locations on several aircraft, and the following explanation of the records described above may be inferred. First the blast wave from the explosion source impinges on the structure and a shock wave is then transmitted through the structure at a speed of 4,000 to 5,000 m/s. The CAM is sensitive to

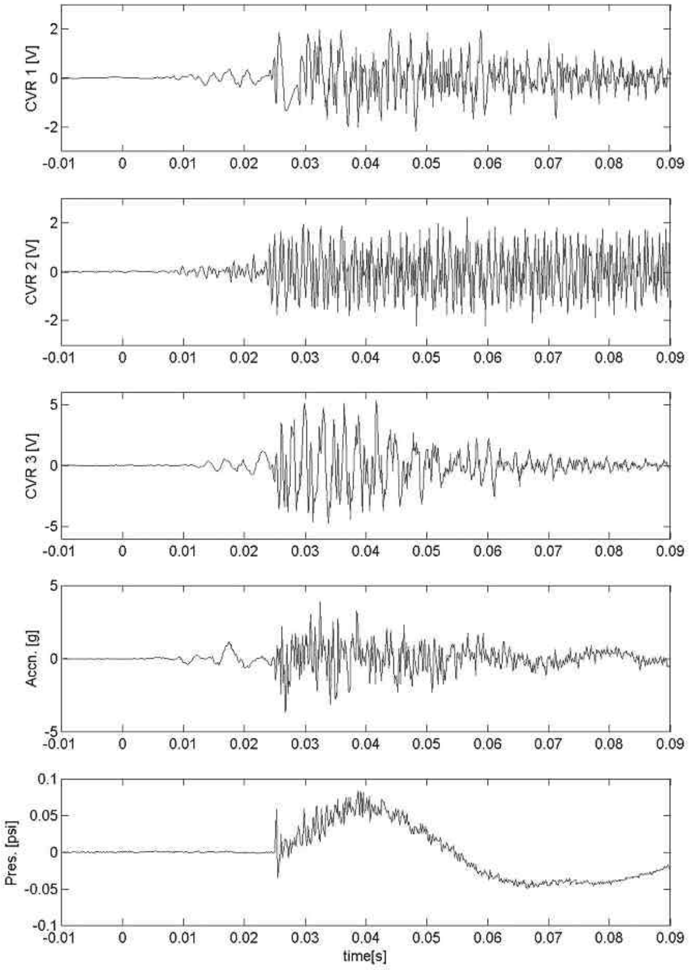


Figure 1: CVR and instrumentation signatures for an explosive device.

vibration and responds to the arrival of the structure-borne shock wave. Meanwhile the air-blast wave travels through the fuselage and eventually arrives in the cockpit. The speed of this wave is dependent upon the yield of the explosion but can be taken as the speed of sound in air of 340 m/s where distances are relatively large and yields are quite small. On arrival in the cockpit, the blast produces both a pressure response from the CAM and produces further local vibration (as seen by the accelerometer) to which the CAM is also sensitive. The instrumentation microphone (bottom graph) responds only when the pressure wave arrives at the CAM and is designed to have very low vibration sensitivity.

Vibration sensitivity

It is interesting that the CAM is quite sensitive to vibration. This phenomenon has been exploited in the past with helicopter gearbox investigations, yet the CAM is intentionally vibration isolated from the structure. The reason is simply that the vibration levels of a few g's are themselves quite high, not that the CAM or vibration isolation is poorly designed.

The results of all these trials appeared to show that locating the seat of an explosion event should be rather straightforward. One simply took the difference in arrival times of the structure-borne and airborne shock waves and computed distance from this difference using values for the two propagation velocities. Formulae for this were given in [4] taking into account the possible delay caused by the propagation of an air-blast wave across the fuselage for a device not attached to the outer skin, so providing lower and upper bounds for the distance from the cockpit to the seat of the explosion.

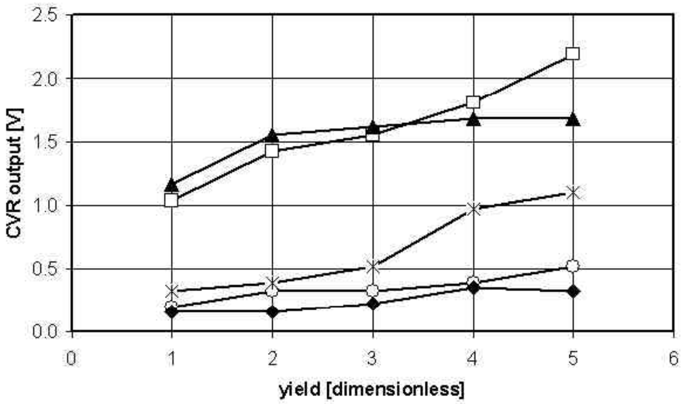


Figure 2: Variation in CVR output with explosion yield for t1<t<t2 for five different CVR/CAM systems. Each symbol represents one CVR type.

However, accident recordings did not appear to show these two epochs with any distinction, so determination of axial location using direct application of this method was not possible. Moreover some trials with larger explosion yields also did not show the two epochs; the explosion response simply arrived and then decayed with time without distinct change in bandwidth or amplitude after the start. Analysis of the influence of explosion yield on the response components helps to explain why this is so.

CVR output related to explosion yield

Trials were conducted on a Boeing 747 aircraft using small yield explosions. The response was measured with five widely used commercial aircraft CVR systems including four tape-based systems and one solid-state recorder. For one series of firings, the same source location was used each time but the mass of explosive was increased linearly from one unit to five units. The results, sets of time series, resembled the time series given in Figure 1 so are not reproduced here. Instead, in Figure 2, we show the peak-to-peak values for the two components in each of the recordings. Suppose we denote the time of arrival of the structure borne wave by t1 and the time of arrival of the air-borne wave by t2. Figure 2 shows the CVR/CAM response amplitude for t1<t<t2, i.e., the response due exclusively to the structure-borne shock. The Figure shows that an increase in yield generally produces a greater CVR/CAM output.

Figure 3 shows the results for t>t2, i.e., the response after the arrival of the airborne blast wave including both sound and vibration. We observe that the amplitude of this response is not only greater than for the phase t1<t<t2 but is independent of the explosion yield. This implies that the physical parameter variation is greater than the dynamic range of the recorder or that the sensors are overloaded and that the recording is saturated and probably highly distorted.

Figure 4 shows a CAM time history for a high-yield explosion on a pressurised Boeing 727 aircraft. The charge was approximately 8.1 m aft of the cockpit; the explosion ruptured the skin of the aircraft. Clearly the CAM does not show a transition at t2. The time taken for sound to travel from the seat of the explosion to the cockpit is approximately 0.024s, and the response clearly be-

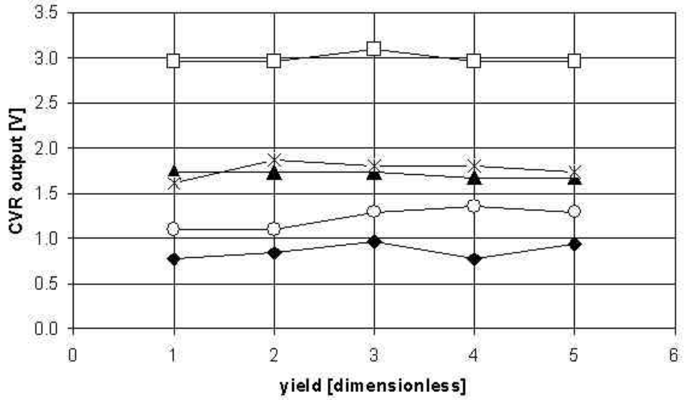


Figure 3: Variation in CVR output with explosion yield for t>t2 for five different CVR/CAM systems.

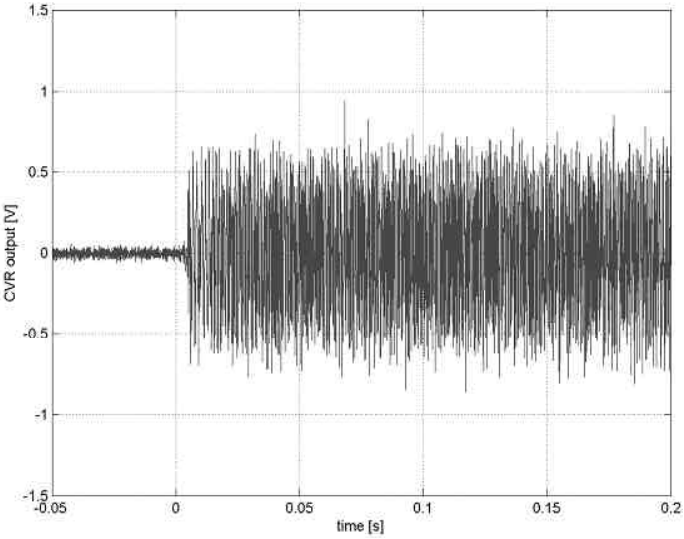


Figure 4: CAM time history for a high-yield explosion on a Boeing 727 aircraft.

gins significantly before this. We infer that the response begins ostensibly at t1 but the magnitude already exceeds the dynamic range of the CAM/CVR so no change in signal magnitude is visible at t2. The record is therefore unable to show the axial location of the charge as was the case for smaller, non-destructive tests.

The yields of all the explosions analysed in Figures 2 and 3 are below the yield that might be expected from a terrorist device. If results from increased yield were produced, the response for t1<t<t2 for all recorder types would exceed the dynamic range and the recordings would be saturated as was the case in Figure 4. There would then be no discrimination between the two phases of the response recording and the section for t>t2 would be indistinguishable from t<t2. It is, therefore, not possible to use the method described above to locate the source for accident recordings.

One extensive study [5-8] has attempted to locate the seat of an explosion using the spectrogram of the CVR recording. The basis of the method is that the structural shock transmission is dispersive, i.e., different frequencies propagate at different velocities. However, the nature of the explosion source and complex multiple transmission paths severely limit the applicability of the theoretical basis. Operationally, the method required placement of a series of curves on an accident recording spectrogram with the intention that their curvature would indicate distance from the source to the CAM. Investigators found this aspect particularly problematic as several sets of curves could be drawn on any given spectrogram leading to ambiguous results. In one part of the study, spectrograms of several accidents were analysed in a blind test but were not able to confirm the validity of the approach. A recommendation arising from a review [9] at the end of the study was that the method should not be used in accident investigation.

The interval t1<t<t2 is due to structure-borne vibration, which is likely to be produced at very high levels under both structural failure and explosion-generated conditions. In the case of an explosion, t2 is the arrival time of the blast wave at the CAM and in the case of a structural failure t2 is the arrival of the decompression wave at the CAM. Decompression waves travel at the speed of sound as with blast waves but are obviously of opposite polarity. Their propagation velocity and arrival at the CAM has been observed in various decompression trials. For both explosions and decompressions, the CVR records are not high fidelity recordings of vibration as (i) the CAM is not designed as a vibration sensor but merely exhibits vibration sensitivity (which may be frequency dependent, non-linear, and directionally dependent) and (ii) because the limited dynamic range of the recording medium and sensor are both (considerably) exceeded. Thus, the CVR/CAM combination is unable to locate the source of a decompression and seems to be unable to discriminate between explosions and structural failure decompressions.

Other transducers to detect explosions/structural failure decompressions

Among the instrumentation deployed in some trials were arrays of pressure transducers. These are effectively very low sensitivity microphones with corresponding low-vibration sensitivity. Figure 5 shows the output of two transducers placed on either side (axially) of an explosion in a pressurized fuselage. Several features in these time histories are noteworthy. First both records commence with a pressure rise. The magnitude of an air-blast pressure rise is a function of explosion yield and distance from the charge and is widely tabulated [10, 11]. The pressure rises occur at different times because the transducers are at different distances from the explosion source. The transducer closest to the charge shows the earliest and greatest pressure rise. The time delay between the two pressure rises can be used to determine the axial location of the device to within 0.5 m. Secondly, both transducers show a pressure fall to a value significantly below the original ambient conditions. This is due to the breach of the pressurized fuselage. The rate of depressurization indicates the size of the hole through which cabin pressure is venting. The precise form of the pressure curve (a series of pressure drops between short periods of relatively constant pressure producing a step-like appearance) has been explained by reference to one-dimensional flow models [2].

Interpretation of the results in Figure 5 indicates that recordings of pressure from either side of an event appear to offer everything the investigator would seek namely:

- the location of the source (from the difference in arrival times)
- the presence of any explosion (indicated by an initial pressure rise)
- any decompression (indicated by a pressure fall)

Although this single result suggests that pressure-transducer-based systems may be widely applicable, trials are needed to consider the

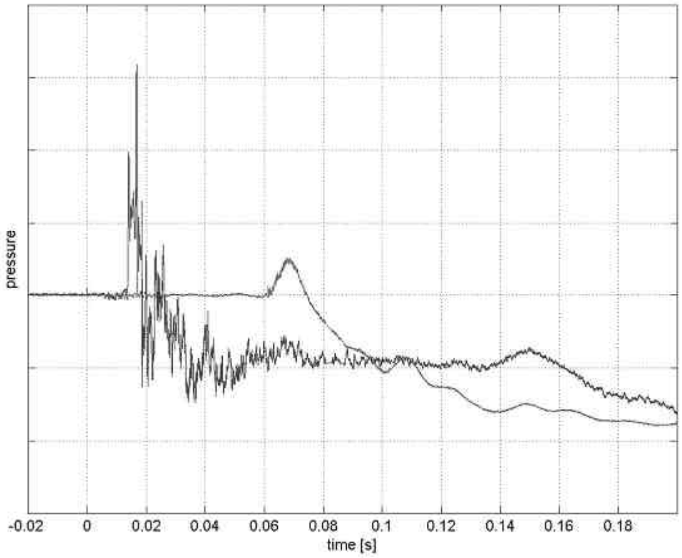


Figure 5: Recordings from pressure transducers placed on either side of an explosion in a pressurized fuselage.

effect of baggage in the immediate vicinity of the explosive device, and of baggage and other barriers between the source and sensors. While vibration has the advantage that it is inevitably transmitted to all parts of the aircraft, it is ostensibly more difficult to analyse vibration records to locate sources. The likelihood of discriminating between explosions and structural failure decompressions from vibration records alone is not fully researched and certainly appears more difficult than the interpretation of pressure records.

Summary

We have seen that CVR/CAM records exhibit vibration sensitivity and that vibration is transmitted from the seat of an explosion/structural failure to the CAM. However, the level of vibration produced in accidents is so high that the dynamic range of the CAM/CVR is likely to be exceeded thereby masking the arrival of the explosion blast wave or decompression rarefaction wave in the cockpit.

It is appropriate to review all CVR recordings (of established provenance) of known explosions and structural failure decompressions. Such a review could confirm (or refute) the assertion that no transition at candidate values of t2 is visible. That is, the accident recordings correspond exclusively to vibration and not to pressure/sound. If so, accident investigators should be relieved to learn that the inability to obtain useful forensic information from the CVR in these cases is not a failing on their part but simply an equipment limitation.

The industry needs to consider if explosion/structural failure decompression sensors are required. If so, there is a need to invest in research to determine the most suitable sensor(s) and appropriate means of recording, possibly exploiting the flexibility now available through solid-state recording media.

Preliminary research suggests that pressure-based systems may be ideal in sudden catastrophic loss incidents, but trials are needed to consider the effect of baggage and other barriers between the source and sensor(s).

Acknowledgement

This paper has used data from a variety of trials. We gratefully acknowledge the support of DSTL (formerly DERA), the Department of Transport (particularly the AAIB), the NTSB, the FAA, and Transport Canada. ◆

References

[1] M M Charles et al., *Report on the Accident to Boeing 747-121, N739PA at Lockerbie, Dumfiesshire, Scotland on 21 December 1988*, Air Accidents Investigation Branch, Department of Transport, Aircraft Accident Report 2/90, HMSO, 1990.

[2] S J C Dyne and J K Hammond, *Identification of the Cause of Failure of Aircraft Structures from Cockpit Voice Recorders*, Proceedings of the Institute of Acoustics, 15, Acoustics '93 Part 3 (book 2), Southampton, April 1993.

[3] M Moshrefi-Torbati and S J C Dyne, *Time-frequency Analysis of the CVR's Signature*, Acoustical and Vibratory Surveillance Methods and Diagnostic Techniques, Senlis, France, October 1995.

[4] S J C Dyne, *Analysis of CVR Transient Signatures*, International Society of Air Safety Investigators, 28(4), ISASI 95, Seattle, September 1995.

[5] F W Slingerland, *Vibration Spectrograms for Aircraft Accident Investigation (an Overview)* , Structural Disaster Diagnosis Canada Inc., Report SDDC/TR/98-002, Revision 001, April 1998.

[6] F W Slingerland, *Development of the CVR Explosion Analysis Technique, An Historical Perspective*, Structural Disaster Diagnosis Canada Inc., Report SDDC/TM/98-003, Revision 001, May 1998.

[7] F W Slingerland, *Spectrogram Diagnosis of Aircraft Disasters*, International Pacific Aerospace Conference, Gifu, Japan, 1991.

[8] F W Slingerland, *Aircraft Damage Analysis by Vibration Spectrograms*, Laboratory technical report LTR ST 517, National Research Council Canada, 1986.

[9] Wayne Jackson (ed.), *CVR Explosion Analysis Technique*: Development and Evaluation, TP 13929E, Transport Canada, May 2002.

[10] G F Kinney and K J Graham, *Explosive Shocks in Air*, Springer-Verlag, 1962.

[11] Department of the Army, *Fundamentals of Protective Design for Conventional Weapons*, Technical Manual TM 5-855-1, 1986.

SESSION III

Learning from 'Kicking Tin'

By Marion C. Blakey, Federal Aviation Administrator, Keynote Speaker

Good morning. I bring greetings on behalf of President Bush, Secretary Mineta, and all of us at the Federal Aviation Administration (FAA). ISASI really is a remarkable forum that brings people together from all over the world. And, it's great to see so many people from so many countries. Aviation safety has no borders, as demonstrated by the presence here today of so many senior officials from the investigation authorities representing four continents.

Thank you all for everything you do in taking on one of the toughest jobs in the world. Bill Adair, who wrote a book on the USAir Flight 427 crash investigation, admired air safety investigators before he started his work. But, after six years of up-close-and-personal, he says he is "constantly amazed at your ability to find the answer from little bits of metal."

And, for the first century of flight, accident investigation has been the bedrock of aviation safety. As our honored guest—founder of the Flight Safety Foundation—Jerry Lederer has said that it was the challenge of safety in part that got the Wright brothers interested in aviation. The 1895 death of German aviation pioneer, Otto Lilienthal, in a glider accident fired their desire to find the solution to safe flight.

One could call Wilbur and Orville Wright the first air safety investigators. On December 14, three days before the breakthrough, Wilbur first tried to coax the Flyer into the air. He almost made it. But he was surprised by the sensitivity of the plane's elevator. He nosed up, stalled, and dived into the dunes. The brothers identified the problem, fixed it, and flew into history three days later.

When Jerry Lederer issued his first safety bulletin at the U.S. Air Mail Service—telling pilots to crash land between trees so as to protect the fuselage—one in six U.S. airmail pilots perished on the job. Today, an airline pilot in the United States faces a risk of a fatal accident about one in every 16 million flights.

And that, in large part, is because of what we have learned "kicking tin." But today's aircraft are much more than thousands of parts flying in formation. They are highly complex pieces of machinery with hundreds of complicated systems. Add to this are the increasing numbers of aircraft, as well as types of aircraft, with different rates of speed and flight patterns from the smallest private aircraft to jumbo jets from helicopters to commercial space launches. And, of course, we all recognize the risks of the greater numbers of aircraft on our runways and taxiways.

And, as we all know from USAir 427, TWA 800, and American Airlines 587 here in the United States and from accidents around the world, accident investigations are increasingly driven by issues involving high-tech safety systems, integrated computer programs, high-grade materials, and electronically generated data and data analysis. I said this when I headed the Safety Board, and it's just as true from the vantage point of the Federal Aviation Administration: the cause of the next major accident is just as likely to be an error in a line of computer code as it is the failure of pilots to set their flaps during takeoff.

We have gotten so good at solving and preventing the single-cause accidents. It's the high-tech and system failures that we have to tackle now. Look at what FAA's head of accident investigation Steve Wallace and the rest of the *Columbia* Accident Investigation Board faced with the shuttle investigation … plotting debris from California to east Texas, the equivalent of a debris field from Paris to Moscow … foam that caused catastrophic damage … extremely high temperatures of space travel … and the pivotal role organization and culture can play in an accident.

As Admiral Hal Gehman says, "Complex systems fail in complex ways." The shuttle investigation was truly a team effort. Investigator Dan Diggins from the FAA … worked on characterizing NASA's decision-making, complete with standards of risk and failure rates. FAA debris-reentry specialist Paul Wilde played a central role in foam impact testing. And Don Day of our Southwest Region helped recover truckloads of shuttle debris. And, of course, NTSB with its store of expertise was tremendously helpful in figuring out where the debris landed.

And it's that team approach that enables aviation to enjoy such a strong safety record. But we can't, and won't, rest on our achievements. However good they are. All of us—government, operators, flight crews, mechanics, and manufacturers—must be committed to an even stronger safety record. The public not only expects, but they deserve, the safest form of transportation.

Our goal at the DOT and FAA is to put accident investigators out of business. You and I know that this is a formidable challenge. But we want aviation to be so safe that investigators can spend more time teaching, training, maybe even spending some time not living out of a suitcase, home with your families.

And to reach that point, the aviation community is changing one of the biggest historical characteristics of aviation safety—our reactive nature. We must get in front of accidents, anticipate them, and use hard data to detect problems and disturbing trends. And that is exactly what the FAA is committed to doing with a system safety approach. We identify hazards, assess and analyze risks, prioritize actions, measure and document results. It's a continuous process that allows us to evaluate results as well as to see where we need to take additional action.

CAST—or the Commercial Aviation Safety Team—is working well and is a perfect example of teamwork and getting in front of accidents. We're making real progress. CAST estimates we can reduce the risk of loss of control or CFIT accidents by more than 70 percent when we implement the agreed-upon safety enhancements. Similar efforts are under way in Asia, Europe, and Central and South America. The Pan American Aviation Safety Team deserves special recognition for translating Flight Safety Foundation training materials into Spanish and Portuguese. More than

12,000 pilots received approach and landing safety training.

That's the power of data, disciplined analysis, and follow through. This data-driven approach is why we're placing so much emphasis on information gathering and sharing. We need as much data as possible to make informed decisions, which is why the FAA is working so hard to support ASAP and FOQA programs.

There are currently 12 major and regional U.S. airlines with FAA-approved flight operational quality assurance (FOQA) programs. By the end of this year, almost 1,800 airplanes will be equipped to collect and analyze FOQA data. This data provides objective information about daily line operations that's not available from any other source. And it's through this data that patterns and trends can emerge that allow us to identify a host of problems, including unstable approaches, exceeding operating limitations, aircraft subsystem malfunctions, and countless more.

Under Aviation Safety Action Programs (ASAP), the FAA provides enforcement-related incentives for employees who self-report possible violations through their local ASAP office. To date, more than 80,000 ASAP reports have been submitted by airline pilots.

But while the information being collected through these programs is valuable, its full potential will not be realized as long as the data remain at the local operator level. To identify trends across airlines, we must move forward with the aggregation of safety data on a national level. The FAA has already issued rules that protect voluntarily submitted data and information from disclosure.

And this has been a stumbling block. We've determined that FOQA data will be protected. We expect to issue a similar determination for ASAP data shortly. Looking beyond our borders, we need to make sure that the safety data are shared worldwide among safety professionals. And this is the entire point of the Global Aviation Information Network, or GAIN, initiative.

Aviation is the most international form of transportation, and I strongly believe aviation safety is one of our nation's most important exports, and it's one of our most important imports. We learn so much from our international partners. In fact, the FAA is taking action on recent recommendations from Canada, Germany, the UK, and Taiwan on a broad range of issues from design and certification process to standardizing responses to TCAS resolution alerts.

And we're addressing safety on the airport surface. The FAA has commissioned 31 Airport Movement Area Safety Systems (AMASS) with 37 total installations planned for 34 airports. We know we have more to do. Improving runway safety depends on greater awareness by pilots, by controllers, and by airport vehicle drivers. This is why we're so focused on increased education, training, and awareness as well as improved airport markings and lighting. Training is so important. The FAA has its own accident investigation school in Oklahoma City and we're in the process of standardizing training courses for international students.

I applaud ISASI for its international seminars. And I challenge you to build and grow and make these available to even more investigators. As the international society, you are ideally positioned to take the lead to look at where aviation and technology is going and lead the development of more training to ensure that your members—especially your airline members who may not have the same level of training available to them—are prepared with tools and training. This would be an enormous contribution to the profession of air safety investigator.

As you think about how you can become even more prepared, here's a role model for you, Jerry Lederer, a man who has spent three-quarters of a century finding the right solutions to make aviation safer. In 1948, he organized the Flight Safety Foundation's first accident investigation course. And I think it's fair to say that if there is one person who can be credited for the outstanding safety record in the first century of flight, it is Jerry Lederer. It is with great honor on behalf of the men and women of the FAA, on behalf of millions of air travelers, on behalf of everyone who takes a calculated risk to defy gravity and returns to earth safely that I present this special award to Jerry Lederer, Mr. Aviation. Congratulations, and thank you, Jerry. ◆

Investigating Techniques Used For DHC-6 Twin Otter Accident, March 2001

By Stéphane Corcos and Gérald Gaubert, BEA, France

***Stéphane Corcos**, 39, is the BEA Investigations Department Head. He joined the BEA as head of the Safety Analysis and Studies Division in 1996. Prior to joining the BEA, he worked for the DGAC (French civil aviation authority) for 8 years, including 4 years as deputy head of the Flight training Organizations Supervision Division. He graduated from the French National Civil Aviation School (ENAC) with a masters degree in aeronautical engineering in 1987, including an internship at the Flight Safety Foundation, in Arlington, Va. He is the current holder of a commercial licence and a multiengine instrument rating. He also held a Beech 200 type rating.*

***Gérald Gaubert**, 30, graduated as an aeronautical engineer from the French National Civil Aviation School (ENAC) in 1995. He received his post-graduate degree in human factors from Paris University. After an appointment as manager of Studies and Research Programs in Aeronautics with the French Civil Aviation Authority (DGAC), he joined the BEA as a safety investigator in 2000. He holds a commercial pilot's license with an instrument rating and an ATPL certificate.*

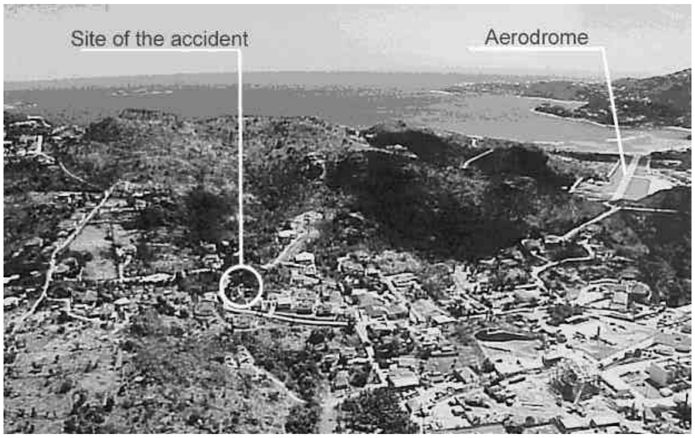
Presentation of the event

On Saturday, March 24,2001, the DHC-6-300 registered F-OGES was carrying out the scheduled service TX 1501 under a VFR flight plan between the island of Saint Martin and the island of Saint Barthélemy, 19 nautical miles away. The aircraft was operated by Caraïbes Air Transport on behalf of Air Caraïbes, which undertakes commercial operations on the route. The captain was the pilot flying.

Cruise was performed between 1,000 and 1,500 feet. The crew left the Saint Martin Juliana aerodrome frequency when abeam of the island of Fourchue, the entry point of the aerodrome circuit located 3 nautical miles northwest of the island of Saint Barthélemy. A few seconds later, they announced on the Saint Barthélemy information frequency that they were passing the Fourchue reporting point. Shortly afterward, they announced passing the Pain de Sucre reporting point for a final approach to Runway 10. That was their last communication.

When the aircraft began its short final before the La Tourmente pass, several people, including the AFIS agent, saw it turn left with a steep bank angle then dive toward the ground. It crashed near a house and caught fire. All of the occupants perished, along with one person who was in the house.

Conduct of the investigation



Aerial view of the site and the aerodrome.

The BEA was notified of the accident by local civil aviation authorities and dispatched a team of investigators to the accident site in the French West Indies the following day.

In accordance with international agreements, because the aircraft was of Canadian manufacture, the BEA invited its Canadian counterpart, the Transportation Safety Board (TSB), to participate in the investigation by nominating an accredited representative. The latter joined the investigator-in-charge on Tuesday, March 27, accompanied by two technical advisers representing the manufacturers, de Havilland Bombardier and Pratt & Whitney Canada. Subsequently, a correspondent of the National Transportation Safety Board was attached to the investigation, with a technical adviser from the propeller manufacturer, Hartzell.

On Aug. 6, 2001, a preliminary report detailing progress in the investigation was published. At that time, a safety recommendation was issued on the carriage of flight recorders for all airplanes carrying more than nine passengers on revenue flights.

Findings and challenges

This was the starting point of an unusual investigation, where we were faced with a public transport accident killing all 19 occupants in which, unlike in the average investigation, very little direct evidence could be found.

First of all, there were no flight recorders since the airplane had been granted a waiver due to its initial date of certification.

Additional initial findings were that

- no abnormal events were reported by the crew at any time during the flight.
- no unusual weather phenomenon was reported by any other flight crews shortly before or shortly after the accident.
- the examination of the crash site revealed the airplane had been subject to a violent impact, followed by an intense fire, that left no chance of survival for any of its occupants. The initial

Crash site.

Descent path 12 percent.

examination of the wreckage (flight surfaces, flight controls, powerplants) showed no evidence of any malfunction.

- two camcorder tapes were found in the debris: one was destroyed; when played back the second revealed no sign of unusual attitudes or any abnormal situation on board 1 minute prior to impact. However, further technical examination was deemed necessary to try to take advantage of any possible clues.
- the ATIS recorder was unserviceable, and no radar tracking was available.
- the autopsy revealed no problem that could have been a factor in the accident.
- the captain lacked recent experience on this airplane type at this airport, where the surrounding terrain, environment, and local wind conditions are such that a site rating is required for operations to and from it (in particular, the final descent path is set at 12 percent).
- further examination of parts from the wreckage and a powerplant and propeller teardown revealed no mechanical malfunctions.

The investigation could, therefore, only rely on significant testimony, both from the eyewitnesses of the final sequence that led to the accident, and from people in the working environment of the crewmembers. The investigators were left with a puzzling triggering event described by eyewitnesses: the airplane banked to the left, in a sharper and sharper left turn, then pitched down toward the ground, then crashed in a steep nose-down attitude.

Analysis of a videotape

The playback and the analysis of a videotape found in the wreckage showed three parts containing useable images:

- during initial climb from St. Martin aerodrome,
- during cruise with a view of the tip of St. Martin island,
- on approach to St. Barthélemy with a view of the northern tip of the island.

In all of the sequences, the left propeller showed evidence of rotation.

The film ended approximately when the airplane was abeam the northwestern part of St. Barthélemy, around 1 minute before the accident.

Spectral analysis of the soundtrack allowed us to determine the propeller rotation speed through frequency measurements.

During takeoff, both propellers were at 2,120 RPM (synchronized). During cruise, they slowed down from 1,825 to 1,690 RPM over 5 seconds then stabilized at 1,685 RPM (synchronized). During the approach, the propellers were no longer synchronized, and the discrimination between left and right propeller was made possible through analysis of the video.

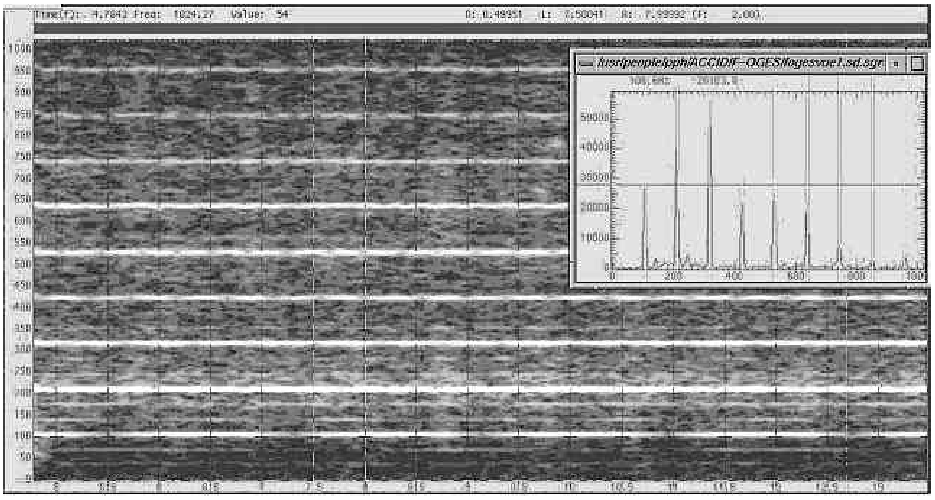
An asymmetry around 9 percent was found between left-hand and right-hand propellers, which is consistent with their normal use.

To summarize, no evidence of any malfunction or misuse was found during the recorded part of the flight.

Three other objectives were pursued: to validate the soundtrack spectral analysis, to estimate the track of F-OGES, and to be better apprised of normal operations in such an environment.

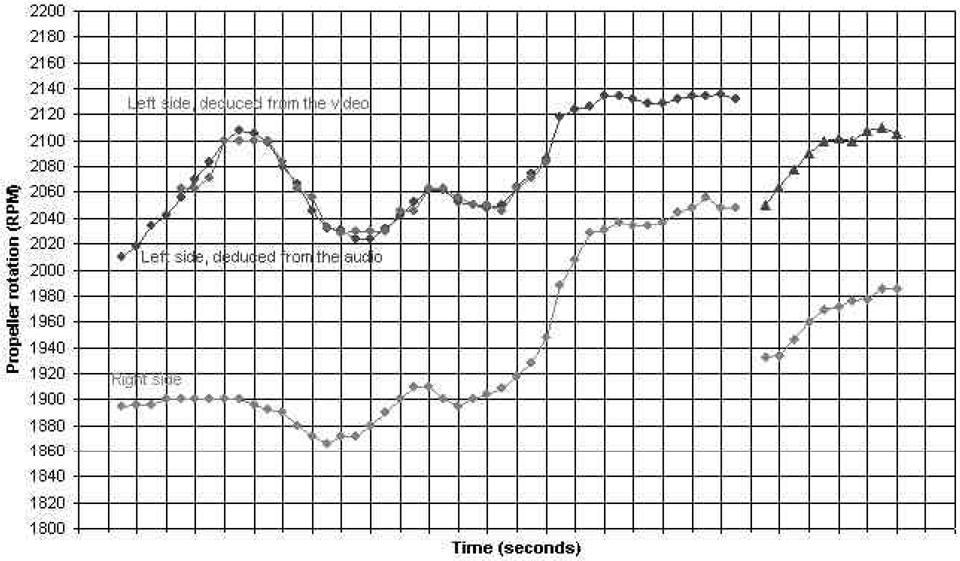
The methodology used was a comparison with recordings on board the same type of airplane, during commercial scheduled flights from St. Martin to St. Barthélemy (on board a local operator's airplane).

The film was shot with the same model of video camera from the same passenger seat. We also recorded engine parameters with a second camcorder, synchronized with the first one, and



Spectral analysis of the soundtrack on takeoff.

Photos copied from the videotape, as an illustration of the calculation of the number of passages of the blades per second.



Propeller rotation during approach sequence.

merged images from both sources into a single film.

We were able to establish several technical facts, among which

- the engine was delivering power from takeoff up to the last image, and was operated in its normal operating range;
- at the end of the sequence, the propeller was selected on full low pitch;
- the altitude was between 1,000 to 1,100 ft. across the Pain de Sucre, which is rather in the lower range of usual altitudes;
- the airplane was probably in descent, and slightly right of the runway track.

Determination of the scenario

The work to identify the events and the potential causes was still to be completed. The work undertaken was based on the following assumption: this accident was the result of identified events, already documented in internationally accepted taxonomy and did not result from unknown phenomena that had never been previously described. With over a century of history in accident investigation, the likelihood that a "discovery" was being missed was very remote and this assumption was deemed acceptable. Therefore, the use of the ADREP model was a natural tool for exploration, since it contains an organized collection of all identified events that have, at one time, led to accidents. The causes were also to be sought in the SHELL model, which is a subcomponent of ADREP (in its latest edition "ADREP 2000"). The advantage of such a method, in addition to its being simple, was to ensure that we would not miss any potential factors. Exploring all potential avenues gave more of a chance for effective prevention. It also helped us eliminate the biases resulting from intuitive assertions, which is a common consequence of brainstorming where the result is so dependent on backgrounds and experience. The disadvantage of this solution is that it can lead to many irrelevant combinations, each one needing a thoroughly argued refutation before being discarded. Finally, it does not provide a definitive scenario, and expert judgment—sometimes based on testimonies and other factual information—is still needed to assess the relative probabilities of causal factors.

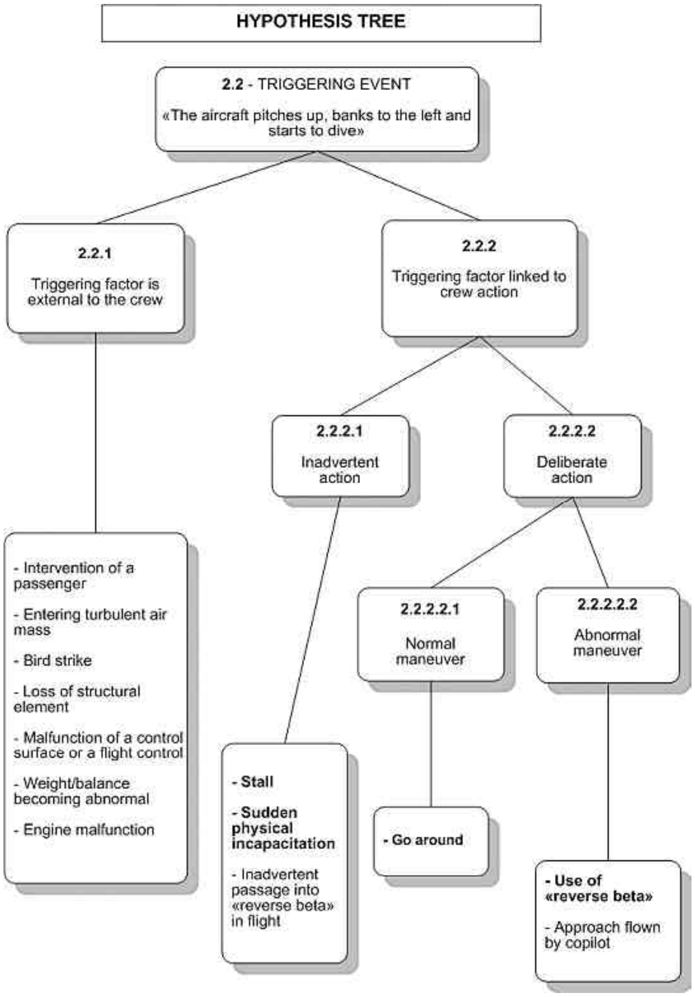
After this work was completed, we needed to condense the results and sort them into a more synthetic approach with the use of a fault tree. The tree was initially based on five levels (dividing lines), but we endeavored to merge two of them into the main three for reasons of simplification. First dividing line: whether the event was crew related, second: whether it was inadvertent or voluntary, third: whether it was the result of a normal action or of a violation. We then came up with a fault tree for the hypotheses, in which we categorized all potential events that we had looked at.

Among the various hypotheses that were analyzed, only four could be retained: two relating to involuntary action by the crew—sudden incapacity of a crew member or a stall due to excessive speed reduction—and two relating to deliberate actions by the crew—loss of control during a go-around or inflight use of the reverse beta range, with, nevertheless, totally different levels of probability.

Of the four hypotheses retained, the first three have a low degree of probability. The most probable is that of a deliberate selection of the reverse beta range for the propellers by the captain to improve control of his track on short final. A thrust asymmetry at the moment when coming out of the reverse beta range would have caused the loss of yaw control, then roll control, on the aircraft.

Elements from the operational context

Other factors were analyzed during the course of this investigation: the lack of recent experience for the captain, a likely get-there-itis, the impact of a strong authority gradient of the cap-



tain over his copilot CRM-wise, the influence of short and repetitive flights on potential deviations from standard procedures, and the difficulty of the approach to Runway 10 at St. Barthélemy.

Conclusion

This event affected a scheduled revenue passenger flight that killed 20, and all of the classic tools that one could expect an investigating authority to use were missing. We, therefore, had to use original solutions to try and get a better grasp of the causes of the accident as rigorously as possible. We took great advantage of the tools developed by ICAO for accident database coding. Finally, we must emphasize the outstanding international cooperation that enabled us to run this investigation so smoothly in the circumstances.

The final report is available on the BEA website at www.bea-fr.org or www.bea.aero. ◆

Investigation Enhancement Through Information Technology

By Jay Graser, Operations Director, Galaxy Scientific Corporation

***Jay Graser** is the Operations Director for Galaxy Scientific's Atlanta office where the On-line Aviation Safety Inspection System (OASIS) was developed. He is a retired Air Force officer with 2,500 aircrew hours and 25 years of leadership and management experience. His background includes managing the C-5 aircraft System Safety Board, Manager of Customer Training for Sikorsky Aircraft, and performance consultant for GE Capital.*

Each year thousands of aviation accidents and incidents occur requiring various degrees of involvement from air safety investigators (ASIs). In 2002 there were more than 1,700 accidents in general aviation in the United States alone. With a finite number of investigators, there is a limit to the number of on-scene and limited investigations they can effectively complete. It is possible for an investigator to be managing as many as 20 investigations at one time. These investigations, characterized by a requirement for constant coordination among various government agencies and parties to the investigation, collection of data and information from numerous sources, and analysis of all pertinent data, all contribute to the investigators' workload. These investigations generate reams of paper and can result in duplicated effort; data are collected in the field and later transferred manually to the proper format and/or database.

In order to enhance processes such as accident investigations, Electronic Performance Support Systems (EPSS) employ existing information technology to deliver integrated end-to-end solutions that provide investigators and associated agencies with the tools and resources to increase productivity, shorten cycle times, lower complexity, eliminate duplicate effort, and reduce costs while facilitating responsiveness, data access, and collaboration.

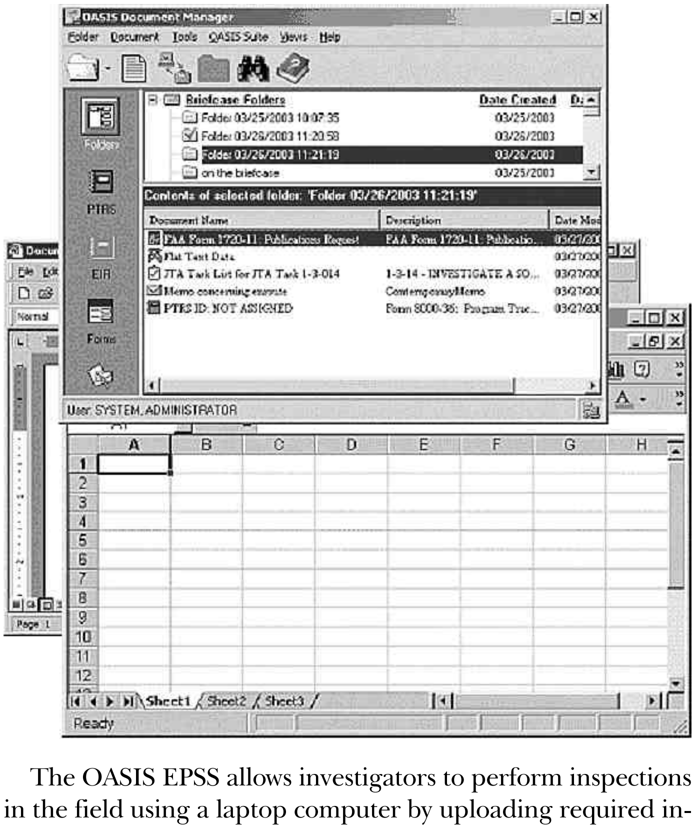
An EPSS is defined as an electronic system that provides integrated, on-demand access to information, advice, learning experiences, and tools to enable a high level of job performance with a minimum of support from other people. [1] [2]

These are four attributes common to an EPSS:

- **Tools**—productivity software (word processing, spreadsheet, etc.) used with templates and forms, such as a word-processing document.
- **Information Base**—on-line reference information, hypertext on-line help facilities, statistic databases, multimedia databases, and case-history databases.
- **Advisor**—an interactive expert system, cased-based reasoning system, or coaching facility that guides a user through performing procedures and making decisions.
- **Learning Experiences**—computer-based-training (CBT), such as interactive tutorials, as well as multimedia training using simulations and scenarios.

EPSS solutions tie together the user interface functionality, data, information processes, and business rules needed to perform specific tasks. This includes tools such as automated "intelligent" forms, rules-based process automation, data integration, and mobility (via laptop, handheld and tablet PCs, wireless connectivity, and ability to operate in disconnected mode). The capabilities can be further augmented with fully integrated components such as global positioning system (GPS), digital photography, electronic sketchpad, etc. Once a detailed study of the tasks involved and desired outcomes is performed, field-proven EPSS applications can be modified for use in accident/incident investigations.

One example of an existing EPSS application is the On-line Aviation Inspection System (OASIS), which is employed by more than 4,000 FAA air safety inspectors and aviation personnel in the field worldwide. An in-depth study indicates that OASIS has produced a 20 percent increase in efficiency and was identified by the safety inspectors as the single most important tool the FAA had fielded.



Briefcase Folders	Date Created
Folder 03/25/2003 10:07:35	03/25/2003
Folder 03/26/2003 11:20:58	03/26/2003
Folder 03/26/2003 11:21:19	03/26/2003
on the briefcase	03/25/2003

Contents of selected folder: 'Folder 03/26/2003 11:21:19'

Document Name	Description
FAA Form 1720-11: Publications Request	FAA Form 1720-11: Publicatio...
Flat Text Data	
JTA Task List for JTA Task 1-3-014	1-3-14 - INVESTIGATE A SO...
Memo concerning example	Contemporary Memo
PTRS ID: NOT ASSIGNED	Form 8000-36: Program Trac...

User: SYSTEM.ADMINISTRATOR

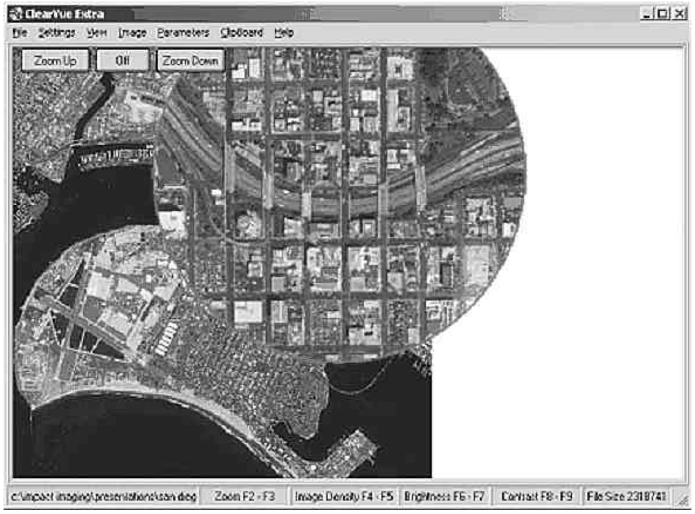
The OASIS EPSS allows investigators to perform inspections in the field using a laptop computer by uploading required information while still in the office, collecting the data in the field while in a "disconnected" mode, and later downloading the information directly to the database. This approach reduces duplication of effort and improves consistency of the data collected through the use of forms that automatically fill in fields based on known information.

The following EPSS features would be integral to a system designed specifically for accident investigations.

Disconnected Mode—The system allows the user to download needed data while connected to the network so that it is available when the investigator is in the field.

Wireless Mode—The system takes advantage of wireless technology by allowing the investigator to upload and download data when a wireless connection is available.

Data and Image Compression—Images are compressed as much as 4000:1 in order to speed wireless transmission and allow for greater data storage in less space.



Encryption—Files are encrypted for protection during transmission or attempted access of the PC or PDA by unauthorized personnel.

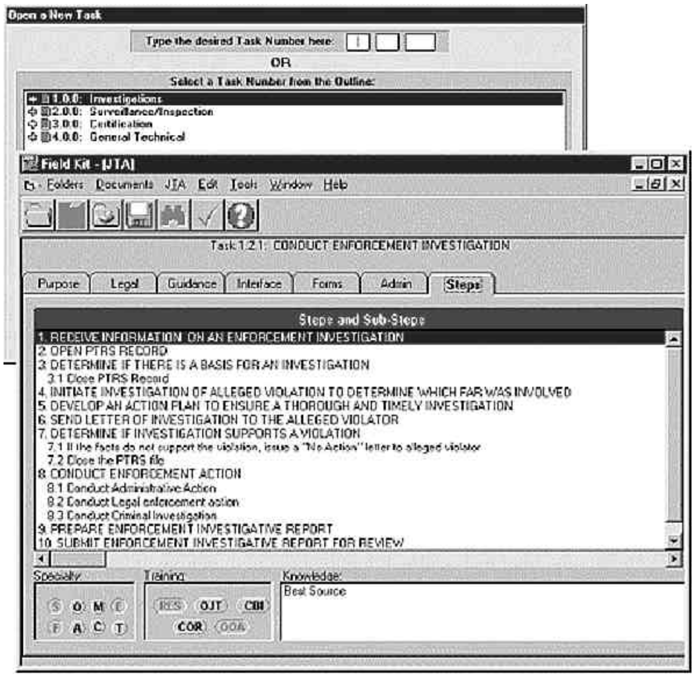
Biometric Security—A thumbprint scanner is integrated into the system to protect the data from unauthorized use.

Multiple Platform Compatibility—The EPSS can be used to varying degrees on different devices, such as laptop PCs, Windows CE, and Palm OS compatible devices.

Integrated GPS Mapping—Area maps are linked with GPS coordinates of debris and photos of the scene where the debris was recovered.

Reference Material—Any reference material that might be needed in an investigation is made available in a digital format from the EPSS.

Text to Audio Conversion—Much like an e-mail reader, the system translates selected documents into an audio file using a synthetic voice. This allows the investigator to be "hands free" learning reference material while performing other tasks, such as driving or walking an accident scene.



Type the desired Task Number here:

Select a Task Number from the Outline:

1.0.0: Investigations
2.0.0: Surveillance/Inspection
3.0.0: Certification
4.0.0: General Technical

Task 1.2.1: CONDUCT ENFORCEMENT INVESTIGATION

Steps and Sub-Steps

1. RECEIVE INFORMATION ON AN ENFORCEMENT INVESTIGATION
2. OPEN PTRS RECORD
3. DETERMINE IF THERE IS A BASIS FOR AN INVESTIGATION
  3.1 Close PTRS Record
4. INITIATE INVESTIGATION OF ALLEGED VIOLATION TO DETERMINE WHICH FAR WAS INVOLVED
5. DEVELOP AN ACTION PLAN TO ENSURE A THOROUGH AND TIMELY INVESTIGATION
6. SEND LETTER OF INVESTIGATION TO THE ALLEGED VIOLATOR
7. DETERMINE IF INVESTIGATION SUPPORTS A VIOLATION
  7.1 If the facts do not support the violation, issue a "No Action" letter to alleged violator
  7.2 Close the PTRS file
8. CONDUCT ENFORCEMENT ACTION
  8.1 Conduct Administrative Action
  8.2 Conduct Legal enforcement action
  8.3 Conduct Criminal Investigation
9. PREPARE ENFORCEMENT INVESTIGATIVE REPORT
10. SUBMIT ENFORCEMENT INVESTIGATIVE REPORT FOR REVIEW

Knowledge:
Best Source

Voice to Text Conversion—The system "learns" the investigator's speech and allows dictation to the system "hands free" while reviewing the accident scene.

Voice Interface—Allows the investigator to move through the EPSS and forms through verbal commands.

Active Help—A system of hints, reminders, alerts, and checklists that prioritize perishable evidence, avoid common causes of errors, and alert the investigator to recent changes. The system keeps track of the current stage of the investigation and provides the appropriate help.

Document Scanning—A small, light hand scanner can be included in the investigator's equipment and used to scan in documents, such as pilot log books, reducing or even eliminating paper document copies.

Sketch Pad—The investigator can annotate photographs of the scene, electronically marking the images using as many as four removable transparencies, without damaging the original photo.

Integrated and Portable Data—Data appropriate to the current investigation is collected, reduced to only what is needed, and stored on the device's hard drive so that it is available in the field. The information is collected from multiple sources, such as both government and nongovernment databases, and presented in a format most useful to the investigator.

Flightpath Simulation—A 3-D flight simulation of the aircraft. It can be used to help witnesses describe what they saw and also help develop possible scenarios of what occurred.

Style Guide—As the investigator is writing, the system suggests wording that is consistent with prescribed and accepted standards.

The following is a scenario where an EPSS could be used in an accident investigation.

Scenario

Notification—Since notification could come from many sources, including law enforcement, insurance companies or air traffic control personnel, the initial data collection must be easy to access and straightforward to use. The person who first takes the call regarding an accident can access the EPSS system via a secure web interface, regardless of his or her location. The EPSS guides the person answering the call through asking a series of questions in order to ensure critical data is not lost. The system establishes a new case file immediately and begins queries of all the appropriate databases to collect the available data on the accident. This search could be based on the aircraft's registration number and any other information the caller could verify. As information is passed from one investigator to another, it remains consistent in the EPSS.

Human factors—Flight plan if available, medical records, training records, inspection records, certifications, and any other data that might provide evidence regarding the aircrew, controllers, operations personnel, and maintainers.

Machine—Aircraft type, images, including background data on the make, possible configurations, engines, avionics, known problems, manufacturer data, production information, maintenance history, and limitations. Previous investigations involving this aircraft and helpful hints in investigating this type of aircraft are also collected.

Environment—Weather conditions in the area during the time of the accident. Additionally, the system would check for conditions of the navigational aids and traffic.

Investigator response—As the assigned investigator prepares to travel to the accident scene, he or she can securely log on to the EPSS and download the file for the accident. Information is packaged in the EPSS so it can be easily studied enroute to the scene. The EPSS checklist tells the investigator current weather in the area; for example, is it cold enough to require cold weather gear and is it a mountainous area. In some cases the trip to the scene would require a long drive or other down time, which can be used to study the available data. The investigator could select the auto reader option for several files of research, and the system would create a file that can be dropped to a CD or MP3. The synthetic voice is similar to those used for e-mail reader systems. While the investigator are preparing to travel, so are the aircraft and engine manufacturers reps who have been assigned to work with you. They received automatic notification from the EPSS system. Their contact information is in the EPSS, so the investigator can contact them, if they don't call the investigator first. If the trip requires a plane ride, the investigator can read some of the research that wasn't converted into audio files and view some of the ultra-compressed images, including satellite imaging of the surrounding terrain and maps of the area, complete with GPS coordinates and any possible hazards. The checklist supplied in the EPSS reminds the investigator to coordinate with local authorities. Police, fire, and disaster response agency contact information is readily available in the EPSS. Had this been a more serious accident, requiring a "Go Team," it would probably have involved other interested government agencies, so the investigator could have used the list of local hotels in the EPSS to call and find rooms and a conference facility. When Go Teams are used, they can use the built-in collaboration tools that allow them to share information and plan the investigation.

On-scene arrival—Upon arrival at the scene, the investigator has already listened to several hours of audio regarding the pilot, the aircraft, the planned flight, and the surrounding environment. If Family Affairs was not called out on this accident, it would be up to the investigator to apply his or her experience and the guidance in the EPSS to provide them the support they will need while not impeding the investigation. As the investigator begins "kicking tin," the "smart" forms in the EPSS are already partially filled out from what the system was able to research based on the "N" number, and almost all of the fields that are not filled out have drop down menus, reducing the number of decisions you need to make.

The voice-recognition system allows the investigator to walk the scene "hands free" and talk to the system using the same headset typically used for his or her cell phone. The investigator can edit the voice-recognition-generated text files back at the hotel or office, but much of the typing is eliminated. The voice-activated interface allows the investigator to navigate the form without ever having to touch the PDA. An audible tone notifies the investigator that the next step in the checklist comes with an alert. Rather than hear the text, the investigator may elect to read it and view the associated pictures. An example of an alert is that the system could remind the investigator that the aircraft may include avionics that have NVM (non-volatile memory). The investigator may need to determine which boxes to prioritize their recovery, because some have internal batteries to preserve the memory.

Even if the investigators get distracted, the EPSS will remind them of where they are in the checklist. If the investigators encounter an unfamiliar situation, the investigation "hints" allow them to tap the collective experience of all the investigators over the years. Additionally, if the investigators have a hint they would like to capture for other investigators, they could use their digital camera to take shots of the area, download them into their PDA, and dictate some text to go along with the new hint. Soon, the investigator has enough data that it would be worth sharing with his or her office. The investigator patches his or her PDA into the cell phone and launches a compressed file to the system. Critical information can be shared with fellow investigators, other government agencies, manufacturers, and operators.

As the investigator begins interviewing eyewitnesses, he or she may realize most of them cannot effectively describe what they saw. Using the EPSS, the investigator can show them a 3-D image of the aircraft and, based on what they tell the investigator, capture their account in a simulation and text. The investigator collects all the accounts of several eyewitnesses and adds the known parameters of weather and debris pattern, and, if there is enough data, the EPSS creates a desktop animation of the possible scenario, based on the same dynamic models used by the simulators.

The investigator will need to deal with the media, either via phone calls or in morning and/or evening press conferences. In order to prepare, the investigator clicks on the Press Report mode and the built-in report generator with style guide suggests a press report based on what the investigator has collected up to that point.

Once the field investigation is complete, on the trip back to the office, the investigator can begin refining the report. The automatic style guide makes suggestions along the way to ensure the investigator's report fits with the accepted format. Any reference to parts of the investigation that are pending, such as lab results, include a pop-up message telling that status of that item and when it is projected to be complete.

Back at the office—Upon returning to the office, the investigator makes a few more entries into the most recent file while his or her thoughts are still fresh and then turns his or her attention to the other six or more reports in progress. After a few days, the investigator receives an e-mail reminder that the lab results the investigator was awaiting are available and that this will allow them to complete the report. Once the report is complete, the investigator can send it electronically to the supervisor, including images, simulations of the most likely scenario, and audio files such as the cockpit voice recorder and ATC communications.

Conclusion

An EPSS applied to accident investigations would enhance the effectiveness and efficiency of investigations, save time, radically reduce paper, and ultimately save lives. Written, audio, and pictorial communication between investigators and interested parties through the use of electronic files and reduce or even eliminate paper features such as case management, and tracking would allow investigators to handle multiple cases with maximum efficiency while still delivering a credible, reliable report on the probable cause of the accident. ◆

Footnotes

[1] Gery, G. (1991). *Electronic performance support systems: How and why to remake the workplace through the strategic application of technology*. Boston, MA: Weingarten Publications.

[2] Raybould, B. (1990). Solving human performance problems with computers. *Performance & Instruction*, *29*(11), 4-14.

Historical Review of Flight Attendant Participation in Accident Investigations

By Candace K. Kolander, Association of Flight Attendants, AFL-CIO

***Candace K. Kolander** is the Coordinator for the Air Safety, Health and Security Department at the Washington, D.C., International office of the Association of Flight Attendants (AFA). As such, she works with the Director to accomplish the research, regulatory, and training mission of the department by providing services to the AFA membership, International Officers, and its Board of Directors. She is also one of the main contacts in the department to deal with security issues. Kolander is the liaison between the safety chairs at the carriers and the International office. She deals with proposed regulatory changes, advisory circulars, and handbook changes. She also provides the training and assistance to AFA participants in NTSB accident investigations. Kolander is a 16-year flight attendant on a leave of absence from her carrier to work for the AFA. At her carrier, she served in multiple roles representing flight attendants in addition to helping plan and teach flight attendant recurrent training.*

Sky Girls begin.

Ladies and gentlemen, I am pleased to be here today for the International Society of Air Safety Investigators (ISASI) 2003 seminar to help celebrate the 100th anniversary of the Wright Brothers' first controlled powered flight. As a historical overview of the cabin environment, I will speak specifically about flight attendant participation in an accident investigation in the United States and some of the improvements that were made in the cabin.

I will review the original role and history of the flight attendant on board the aircraft, then look over a few historical accidents and some of the lessons learned from them. The entire premise of accident investigation is to look at the details of a particular accident and determine the probable cause, and then make recommendations for the purpose of preventing future accidents. Trained flight attendants can assist in an accident investigation and provide valuable recommendations for use in preventing future accidents or problems regarding an evacuation.

Let's begin with a brief history of the flight attendant. During the 1920s and 30s, we first began to see the start of the flight attendant role on the aircraft. With the advent of the U.S. mail contracts, we saw airlines begin to carry a limited number of passengers. In 1922, some of the first cabin boys were employed in Europe by Britain's The Daimler Airway.(1) These stewards would load baggage and provide inflight services to passengers. It was a way to entice passengers to fly on the sometimes unreliable and dangerous airplanes.

Then in 1930, against some management opposition, United Airlines began a 3-month stewardess experiment on their cross-country flights. They hired eight nurses to fulfill the new role. On May 15, 1930, the first "sky girl," Ellen Church, worked the flight from Oakland to Chicago on a Boeing Trimotor. She and her eight colleagues were hired to quell the nervousness of new fliers on those long, arduous journeys that sometimes took between 18 and 24 hours to complete, in an airplane that was not pressurized, heated, or air conditioned. In addition to being registered nurses, those original "sky girls" also had to be single, childless females under the age of 25, and under the weight of 115 pounds.(2)

In the early years, flight attendants were on board commercial aircraft for practical and marketing reasons. We dressed appropriately for the work and environment; wool suits and capes were the standard attire, replaced with nurses' uniforms worn inflight. Shoes were sturdy and lace up—this was a no-nonsense style that was utilitarian, yet professional. This image would change dramatically in later years as our role took on a sexual undertone exploited for company profits. I personally cringe when I hear the old marketing slogans, "Coffee, tea, or me?" or "I'm Cindy, fly me!"

As far as I can tell, the earliest reference to the requirement for a flight attendant seems to be in 1941 regarding altitude of flight operations. The Civil Aeronautics Board (CAB) had the authority and responsibility for economic and safety rulemaking and accident investigation.(3) Civil Air Regulation (CAR) § 61.742 read: *Maximum altitude of flight operations. In scheduled air carrier aircraft carrying passengers and operating at air altitude above 15,000 feet above sea level, there shall be a competent cabin attendant provided to observe and care for the passengers. Scheduled air carrier flights above 15,000 feet are prohibited except for the periods of time which are necessary to clear obstructions to flight and to avoid hazardous weather conditions. Scheduled air carrier flights at altitudes above 18,000 feet are prohibited unless specifically permitted by the terms of the weather competency letter.*

The next modest proposal was initiated by the CAB in 1953, specific to the requirement for a flight attendant. Civil Air Regulation § 40.265 read: *Flight attendant. At least one flight attendant shall be provided by the air carrier on all flights carrying passengers in airplanes of 10-passenger capacity or more.*

While the general public thought that these new stewardesses held glamorous jobs, the reality was that the stewardesses were disillusioned by the poor working conditions, long hours and poor salaries. For example, her seating environment often put her within flying distance of loose galley equipment such as ovens, coffee pots, soda cans, and serving utensils. That is because they were often only secured by flimsy thumbnail latches or cloth strips. Within little more than a decade, the earliest stewardesses formed their own union. The Air Line Stewardesses Association (ALSA) is the predecessor to my current organization, the Association of Flight Attendants (AFA), AFL-CIO. Today, AFA represents 50,000 flight attendants at 26 airlines.

The attitude of society during those early years was often discriminatory toward women. At the time my union was founded, the labor movement, with rare exceptions, was also dominated by men. This male domination was also evident regarding the flight attendant union's role in an accident investigation.

From 1949 until 1973, the present day AFA was affiliated in one way or another with our brother organization, the Air Line Pilots Association (ALPA). It was within this affiliation that flight attendants began to document and work on accident investigations.

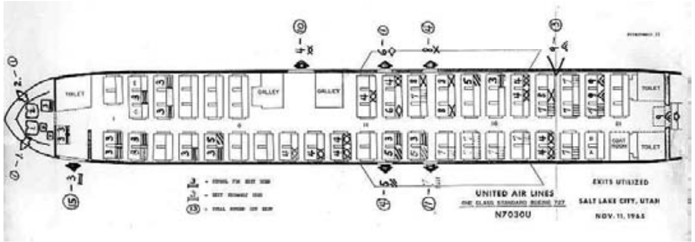
I have searched AFA's accident files from 1951 to 1970 for any documentation of flight attendant participation in an accident investigation. I will admit some of the current files at AFA are very scarce in "content." I am still working with ALPA to obtain some of these past accident files when we were affiliated with them.

The current National Transportation Safety Board came into existence in the spring of 1967. Prior to that, the CAB did accident investigations. The CAB accident investigations were primarily aimed at finding out why the airplane crashed. When I reference an accident report prior to 1967, I am referencing accident reports done by the CAB, not the NTSB.

In my review of the AFA accident investigation files during the years prior to 1960, few made mention of cabin conditions prior to, during, and after an incident or accident. The in-cabin factors, which affected the safe evacuation of passengers and flight attendants, were largely ignored. A few of the accident reports did not even mention the name of the deceased stewardess in the report; the only reason I knew there was a stewardess on board was because of our internal office memos at the time. Some of the final reports were barely 10 pages long.

Throughout those years, it was interesting to see the predecessor to the *Federal Register* notice of a hearing. Some of the files have the original Western Union Telegram announcing the hearing date and location. During the 1950s, members of this union did attend some of these public hearings. In fact, at a public hearing in 1955 for Eastern Flight 642, the steward and stewardess representative was recognized by the Board at the end of the public hearing and asked if the representative had any comments. Because this was a non-survivable accident, the representative was unable to offer any comment. But it was a beginning in recognizing the benefits of the knowledge the flight attendant could offer.

As far as I can tell, the first time my union predecessors participated in an accident investigation it was Trans World Airlines Flight 400, a Martin 404 that crashed and burned immediately following takeoff from the Greater Pittsburgh Airport on April 1, 1956. "The hostess and 21 of the 33 passengers were killed; both pilots survived. The aircraft was destroyed by impact and fire."(4)



Although we were still under the wing of ALPA, we would have a member of the National Safety Committee of the Air Line Stewards and Stewardess Association (ALSSA) listed as an official member of the Flight Operations and Witness Group. Just for the record, this was a male who participated in the group for ALSSA. This group focused on the facts concerning the history of the flight and flight crew activity in the final phases of the flight, as well as questioning persons who may have seen, heard, or participated in some portion of the flight. The flight was not designated as survivable or non-survivable. The only reference in the final report regarding the cabin states: *"As the aircraft cartwheeled up a small incline, the left wing disintegrated and the wreckage came to rest with the right wing elevated. This resulted in fuel from the ruptured fuel tanks of the right wing flowing down and under the shattered fuselage, feeding a fierce gasoline fire and quickly trapping many occupants."*(5)

In 1960, my union went through further transitions with our affiliation with ALPA. ALSSA, as mentioned above, became a completely separate division under ALPA. This changed the ALPA organizational structure dramatically. We would now be called the Stewards and Stewardesses Division (S & S) of ALPA. The other division, of course, was the Pilot Division. In addition to the organizational change, we would see a change in the way ALPA related to our organization.

ALPA hired a staff member for the express purpose of working with the members of the S & S Division to improve the safety of flight attendants and to assist the other members of the Safety and Engineering Department in matters that were closely related. The staff member ALPA selected for the position had flight attendant experience as well as a degree with a strong emphasis in human factors.

The ALPA Safety and Engineering Department and the Safety Chairman of ALPA's technical committees, which had an interest in areas similar to the flight attendants, began to invite the staff member assigned to help flight attendants to various activities that had to do with crashworthiness, fire and rescue, training, human factors, and physical standards. The staff member ensured that flight attendants were also present at these meetings. Thus, an understanding of the problems of flight attendants was born. But perhaps even more important than that, the pilots began to admire the intelligence and knowledge of the flight attendants who participated in these meetings.

As flight attendants continued to assist in these meetings, a new idea was being considered: Could a female flight attendant be included in the actual accident investigation?

The idea was met with resistance. Many pilots, government accident investigators, and company personnel were very paternalistic and felt that some of the grisly accident scenes would just be too horrible for any woman to see, and at the time, most of the flight attendants were women.

Today, we do recognize that not all individuals will be able to withstand the emotional impact of a crash site, but I do not believe this is gender specific. For that reason, under our current guidelines, before we send flight attendants to a crash site we ensure that they have the unique knowledge and training required for the task, as well as common sense and an emotional character that we believe can deal with the task at hand.

There was also a growing recognition that the flight attendants possessed necessary, firsthand knowledge of many safety problems that were related to flight attendants and their job. One of the major problems was flight attendant seats and restraints.

As far as we know, the first time a female flight attendant was part of the accident investigation team was at the investigation of the Mohawk Airlines, Martin 404 accident at Rochester, N.Y., on July 2, 1963. United flight attendant Iris Peterson helped in the accident investigation and was listed as an official member of the Human Factors Investigative Group.

The Martin 404 had a flight attendant seat all the way in the back and next to a carry-on baggage rack with only one strap across each shelf for restraint of the baggage. The United "stewardess" was living in New York and was available, so when she got the call she rushed out to the accident scene. She and one of the pilot investigators took pictures of the seat and the luggage that had shifted. Her knowledge and her professionalism impressed the pilots and other accident investigators.

While the Human Factors Investigative Group did a very extensive examination and documentation of seat damage to every seat on the aircraft, the final CAB report was similar to many other ones during the time: It focused on the cause of the accident and not cabin issues. The reference to the cabin interior in the final report reads: *"The forward section was reduced to a mass of torn, twisted, and compressed metal. The center section remained intact and attached to the center wing panel, sustaining only interior damage. During and following the principal impact, all 20 double passenger seats were torn free from their attachments. Most seats were thrown free of the wreckage."*(6)

The flight attendant seat on this accident did not fail, but the seat pan was deformed. Seven of the 43 persons aboard, including both pilots, were fatally injured in this accident.

From then on, ALPA tried to send a member of the S & S Division to each survivable accident investigation where the flight attendants assigned to the air carrier involved were members of the ALPA S & S Division. S & S Safety Chairmen were supposed to work closely with the Pilot Division Safety Chairmen. Most of the time this worked quite well. The airlines were smaller in those days and as most flight attendants did not hold many years of seniority, they could use the guidance of the Pilot Safety Committee members and were glad to get it.

In the ideal situation for an accident investigation, the procedure would go something like this: The company would notify the appropriate ALPA representative and that person would decide who needed to go to the accident investigation and would coordinate with ALPA headquarters. ALPA had an accident investigation manual that was followed by safety representatives of both divisions. It contained information about contacts, what to do when you got there, how to deal with the government accident investigators, how to deal with the press, etc.

Sometimes a member of the ALPA Safety and Engineering staff would go to the accident site and participate in the accident investigation. However, the ALPA representative who was at the site was in charge of that accident investigation as far as ALPA, the ALPA staff, and the ALPA S & S division were concerned; this was the person to whom the flight attendant reported upon arrival at the accident location. The bottom line is that flight attendants were still part of the ALPA investigation team.

At first, the flight attendants focused on things that could affect the flight attendant's safety. And there were quite a few. According to the National Transportation Safety Board statistics, between 1964 and 1970, 43 percent of the flight attendants involved in survivable accidents on takeoff were either killed or severely injured, and 48 percent were killed or severely injured on the landing phase. The primary cause of these injuries and deaths was the flight attendant seating arrangement. So, of course our early emphasis during an accident investigation was mainly on flight attendant seats and restraint systems. There were flight attendant seats that literally fell off the wall with little or no impact on them—even in normal flight. There were flight attendant seats tucked in corners, attached to cockpit doors, side facing, or tucked into storage areas. Many of them were located in just plain awful places such as the flight attendant seat in the Mohawk accident. In fact, most flight attendant seats did not have shoulder harnesses, nor did they have padding for the head. Other concerns were the deficient latching mechanisms on galley items that enabled these heavy or dangerous items to come loose during an emergency.

During these early years, other concerns were noted in internal documents. Of course, we had written recommendations regarding flight attendant jumpseat durability and locations, the need for better evacuation training, better education of the passengers, and increased restraint mechanisms for galley equipment.

There was one flight attendant seat that was in the lavatory, side facing, with no shoulder harness and where the flight attendant faced a mirror. Now the mirror was supposed to be shatterproof, but little consideration was given to the fact that the flight attendant was side facing. One of the flight attendant seats on the McDonnell Douglas DC-8 was in a closet, also side facing. Other flight attendants were seated in lounge areas on the different aircraft. So the first thing the flight attendants did when they got to the accident site was look at the flight attendant seat, take pictures of it, and talk to the flight attendant about how it worked.

We all know that a flight attendant is on board an aircraft for emergency and evacuation purposes. Yet during those years, there was a very good chance that the stewardess was not going to be around to deal with any of those things considering all the cabin problems and high death rates of the stewardesses.

One of the major benefits of having the flight attendants actually participate in the accident investigation was the contact they made with the government accident investigators and others who participated. Over the years, this was to prove more and more valuable.

For example, flight attendants discovered that some of the latches used to restrain the equipment were not strong enough. Equipment would come loose and could cause an injury or block an exit. Conversely, it was also discovered that some of the equipment were impossible to remove from its stowage area. Many times, the restraint of the equipment was changed because of these discoveries. In some cases, it became apparent that the flight attendants involved in the accident felt the procedures were not adequate or their training was not sufficient.

In one case, the flight attendant had only been trained on one model of this type of aircraft, and yet the door that she tried to open did not open like any of the doors on which she had been trained. The operating mechanism was just not the same.

As things progressed, there were accidents where more than one flight attendant would go to the site. This enabled the ALPA accident investigation team to get more involved in what happened during the actual aircraft evacuation. Because the flight attendants assigned to the involved carrier knew what the procedures were, they could help figure out if these procedures worked.

In the early years, the slides that were usually installed on the aircraft were not inflatable. It was quite an operation to install them. There were straps that were color-coded that had to be fastened to the same color of "eyes" on the airplane. Never mind that if the airplane was dark, no one would be able to see the colors. So accident investigators realized how important the flight attendants and their knowledge could be to the investigation of the accident. They would go with the government investigators to interview the survivors, especially the flight attendants.

They helped to "map" the seats and egress routes for passengers, and they asked the questions about how the slides worked. Remember that for non-inflatable slides an able-bodied man (yes, they were men in those days) climbed down the slide and then held them. It was fast becoming obvious to everyone that something else was needed. People were having a hard time getting out of airplanes and many were jumping from doors and hurting themselves.

In the early 1960s, there was a lot of work being done on aircraft evacuations. In 1964, the FAA started requiring full-scale evacuation demonstrations where the aircraft must be evacuated in 120 seconds. (This was changed to 90 seconds in 1967 when some of the rules regarding installation of inflatable slides were changed.) I believe the reason for this requirement for evacuation demonstrations was based on the concern of a lot of people about where the industry was going with the larger and longer airplanes. Were these planes actually safe? Were more exits needed? What about the procedures that the airlines used? What about the number of flight attendants? What about the slides?

As the flight attendants gained experience at accident sites, they began to walk through the cabin of the airplane and establish things such as the location of safety and emergency equipment. They also began to put more and more emphasis on the flight attendant interviews. This information would be part of the overall report of the ALPA Crashworthiness Committee report on that accident. Sometimes the information was also included in the government reports on the accidents.

In 1965, United Airlines had a tragic accident in Salt Lake City. It was perhaps coincidental that two well-qualified flight attendants, one from United and one from Braniff, participated in the investigation of this survivable accident and proved the value of their knowledge and unique qualifications. This tragedy and its resultant investigation caused a complete realization by appropriate authorities that the cabin conditions prior to and after a survivable accident had a direct bearing on the number of survivors.

United Airlines Flight 227.

Perhaps it was also coincidental that many changes in cabin procedures and equipment are in effect today as a result of this team's recommendations, as well as some of the internal recommendations regarding the Mohawk accident. We know these changes were made, but no one knows the numbers of lives saved as a result.

United Airlines Flight 227 crashed during an attempted landing in Salt Lake City, Utah, on Nov. 11, 1965. Of the 85 passengers and six crew, there were 43 fatalities, including two passengers who succumbed in the hospital several days after the accident.(7)

Fifty occupants successfully evacuated this aircraft; the remaining 41 occupants were overcome by dense smoke, heat, or flames.

The impact produced a large impact hole from the right main landing gear assembly and ruptured fuel lines on the right side. The fuel ignited, causing an entire section of roof and cabin area to be consumed by fire. The attempts of the stewardess to open the forward main loading door were hampered by the passengers pressing into the area. The door was finally opened by the second officer.

The galley door and overwing exits were opened by passengers. However, the galley door slide was not inflated until a deadheading United stewardess was able to instruct a man to activate it. Both were outside the aircraft at the time.

The aft stewardess tried to open the ventral stairway to see if it could be used for evacuation, but it opened only several inches. She and two other passengers tried to return to the cabin to seek another exit but were blocked by flames and smoke. They began pounding on the fuselage and yelling to firemen outside. Eventually a fire hose was passed into the three survivors to help control the fire. They eventually were rescued through a large hole that had burned through the aft cabin wall. *"The impact of the crash did not produce any traumatic injuries which would have precluded the escape of every passenger. On the contrary, it was the speed with which the passengers progressed toward the exits that prevented the stewardess from reaching her assigned duty station for evacuation. Following the accident, the stewardesses recommended that they be seated near emergency exits for all takeoffs and landings. This practice has been adopted by UAL as standard procedure on all B-727 flights."*(8)

At the end of the CAB report, the Board recommended that the positioning of stewardesses near exits should be reviewed. They also recommended that crash fire-prevention research programs under way be "pressed with vigor." This should include requiring newer aircraft to be fitted with newer materials less susceptible to combustion. The final report also suggested that the emergency lighting system be rewired so that a loss of electrical power source for normal cabin lighting activated the emergency lighting. This was because the lights had failed to activate in this accident.

By 1970, it was routine for flight attendant safety representatives to participate in accident investigations. They accompanied the ALPA representatives and basically did what the government accident investigators asked them to do. This included reviewing the flight attendant manuals, helping determine the efficiency of the slides, interviewing flight attendants, helping to determine if there was a problem in flight attendant training, working with the pilots to establish the level of crew coordination, interviewing survivors to determine escape routes, and determining the usefulness of emergency equipment and restraints.

I would like to say that by 1970 we had resolved the flight attendant seat issue, or should I say a poor excuse for a so-called "seat." But we hadn't. In reviewing the AFA historical documents, I noted that we began requesting improvements to the unsafe aspects of flight attendant seats in 1959. Ten years later, we were still asking for help with this unsafe condition. We had submitted reports about potential hazards of "snapping" jumpseats, submarining under safety belts, harness and bulkhead problems, projecting door handles, loose liquor carts, and overhead coffee urns in areas where flight attendants had to sit for takeoff and landing.

By 1972, when the Federal Aviation Administration finally decided to look at our jumpseat concerns, there had already been other accidents in which jumpseat deficiencies were an issue. In the Capitol DC-8 accident that occurred on takeoff in Anchorage, Alaska, in 1970, one flight attendant's jumpseat folded up under her and she became entangled in her seat belt.(9) Another flight attendant's cloth to metal seat belt opened on impact. Life rafts and galley equipment fell on the flight attendants, temporarily rendering them unconscious. The one flight attendant assigned to a passenger seat in the forward cabin was not injured, while those in their jumpseats were.

The Mohawk Airlines crash in Albany, N.Y., in 1972 was another event in which one of our flight attendants lost her life.(10) After the accident, the FAA issued an airworthiness directive prohibiting further use of all aft-facing stewardess' seats mounted against the wall in the Fairchild Hiller FH227B aircraft.

The 1972 FAA study stated there were problems that should be addressed but that in general the seats were in compliance with the current regulations. And the clock kept ticking. Even after additional accidents, a request for rulemaking regarding flight attendant seats, grievances regarding side-facing seats, a request to CAMI for seat testing, a 1972 U.S. Army report saying that side-facing seats should not be used because of poor protection, and more letters, a proposed rule change was not issued until August 1975.

The rule would finally make side-facing seats and seats mounted on cockpit doors illegal. Seats with a safety belt and shoulder harness would be required, as well as located near an approved floor level emergency exit. Finally, after 16 years of fighting to protect our members, we would get better jumpseat protections.

Although I only concentrated on one aspect of aircraft crash survival, the flight attendant seat, there are other issues that improved throughout the years resulting from continued documentation of the problems.

Years ago, one of the main concerns of the flight attendant organization was jumpseats placed in galleys with large containers and carts facing them. This research made me think about my own working environment on an aircraft that has an entire back "wall" of galley carts and ovens facing directly at me as I sit in the jumpseat.

And what about future concerns? The very large transport aircraft have the capacity of carrying more than 500 passengers. These airplanes are now being developed, and we must look forward into concepts that are not yet on the production schedule. Double or triple passenger decks, extreme wide bodies, extra-long stretch aircraft, flying wings, and other yet-unimagined approaches fall into this category. These could very realistically pose new challenges for flight attendants regarding passenger management, emergency response, and evacuation scenarios. These concerns will need to be documented. We must remain vigilant in ensuring the safety of all occupants on board an aircraft.

Along the same lines, it is important to recognize the value of flight attendants at an accident location. They are the women and men who fly these aircraft daily. They know the uniforms worn by the flight attendants, the amount of galley equipment utilized on the aircraft, and the location of the emergency equipment. The flight attendant knows the service required for a particular segment of a flight, and where they would have been in the aircraft at the specific time of the accident. They know almost every motion of that aircraft on a normal flight, and they know the training they were given by the operator in dealing with specific emergencies.

I believe flight attendants are well qualified to participate in an accident investigation and their important life-saving recommendations can help provide better cabin safety for everyone. We must continue to look ahead to future safety improvements, not only for new aircraft but also for aircraft currently in service.

As Iris Peterson said to me regarding her participation in the investigation of the Mohawk accident, "It is, after all, an advantage to everyone to have a flight attendant participate in an investigation because no one knows the aircraft cabin better than a flight attendant." ◆

Footnotes

1. United Airlines website; united.com; Flight Attendant History, The Experimental Years.
2. Panter Nielsen, Georgia, *From Sky Girl to Flight Attendant: Women and the Making of a Union*, 1982.
3. 8300.10 Change 9, Chapter 6, The FAA and Flight Standards: History, Organization and the Public Law, 8/13/93.
4. Trans World Airlines, Inc., Martin 404, N40403; Near Greater Pittsburgh Airport; CAB Accident Investigation Report; File No. 1-0070; Adopted September 11, 1956, Released September 14, 1956.
5. Trans World Airlines, Inc., Martin 404, N40403; Near Greater Pittsburgh Airport; CAB Accident Investigation Report; File No. 1-0070; Adopted September 11, 1956, Released September 14, 1956.
6. Mohawk Airlines, Inc.; Martin 404, N449A; Rochester, New York, July 2, 1963; CAB Accident Investigation Report, File No. 1-0008; Adopted May 13, 1964, Released May 20, 1964.
7. United Airlines, Inc.; Boeing 727, N7030U; Salt Lake City, Utah, November 11, 1965; CAB Accident Investigation Report, File No. 1-0032; Adopted June 3, 1966, Released June 7, 1966.
8. United Airlines, Inc.; Boeing 727, N7030U; Salt Lake City, Utah, November 11, 1965; CAB Accident Investigation Report, File No. 1-0032; Adopted June 3, 1966, Released June 7, 1966.
9. Capitol International Airways, Inc.; McDonnel-Douglas DC-8-63F, N4909C; Anchorage International Airport, Anchorage, Alaska, November 27, 1970; Human Factors Group Chairman's Factual Report, Docket No. SA-423, Exhibit No. 6A.
10. Mohawk Airlines, Inc.; Fairchild Hiller FH-227B, N7818M; Albany, New York, March 3, 1972; Human Factors Group Chairman's Factual Report, Docket No. SA-431, Exhibit No. 6A.

Accident Investigation Without The Accident

By Michael R. Poole (M03278), P. Eng., Managing Partner, Flightscape

***Mike Poole** is a professional engineer with a current pilot's license and is recognized worldwide as a leading expert in the field of flight recorder analysis. He represented Canada as the national expert panel member to the International Civil Aviation Organization's Flight Recorder Panel. He started in the field of aircraft accident investigation in 1977 and has worked for more than 20 years with the Transportation Safety Board of Canada. For the last 15 years of his career at the TSB, he was the head of the flight recorder and performance laboratory, which he developed for the Board. He was the Flight Recorder Group Chairman on all major accidents in Canada as well as several international accidents during his tenure as the Recorder Laboratory Head. In 1985 he was responsible for initiating the project that led to the development of the Recovery Analysis & Presentation System (RAPS) that is used by many States' flight recorder labs and was eventually commercialized by the TSB. Poole joined Flightscape in February 2002, a flight safety company specializing in flight sciences and flight data analysis systems. Flightscape maintains and supports RAPS and other product lines for handling flight data. His hands-on flight data analysis and investigation experience, lead roles on international committees in flight recording, and his technical knowledge bring significant expertise to the Flightscape team.*

Abstract

This paper will discuss the growing trend of airlines wanting to analyze flight data on a regular basis for accident prevention and the numerous similarities to accident investigation. Investigation authorities with substantive flight recorder labs have been analyzing data for years with highly specialized tools that have evolved over many years. This relatively small group of people has gained valuable experiences related to the limitations of flight data and in particular the pros and cons of flight animation. With the recent trend to routinely analyze flight data, there is an increasing demand for flight animation systems within the airlines and a tendency to want automatic tools that require no or little experience on the part of the operator. While flight animation is extremely beneficial, investigators have considerable experience with the numerous associated pitfalls whereby animations can be misleading. The paper will outline some of these pitfalls and stress the importance of the airline and investigation communities learning from each other.

Introduction

Flight data volume and availability has come a long way since the beginning days of aviation. Traditionally, accident investigators were the only people who examined flight data in great detail, in aid of detailed investigation. Today, with airlines embracing routine flight data monitoring (FDM) programs (Note: Flight data analysis [FDM] is ICAO nomenclature, flight operations quality assurance [FOQA] is U.S. nomenclature, and FDM is Canadian and some European nomenclature) and the most recent trend for the airlines to use flight animation to replay the data, the domain of flight data analysis is rapidly being driven by the larger airline industry. This paper will argue that the airlines, in many ways, are performing "accident investigation without the accident," and that there are some significant benefits from examining some of the lessons learned from the relatively small accident investigation community.

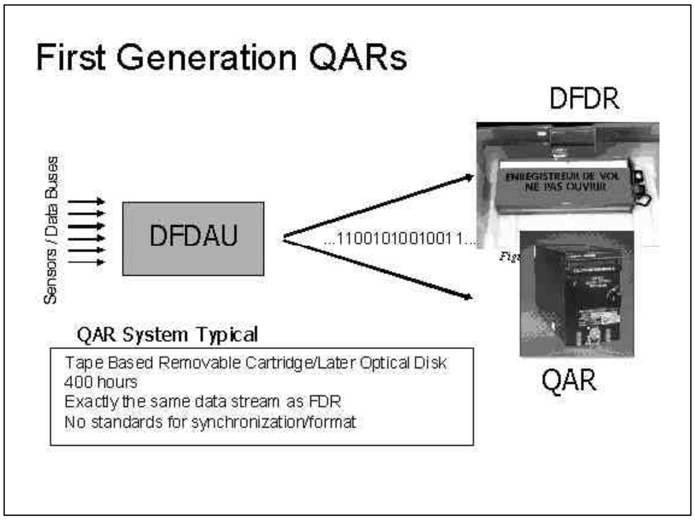
A common statement I have heard lately is that FDM programs and accident investigation are not the same and therefore require different tools and there is perhaps a misperception that "accident investigation" tools are not needed for FDM.

History of flight data

Before exploring this issue, a brief recap of the evolution of flight data is worthwhile. In the early days (1960s) came the metal foil recorder, which recorded analog traces of five basic parameters (airspeed, magnetic heading, pressure altitude, vertical acceleration, and VHF keying, on a time base). Then came the digital era (early 1970s), where flight data were digitally recorded on magnetic tape and the FDR name was changed to DFDR to denote digital FDR (there are no analog FDRs today so the D is not used anymore). Although the military introduced solid state (digital data stored on memory chips) in the 1980s, it wasn't until the early 1990s before solid-state memory was acceptable for use in civilian aircraft. The military was able to use solid state before civil aviation because the military recorded typically much less data than civilian aircraft and did not have the same crash survivability requirements as civilian standards, thereby being able to take advantage of early chip designs that did not meet international FDR/CVR standards at the time (Eurocae ED55 & ED56). The digital flight data acquisition unit (DFDAU) provided the data source for the FDR, accepting inputs from various sensors and data busses on the aircraft and "packaging" them into a serial bit stream that was sent to the FDR.

Some airlines, such as British Airways and SAS, were already routinely analyzing flight data for maintenance, prevention, and operational anomalies. In fact, SAS even had two people whose sole job was to sit in front of a magnifying glass and read out foil recorders looking for problems. In these days, no flight animation was available or done, and the parameter sets were few in number.

Airlines quickly discovered that to extract data from the mandatory FDR was by no means an easy process. For many, this meant only pursuing the data in reaction to a significant event. The recorder had to be removed from the aircraft and in some cases opened and recertified. Copy processes took hours and were fraught with "dropouts" or bit errors due to the mechanical nature of the recording system. This inspired the first generation of



First Generation QARs

QAR System Typical

Tape Based Removable Cartridge/Later Optical Disk
400 hours
Exactly the same data stream as FDR
No standards for synchronization/format

quick access recorders (QARs) in the early 1970s. They were built with a removable media (initially tape as well) so that the airline could simply pull out the media and substitute another at any time. In the majority of these early systems, the FDAU sent the *identical* data stream to both the FDR and the QAR simply to facilitate easy access to the data.

Effectively, airlines had two recorders on board the aircraft, one that confirmed to rigorous standards (FDR) and one that conformed to no standards (voluntary), and both recorded the same information.

The data stream in those early days was, by some airlines, not enough, so they asked if they could have more. It is important to note (and it is a very common misconception) that the issue of capacity is rarely an FDR problem; rather it is an acquisition problem. The reason that we did not have larger mandatory parameter lists is because of a lack of data availability, not a lack of FDR capacity. If the data were to be added to the FDR, it did not help the airline because it was not accessible, and any changes to the FDR meant rigorous recertification issues. The data were naturally added to the QAR instead, and in some cases a complete additional voluntary FDAU was added to the aircraft that the airline could reconfigure at will to determine which parameters were recorded.

Around this time, solid-state memory media recorders were introduced. The advent of solid state was a great advancement in data quality and FDR reliability since there were no moving parts. They were also readily downloadable making them "*quick access.*" I remember being at a Eurocae meeting in Washington in the early 1990s and I said to the QAR manufactures that they need a new name because "quick access" was no longer a good differentiating term since SSFDRs were also quick access. Many of us thought the QAR would simply die a natural death with the advent of SSFDRs. Why did investigators come to dislike the QAR? The Swissair Flight 111 MD-11 accident off Peggy's Cove in 1998 is a good example. The Swissair 111 FDR was a solid-state recorder with 64 words/sec. The QAR was a 384 word/sec tape-based unit, arguably less quick access than the FDR! The FDR survived but the QAR did not. The data were available but in the wrong box! The QAR was developed because the FDR was not accessible and has now surpassed the FDR in terms of data quantity. Parameter rules must consider many aircraft types and therefore tend to cater to the lowest common denominator. Additionally, early standards *encouraged* a separate box for fear of adversely affecting the mandatory box. Any change to the mandatory box meant costly certification issues. Airlines on the one hand complained about the costs of additional parameters and on the other hand went to the trouble and expense of recording extra data for their own purposes.

There were some other factors that affected the continued use of the QAR despite logic dictating that it should become a thing of the past. If you added a parameter to the FDR and if the parameter became problematic during routine FDM, regulatory bodies invoked the MEL and grounded the airplane. In the late 1980s, Air Canada actually removed non-mandatory parameters from the FDR because of MEL problems! Operators, still today, do not want to add parameters to the FDR because of the regulatory interpretation of the MEL. The reality is that 99 percent of parameters today are from a digital data bus and the parameters exist for the operation of the aircraft, not the FDR. The FDR is simply taking advantage of their ready availability. If the airspeed does not work on the FDR for an Airbus A320, for example, it is not an FDR problem—it is an aircraft problem yet some still interpret this as a reason to ground the FDR system. Parameters from digital data busses are incredibly reliable; yet the rules were developed from the old days when sensors were dedicated to the aircraft, and they have not really been updated.

It makes much more sense to have an integrated system whereby airlines can routinely access the data and the same data set is available to the accident investigator. In some ways it is simply a "packaging" issue. There was no technical reason why all of the Swissair data going to the QAR could not have also been going to an FDR. There tends to be two different groups in the industry, those who deal with the mandatory FDR and those who deal with the QAR, and it is long overdue that they talk to each other.

Eurocae ED112 and the recent U.S. Future Flight Data Collection Committee is trying to change history in this regard.

ED112—"*With today's solid-state technology, significantly increased capacities, readily available data on the aircraft, and affordable ground-based wireless download capabilities, an integrated crash protected recording system that satisfies both accident investigators and operator's routine playback needs is highly desirable.*"

"*… it is recommended that industry provide operators with solutions that protect the core mandatory list while allowing the operator to change the recorded data (e.g., additional data, sample rates or resolutions) in the crash protected medium without requiring recertification of the flight recording system*"'

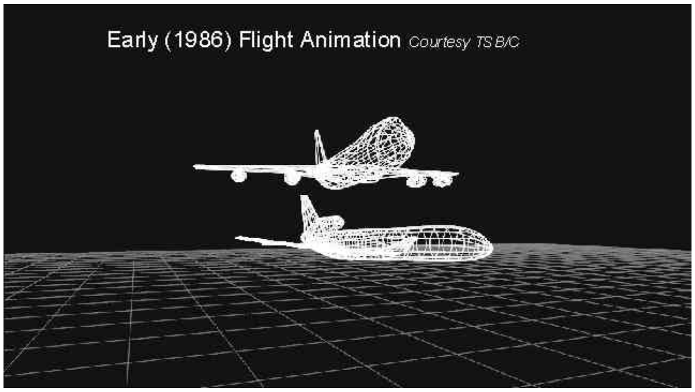
The bottom line is that it is really unacceptable to record more data for routine monitoring of flight data than for a major accident investigation.

Flight animation

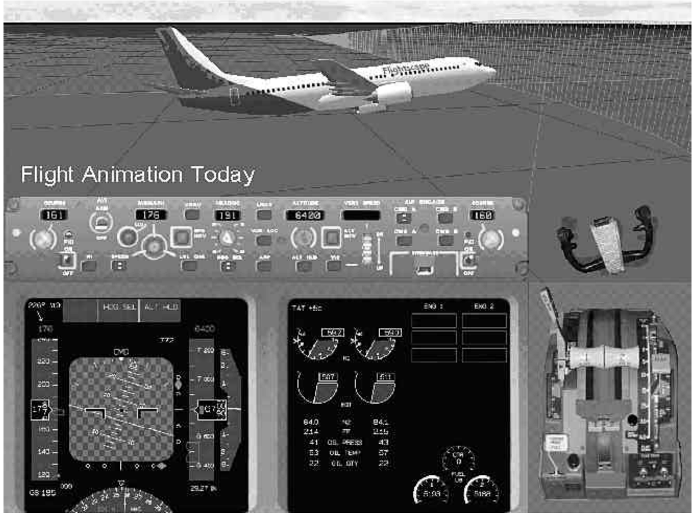
Accident investigators have been using flight animation since the early 1980s. Airlines did not because there were no commercial systems at this time and it was relatively expensive to do. Today, flight animation is readily available, and numerous systems are commercially available.

Investigators have long known about the benefits and pitfalls of animation, and there have been ISASI papers well into the past as they became increasingly popular and controversial in the late 1980s and throughout the 1990s.

Benefits of flight animation



Early (1986) Flight Animation *Courtesy TSB/C*



Flight Animation Today

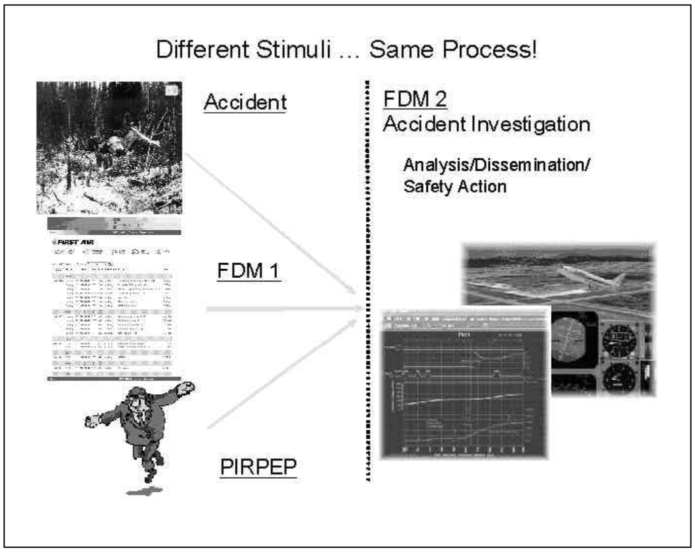
- Assimilate complex information
- Facilitate analysis
- Stimulating and effective means of communication
- Powerful and compelling
- Effective training tool
- Easy to disseminate
- Lend credibility to findings

Pitfalls of flight animation
- Pretty picture syndrome (seeing is believing)
- Fabrication
- Subjective information
- Drawing conclusions without understanding underlying principles
- Misplaced credibility

Accident investigation vs. flight data analysis programs

We all know and understand the elements and reasons why we investigate accidents. FDM programs are very valuable as it makes a lot of sense to study the data *before* things become catastrophic. FDM is a proven concept and is being embraced worldwide. So what is the problem? First, let's define an FDM program.

FDM is part of a safety management system. It is a systematic collection of flight data for improvement in the areas of
- Operations
- Maintenance
- Training
- Risk management



Different Stimuli ... Same Process!

Accident

FDM 1

PIRPEP

FDM 2

Accident Investigation

Analysis/Dissemination/
Safety Action

It is effectively an IT system to distribute objective information to reduce operations and support costs and improve dispatch reliability. Above all, it is a system that identifies precursors to accidents. For clarification purposes, I like to break FDM down into two distinct components:

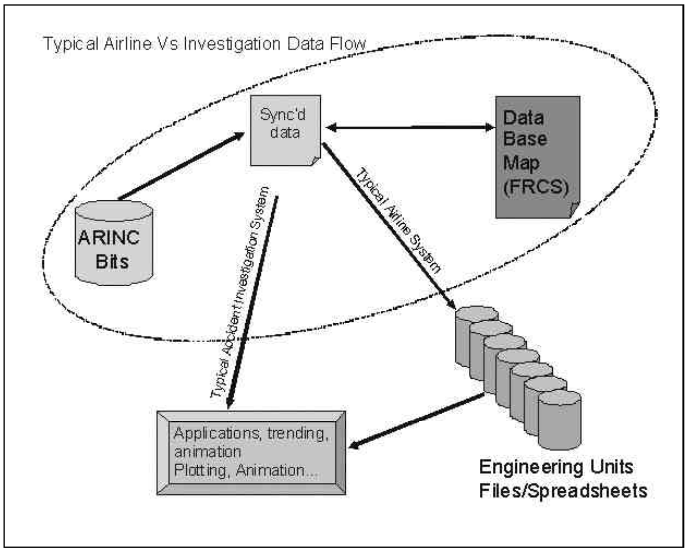
FDM 1 event detection
- Routine monitoring of flight data
- Automatic detection of events
- Until recently, plagued with poor quality data
- Outputs statistical database
- Flight animation not useful
- Examining daily flights in small detail

FDM 2 occurrence investigation
- Examination of a single event(s) in great detail
- Similar to accident/incident investigation
- Flight animation is very useful for routine events and complex

Regardless as to whether the stimuli to study a flight sequence is an accident, incident, FDM 1 event, or a PIREP, it can be argued that once you perform the study, there should be no difference in the techniques, expertise, and tools required. Whether the aircraft hits the ground or not has no bearing on the analysis of the data leading up to the event that initiated the analysis. FDM 2 is arguably accident investigation without the accident.

Unfortunately, there is a component of the industry that believes and/or advertises that "investigation" skills/tools are not necessary for FDM programs in the quest to provide user friendly automatic tools to eliminate the need for expertise. Some believe that you have to be an expert to use an "investigation" system but you do not need to be an expert to use an "airline" system. The fact is that the expertise required is not a function of the "tools" one uses, but rather it is a function of the flight data itself. If you did not need to have expertise to analyze flight data, we would not need expert accident investigators.

Many airlines want to routinely animate events for training purposes; just hit a button and up pops the animation. While virtually all software out there can do this, it should be noted that flight animations are actually quite useful for analyzing complex events and understanding and disseminating them. The current limitations of sample rate, resolution, accuracy, and number of parameters is such that often significant judgment is required.



Accident investigators grew up with lousy tools in the 60s, 70s, and 80s and their experience in flight data analysis and the tools used to perform the job grew together. Today the airline can jump in with very attractive tools that have internally automated many of the steps investigators performed manually. With this automation and marketing of products as automatic requiring little expertise to use comes a significant danger that the judgment is simply lost in the process.

Airline playback systems were originally designed for maintenance and only in recent years have they been used for detailed operational analysis of events, partly inspired by readily available animation capability. Airlines are going to increasingly make operational decisions based on their flight data analysis well beyond this traditional role.

There are many technical examples that illustrate some of the concerns. One example is the problematic trend in the airlines to use engineering units (EU) or CSV (comma separated variables or spreadsheets) to pass the data to their analysis/animation systems. The problem with passing EU files is that your analysis/animation tool may be showing you an artifact of the recorded data instead of the real data due to processing that you may be totally unaware of. Investigators use systems that interactively handle the ARINC bit stream data directly. That is, all applications interact with the source binary data and convert to EU "on the fly" as required. Many systems in use by the airlines, however, cannot accept ARINC data and must first have the data pre-processed by another application so that it is "readable" by their analysis/animation system. This is largely because handling the ARINC data from the aircraft directly is a significant process in itself. Flight recorder manufactures like to sell boxes and sell hundreds of FDRs for every replay station they sell. Consequently, their replay systems, while they will recover the data, have fairly poor analysis tools. Other companies capitalized on this and developed analysis tools but relied on someone else to perform the actual data recovery.

When you have to pass EU files from one process or system to another as a CSV or spreadsheet file, it becomes problematic to pass all of the recorded parameters. A modern aircraft may have well over a thousand parameters. Imagine an Excel spreadsheet 1,000 columns wide! In fact you cannot do it in Excel due to limitations. What is typically done is to send only the parameters you need. Although the person at the other end may normally only want to look at a core set, his ability to "investigate" the data is compromised because he does not have all of it and he must prejudge what is important. As a former TSB investigator, I do not like to have to prejudge what I think I might be interested in. Since investigation systems access the ARINC binary data file, which is a relatively small and nicely packaged file already, investigators have access to all of the data all of the time.

Another more serious problem with passing EU files around for analysis is the time element. Two parameters that are both recorded at one sample per second are actually not sampled at the *same* time within the second. There is a relative offset based on the word location. For example, aileron position and control wheel, while both sampled once per second, will be offset from each other by as much as just under a second. In order to maintain the timing resolution of the original data, the EU file must be incremented at intervals coincident with the data frame rate. For example, a 64 word/sec rate would require the data printed out in 1/64 time intervals to maintain the same time resolution for each parameter. This means that if you want to look at 25 hours of data using EU files, you would need 64 lines of data for each second. To pass 25 hours of all of the flight data to someone in an EU file format maintaining the recorded accuracy would require a spread sheet 5,760,000 lines long and 1,000+ columns wide! If you move to a 256 or 512 word/sec recording, the numbers get even more impractical. Instead, shortcuts are taken by prejudging what parameters the analysis or animation system needs and by truncating the data all to the nearest second. The NTSB and other investigation agencies have given papers on how important it is that we be able to trace data latency. They are talking about latencies within the second for the most part. For all of these systems out there that truncate the data to the nearest second, there is no point in worrying about latency—you have already reduced the accuracy well beyond the latency concerns. This is simply unacceptable for accident investigators who have expertise in flight data analysis. Systems that can process the ARINC data on the fly do not suffer from this problem and they will display the data at precisely the times it was recorded.

While in many flight animations, it will not matter that the data are inaccurate in the time domain as there are lots of smoothing processes going on internally (a whole other paper), and the animation is being used to look at a relatively simple, routine event. However, should the team come across a more complex event, it is human nature that the team will try to use the tools they have to do the work. This has already happened where an airline has run incidents through its "automatic" tools before the investigation authority even has the data. If we believe that FDM is accident investigation without the accident and accident investigators are not willing to compromise data quality and have stringent standards, why is it acceptable at the airlines? The answer is it shouldn't be, and, like the QAR dilemma, it is another example of how history has got us to a place that we do not really want to be and it is very hard to undo.

Aircraft manufactures are also becoming aware of this growing problem as airlines will frequently wish to send data to them for assistance in troubleshooting something. They send a CSV file and the analysts at the other end do not get all the parameters, do not get the proper time resolution, and do not have the ability to check the EU conversion process if they suspect a problem. The EU conversion process has many opportunities for error, especially with parameters infrequently analyzed, and one should never accept the EU data as factual. Since the ARINC data file is magnitudes smaller to send and has no compromises, it does not make much sense to be passing EU files, and manufacturers are starting to ask that the airlines please send the raw data, not some artifact of the data in which they have no way of assessing its validity.

Summary

ICAO Annex 13 Appendix D recognizes the difference between an "airline" facility and an "investigation"' facility and recommends States use investigation facilities. This was written by the ICAO FLIREC Panel because some States started taking the recorders to airline facilities after a major accident, and other States with significant recorder labs felt that this could compromise an investigation. This was written before FDM programs were popular. With the FDM evolution, ICAO will need to revisit this as the stakes have gone up as airlines can now have flight animation done very quickly. If it is not accurate or misleading, it is very hard to backtrack once people have seen it. The golden rule of accident investigation is to get it right before disseminating the results. With the accessibility of "automatic" flight animation systems and the manner in which some systems process the data, combined with philosophies that purport that you do not need any expertise to generate animations, we are setting ourselves up to compromise this golden rule.

As airlines make more and more decisions based on routine flight data, it will become increasingly important that similar standards or data recording, extraction and processing that have evolved from years of accident investigation are applied to the rest of the industry.

With flight animation becoming a more and more popular part of FDM programs, airlines will almost certainly go down the same path the investigation labs have already gone down and eventually demand the same tools and require the same expertise. If you are using animations for training, you still need to make sure that it is right—you can't always jump from the data to training with the investigation part in the middle! The investigation part may be trivial for routine events but will not be trivial for complex events. When is the transition whereby the investigation expert is required, and will you know when you have crossed it? Like most things in life, nothing is free. The proper solution is to make sure you treat the data with respect and develop an expertise and thorough understanding of the process you are operating. ◆

SESSION IV

Growth of ATC System and Controllers Union

By John Carr, President, National Air Traffic Controllers Association, Keynote Speaker

Good afternoon. My name is John Carr, and I am the president of the National Air Traffic Controllers Association. It is an honor and privilege to represent NATCA and speak before this very distinguished gathering of aviation safety professionals.

Founded in 1987, the National Air Traffic Controllers Association was chartered to ensure the safety and longevity of air traffic controller positions around the nation. Today, NATCA has grown to represent more than 15,000 air traffic controllers throughout the United States, Puerto Rico, and Guam, along with 2,500 other bargaining unit members that include engineers, architects, and other aviation safety professionals. NATCA is very proud to represent not only the interests of our membership, but also the safety interests of the flying public, as well. Our motto, Safety Above All, is the litmus test against which all our decisions are based. We continually strive to improve and enhance aviation safety, and we proudly provide the safest air traffic control system in the world.

First and foremost, NATCA is committed to promoting aviation safety and is committed to aircraft accident investigation through its own Air Safety Investigators Program. This Program maintains a cadre of specially trained air traffic controllers that provide expert real-time knowledge to aid in aircraft incident and accident investigation. The interesting thing about aviation was best captured by Paul Theroux, who said: "There is not much to say about most airplane journeys. Anything remarkable must be disastrous, so you define a good flight by negatives: you didn't get hijacked, you didn't crash, you didn't throw up, you weren't late, you weren't nauseated by the food."

As the aviation community celebrates the 100th anniversary of the Wright brothers' inaugural flight, it is interesting to note that the air traffic control community also celebrates an anniversary of almost 80 years of government direction. Air traffic control has come a long way since Archie League stood at the end of a grass strip with two wands and a wheelbarrow, and airplanes navigated via radio beacons, radio ranges, and bonfires. In December of 1935, the airlines established the first Airway Traffic Control Center in Newark, N.J.; a second center was established in Chicago, and a third center in Cleveland in June the following year. Finally, on July 6, 1936, the United States government assumed the operation of the three centers and established five more centers. The Civil Aeronautics Act of 1938 established new regulatory codes and air traffic rules, and the Civil Airways System was established with controlled airports, airway traffic control areas, and radio fixes as required reporting points.

Throughout history, aviation accidents have changed the way air traffic controllers are required to do their jobs. For example, on June 30, 1956, a TWA Super Constellation and a United Airlines DC-7 collided over the Grand Canyon resulting in the loss of 128 lives. Although tragic, this accident highlighted the need for increased government regulation of air routes and modernization of the air traffic control system. In December of 1974, a TWA B-727 crashed into high terrain on approach to Dulles Airport. This accident identified a lack of clarity in ATC procedures when flying on unpublished routes without clearly defined minimum altitudes and identified inadequacies in the depiction of altitude restrictions on the approach charts. Both accidents resulted in the federal government enacting changes in air traffic procedures.

Air traffic controllers serve in a unique, complex, and safety-critical occupation. They prevent collisions between aircraft, and at the same time facilitate maximum efficiency in airspace and airport utilization by all classes of air traffic. An air traffic controller's decision-making process requires quick thinking and the ability to be flexible yet uncompromising without reducing the margin of safety. This nation's air traffic controllers ensure the safety of more than one million aviation passengers per day while working in stressful, high-energy environments where every controller knows there is no room for error. Perfection is the minimum acceptable performance standard.

The increased demand for air travel has brought the entire system to near capacity in recent years. We have all seen the pictures of endless rows of airplanes queued for runways. We have all experienced the delays on the taxiways or ramps. Much of the responsibility to meet this increasing demand for air travel lies with air traffic service providers—the air traffic controllers. One challenge facing the aviation community is to continue to improve the air traffic system by increasing system capacity while not compromising or reducing the margin of safety. Your dedication to aviation safety has made air travel the transportation infrastructure of the 21st century. I flew to work today. I woke up in Tampa, ate breakfast with my family, and got on a plane to speak to you folks. When I'm done, I'll get on a plane and be back in Tampa for dinner tonight.

Air traffic controllers are, by character, safety minded, and they see the consequences of an overloaded system daily. Aviation incidents and accidents often highlight critical issues in the air traffic control system. Safety records, dependability, convenience, and cost aid in determining the state of the aviation industry including the air traffic control system.

In NATCA's opinion, the utmost concerns facing the United States air traffic control system include modernization of equipment, staffing shortages, aviation security, labor relations, and, most importantly, privatization. The most urgent issue facing air traffic controllers in the United States today is preventing the privatization of the air traffic workforce. In our view, air traffic control is an inherently governmental function, which directly and significantly affects the lives of everyone. Air traffic control is intrinsically linked with the public interest so much so as to mandate its performance by government employees. Over the next few weeks, this critically important subject will again be addressed in the U.S. Congress. NATCA has been working this month to build support for our stance on the issue of privatization and have asked lawmakers to stand behind their votes and support the safety of our air traffic control system. Simply put, privatization of our industry stands to put profits over safety and that is unacceptable.

How does that affect you, you might ask?

Well, I don't have to tell any of you that it is essential that investigations of air traffic incidents remain independent of external influence and blame and focus on accident prevention. But when you deal with privatized air traffic control systems, there are problems that muddy the waters.

We have been watching Canada, and other privatized air traffic control systems, and how they work with investigative bodies. In Canada, in spite of the wishes by the Canadian safety board, management officials rather than front-line controllers participate in the investigative process. Of course, this makes absolutely no sense. In the United States, our obvious fear is that the same scenario would hold true. In fact, there have been instances where controllers were denied party status to investigations of incidents involving contract towers.

Here's something else to consider: While claiming to maintain oversight of the Contract Tower Program, the FAA cannot answer why tapes and records of midair collisions at FAA facilities are open to the public via the Freedom of Information Act, yet when a midair occurs at a contract tower, the tapes are hidden from FAA oversight and public view. Without the tapes, how do you conduct an investigation or work to prevent future incidents?

I'm sure you saw a copy of the major newspapers this morning with your coffee. On page 13 of the *Washington Post* today [Aug. 27, 2003], the headline reads "Safety versus Profit—Contractors Had Potential Conflict." In the *Wall Street Journal*, the big story today says a push toward privatization that began in the mid-1990s led to an abdication of responsibility for overseeing safety. If we needed any evidence that profit runs contrary to safety, just look at the paper.

I would like to now take a few moments to discuss the tragic events of Sept. 11, 2001, and the role of air traffic controllers all over this nation that morning. That fateful day may stand alone as truly the worst day in the 100 years since the Wright brothers first flew. However, during this single event, one of the most horrendous acts in United States history, the nation's air traffic controllers, true champions, never lost their composure and maintained exceptional dedication while performing their jobs flawlessly.

When Transportation Secretary Norman Mineta issued the order to shutdown the National Airspace System at 9:45 that morning, air traffic controllers all over the United States landed more than 700 airplanes within four minutes. Air traffic personnel directed every aircraft to land at the nearest airport immediately, effectively rerouting one aircraft every second. Over the next four hours, controllers safely guided another 4,000 airplanes with no errors. This unprecedented challenge, an undertaking never before practiced, trained or imagined, tested the resolve of everyone. Their extraordinary actions most likely prevented additional loss of life, further demonstrating an outstanding achievement never before accomplished in the history of aviation.

As a result of the events that day, the complexity of the National Airspace System has increased significantly. During the initial weeks after the attack, controllers contended with almost daily changes in procedures and rapidly changing and often confusing airspace restrictions. Everyone worked intensely under incredibly dynamic and exhausting conditions during that time, and the commitment and professionalism displayed was a true example of the valued teamwork upon which the FAA and the flying public has come to depend. On that infamous day, the spirit of air travel changed in a cataclysmic and abrupt way forever; however, the efficiency of the safest and most effective air traffic control system in the world was never compromised.

On that fateful day, these men and women of public service not only witnessed the tragedy of Sept. 11, 2001, but also accomplished a feat never imagined with skill, determination and professionalism.

I like to say that safety is my business, and I'm here to tell you today that business is good. I represent thousands of professionals who put safety above all else and hold it as their sacred trust. The safety of our skies is not for sale, not to anyone, and we will continue to fight for safety above all else as we begin the exciting journey into the next 100 years of aviation history.

I'd like to leave you with a couple of closing thoughts.

- Remember, you're always a student in an airplane.
- Keep looking around; there's always something you've missed.
- Try to keep the number of your landings equal to the number of your takeoffs.
- You cannot propel yourself forward by patting yourself on the back.
- There are old pilots, and there are bold pilots, but there are no old, bold pilots!
- Things that do you no good in aviation: Altitude above you. Runway behind you. Fuel in the truck. Half a second ago. Approach plates in the car. The airspeed you don't have.
- Flying is the perfect vocation for a man who wants to feel like a boy, but not for one who still is.
- And finally, gravity never loses! The best you can hope for is a draw! ◆

Crashworthiness Investigation: Enhanced Occupant Protection Through Crashworthiness Evaluation And Advances in Design— A View from the Wreckage

By William D. Waldock

***Bill Waldock** holds the rank of Professor of Safety Science and is the Associate Director of the Center for Aerospace Safety Education at Embry-Riddle Aeronautical University in Prescott, Ariz. He teaches graduate and undergraduate courses in accident investigation and crash survivability. He is an active pilot and retired U.S. Coast Guard officer and has been involved in aviation, safety, and accident investigation for more than 25 years. He has authored more than 50 articles on aviation safety and is frequently quoted in electronic and print media. He is president of the Arizona Chapter of the International Society of Air Safety Investigators.*

This paper will examine the history and beginnings of crashworthiness investigation, and how such investigations provide the opportunity to change design or procedure to improve survivability in aviation accidents.

To start with, I need everyone to reach behind your right ear and find your "safety" switch." Now flip it from PREVENTION to MITIGATION. "Crashworthiness" is the technology and means by which we MITIGATE the effects of accidents. Nothing we do in crashworthiness will ever prevent an accident, only change the outcome. For some folks (including investigators), this requires a fundamental paradigm shift. Much of what we do in safety and accident investigation is focused on stopping the accident. To do crashworthiness, we must assume that we WILL have accidents. Only then can we learn and accomplish the things necessary to protect the occupants of aircraft in accidents we cannot stop.

A proper definition of accident survivability gives us background and a starting point. A survivable accident is one in which **the impact forces that reach the occupants remain within human tolerance, AND occupiable space is maintained through the impact sequence, AND the environment remains livable throughout the impact and beyond.** All three situations MUST exist for survival to be accomplished.

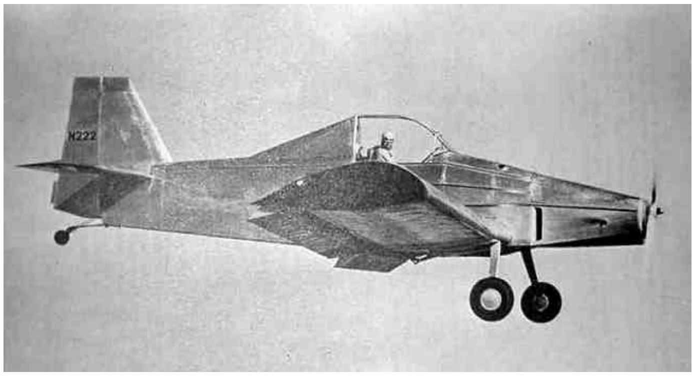
In the beginning

Accident investigation is like the discipline of history in many respects. We start from today and work backwards through time, gathering the data, evidence, and information necessary to understand how we got to where we are. There are some people who believe that crashworthiness is a somewhat new approach. In reality, we are building on the work of those who came before. I could spend hours telling you about folks like Dr. Jerry Snyder, Harry Robertson, Doc Turnbow, Vic Rothe, Chuck Miller, Richard Chandler, and many others. Many survivors of crashes owe their very lives to those folks. In the field of crashworthiness INVESTIGATION, two people stand out, for they started it all. Hugh DeHaven is literally the "father" of crashworthiness. Like so many folks in aviation safety, he started with a plane crash—his own. In 1916, while training to be a Royal Canadian Flying Corps pilot, he was involved in a mid-air collision in which everyone but him was killed. He was seriously injured in the crash and spent 6 months in the hospital. After that, since he couldn't fly anymore, he was assigned to investigate plane crashes. He was intrigued by several crashes in which the airplane was relatively intact, but in which the occupants were killed or seriously injured. This put him on the road to the study of INJURIOUS MECHANISMS. He was a graduate of the "first" formal training course for aircraft accident investigators, his certificate signed by Jerry Lederer himself. Through his work at Cornell, AvCIR, and beyond, he founded the belief system that we use today. His "packaging principles," first published in 1950, provide the basis for any crashworthy design.

They are

1. "The package should not open up and spill its contents and should not collapse under expected conditions of force and thereby expose objects inside it to damage."
2. "The packaging structures which shield the inner container must not be made of frail or brittle materials; they should resist force by yielding and absorbing energy applied to the outer container so as to cushion and distribute impact forces and thereby protect objects inside the inner container."
3. "Articles contained in the package should be held and immobilized inside the outer structure by what packaging engineers call INTERIOR PACKAGING.

Hugh DeHaven, literally the "father" of crashworthiness.



AG-1 concept.

This interior packaging is an extremely important part of the overall design, for it prevents movement and resultant damage from impact against the inside of the package itself."

4. "The means for holding an object inside a shipping container must transmit the forces applied to the container to the strongest parts of the contained objects."

If we assume that the "container" is an aircraft fuselage, and the "interior packaging" is the restraint system and tiedown chain, then we have an excellent perspective on impact crashworthiness, and can understand how to design systems to minimize injury.

DeHaven's assistant at Cornell was A. Howard Hasbrook. Like DeHaven, Hasbrook survived a near-fatal plane crash while crop-dusting in 1946. As Administrator of Field Research at the Crash Injury Research center, Hasbrook became convinced that investigation into "survivability factors" would allow changes in design and construction of aircraft to reduce the likelihood of injury or fatality. In 1951, the Cornell University Medical College published the first guide (written by Hasbrook) for accident investigators to use in gathering the types of information necessary to do a crashworthiness evaluation of an aircraft accident. It specified procedures to use at an accident scene to preserve survivability aspects and identified the types of data necessary to the crashworthiness investigator. Most of it is as pertinent today as it was then. It identified the three basic pieces of evidence that MUST be gathered: angles, velocities, and distances—measurements that are often lacking in accident reports today. It also provided guidance to correlate the physical evidence gathered at the scene with injury patterns determined by autopsy or medical examination of survivors. Hasbrook conducted the first "crashworthiness" investigation on an airline plane crash in August 1952 of a Northeast Airlines Convair 240 accident at La Guardia. In 1954, DeHaven "retired" from the Aviation CIR program, and Howard Hasbrook became the Director.

Hasbrook's lifelong devotion to crash survival investigation continued through his tenure at AvCIR and later the FAA Aeromedical Branch. During his career, he wrote many articles and reports, mostly focused on how to improve survival in plane crashes. Though he was already at the FAA, Howard provided technical advice during creation of the first "crash survival investigator's school" through AvCIR in Phoenix. He remained an active pilot virtually till the end of his life. I was privileged to have known and worked with Howard during his last years. I'm sure many of the folks who are members of ISASI remember him, perhaps as a spur pushing the need for survival investigation, perhaps as a friend, perhaps as a mentor.

Applying the lessons learned

In 1950, Fred Weick designed the AG-1 at Texas A & M. This was a crop-duster incorporating recommendations made by DeHaven and Hasbrook. The concept involved positioning the cockpit above and behind much of the mass in the airplane, with that structure being designed to progressively deform in a crash, thereby absorbing energy and attenuating the g-loads that reached the cockpit. It had a tri-axial steel roll cage around the pilot and tied him into the seat with a five-point harness that locked automatically using inertia reels. It was designed to provide a "40-g island of safety" for the pilot. The AG-1 evolved into the Piper Pawnee. Crop-dusters today still incorporate much of this technology (refined a bit) to protect the pilot in a crash. Most of you who have investigated AG accidents would agree that pilots in these crashes experience a much lower injury and fatality rate than those involved in accidents with other types of aircraft.

In the general aviation world, Beechcraft was the first manufacturer to use "crashworthiness" in design of its aircraft. The 1950s vintage Bonanzas and twin-Bonanzas had a long nose section, a reinforced keel and cockpit area, a wing designed to attenuate energy in a crash, seats that were attached with bolts to the spar trusses with belts attached to the seats, and a break-away instrument panel and yoke designed to reduce head and upper body trauma. They even incorporated shoulder harnesses in some models (not required in the rest of the GA fleet until those aircraft manufactured after 1978). To a crashworthiness investigator, these ideas seem like mom and apple pie. Beechcraft began a public relations campaign to "sell" safety, based on DeHaven's and Hasbrook's work at CIR. The details are spelled out in a report authored by DeHaven in 1953, "Development of Crash-Survival Design in Personal, Executive, and Agricultural Aircraft." The folks at Beech were ahead of their time. Crashworthiness was a marketing flop. GA aircraft owners didn't want to pay for the extra systems in their aircraft. Aircraft should be made to fly, not to crash. They might even be trapped in a burning airplane by the shoulder harnesses. By 1960, Beechcraft abandoned its crashworthiness efforts and went back to building "standard" airplanes.

In 1959, the Cornell-Guggenheim Foundation became affiliated with the Flight Safety Foundation and Flight Safety Foundation took over administration of what was now AvCIR (Aviation Crash Injury Research) in Phoenix, Ariz. The main focus of the program was now to develop and carry out test crashes using real aircraft to gather data on what actually happens in a crash. In a joint effort with NASA, the U.S. Army, and the FAA, 43 tests were completed, including the famous DC-7 and L1649 Connie crashes. Experiments gathered data on kinematic and impact-related issues, seat and restraint systems, fuel containment, and fire. Many of the pioneers of aviation safety were affiliated with the program over the years, including Jerry Lederer, C.O. Miller, Doc Turnbow, Harry Robertson, John Carroll, Joe Haley, Stan Desjardins, and, of course, Howard Hasbrook. Doc Turnbow and John Carroll started the first crash investigator's School (now the International Center for Safety Education run by SIMULA), and Doc continues to dazzle students with kinematic evaluation and application.

On the federal side of the house, Dr. Stan Mohler and Dr. John Swearingen ran the Civil Aeromedical Research Institute (CARI), which later became CAMI. They brought Hasbrook over to the FAA in 1959 and began investigating crashes to understand how people were injured or killed. In 1960, Dr. Jerry Snyder joined CARI and became chief of the Physical Anthropology Lab and the Protection and Survival Lab at Oklahoma City.

Dr. Snyder's many articles and reports are another excellent source of survivability information. In 1966, the name was changed to the Civil AeroMedical Institute (CAMI), and over the years the programs and research have continued to provide data and guidance relating to survivability and crashworthiness. Several facilities have provided critical crashworthiness data over the years. The FAA Technical Center in Atlantic City continues to research impact and fire survivability issues. This discussion is not about the many fine test programs though. Our focus here is on the lessons to be learned from investigation of actual crashes.

Airline crashworthiness investigation

Since Hasbrook first investigated an airline accident from the crashworthiness perspective in 1952, we've come a long way. Particularly over the last 25 years or so, "survival investigation" is an essential part of any "major" investigation. The NTSB has gotten very good at investigating crashworthiness issues in major airline crashes. The FAA has been gradually applying the lessons learned from these investigations and has improved the survivability of modern airline aircraft. Three examples are case in point:

The first involves Air Canada Flight 797, which experienced an inflight fire in 1983. The aircraft made an emergency landing at Cincinnati after 18 minutes, with the smoke and toxic gasses building up through the entire descent. Twenty-three of the 46 people on board died. Among the survival issues examined were the early stages of the fire in the lavatory during which it was not detected. As a direct result of this accident, the FAA mandated that smoke detectors be installed in airline lavatories. Another issue was the rapid involvement of the cabin furnishings and how significantly they contributed to the smoke and toxic gas buildup. The focus remained on the various plastics in airline cabins for the next few years. Ironically, the fire had not originated from someone throwing a lit cigarette into the trash bin, but was electric in origin. To this day, some folks still believe that it started with a cigarette.

The second accident happened in Manchester, England, in 1985. During the takeoff run, a combustor can exploded on the left engine of the 737, through a section of the can through the shroud and into the underside of the wing. It hit a cast aluminum inspection plate and shattered a 6-inch hole in the wing, resulting in a massive fuel leak. Due to somewhat unusual circumstances, the fire burned much hotter than Jet A normally does, resulting in a burnthrough and penetration of the aircraft sidewall skin in about 20 seconds. The cabin furnishings became involved very quickly and generated a tremendous amount of toxic gasses. Combined with major compromises to the evacuation, 55 people lost their lives, even though the crash fire rescue efforts and actions of the crew were magnificent. This accident caught quite a bit of attention and, in combination with the Air Canada accident and efforts of the FAA Tech Center, resulted in major changes to materials used in airline cabins. Experiments began to focus on fire suppression as well, including use of cabin water spray systems. Dr. Helen Muir and others in Britain began to experiment with smoke hoods and changes in seating configurations. The CFR community experimented with ways to introduce foams into a burning airliner cabin; culminating in the Snozzle device in use today.

The last example is the Continental DC-10 accident at LAX in 1978. The aircraft blew tires on the left main landing gear at V1 and the crew rejected the takeoff. The aircraft overran the end of the runway and the left main gear collapsed. When the tires failed, they threw fragments into the underside of the left wing, opening several holes in that fuel tank. When the aircraft stopped, the pooling fuel ran toward the fuselage and ignited. The fire was concentrated mostly on the left side of the aircraft and center fuselage. Most of the emergency exits were unusable due to the fire. The two right forward exits deployed properly, but the slides were painted orange-yellow for visibility if used as life rafts. Fire never touched the forward slide, but due to the radiant heat uptake, the slide burst. Several passengers and a flight attendant had to exit through the copilot's side window. Some were injured by the rope or dropping the 8 feet or so after they were outside. A major change here was the requirement that slides be covered with a reflective outer layer, to reduce the radiant heat susceptibility and allow the slide to remain functional longer during an evacuation.

These examples focus mainly on fire crashworthiness. Harry Robertson is perhaps the premiere fire safety investigator in the world. His designs for improving fire survivability are in use on military aircraft around the world today. They are even used in Indie cars to reduce the likelihood of fuel spill in a racecar crash. A current research project is under way to better understand how to minimize the possibility of fuel release in a crash and therefore reduce the likelihood of impact or post-impact fire. In the airline world, fire and its by-products pose the greatest threat to occupants during a crash, yet fire is involved in relatively few crashes.

Over the years, many improvements

British AirTours 737 accident.

have been made in impact survivability as well. The seat/restraint systems are a major focus in airline crashes. The old standards for certification were grossly inadequate, requiring only that a passenger seat withstand 9 g's horizontally, 4.5 vertically, and 1.5 laterally. These seats were only required to be tested statically. Over the years, after many investigations in which passengers were injured or killed because seats failed or pulled out of the floor tracks, changes were made to require 16 g's horizontally, and be tested dynamically. We've gotten better, though we still have a ways to go. One problem remains involving old aircraft. Installing a 16-g seat in a 9-g track and floor just changes the weak point and moves where it fails. Plus, thanks to Col. Stapp and others, we know that a properly restrained human can withstand much high g-loads in a crash than the seats. A focus for the future.


Left, S-tube seat. Right, pre-1988 general aviation seat.

General aviation crashworthiness

In the report, "Survivability of Accidents Involving Part 121 U.S. Air Carrier Operations, 1983 Through 2000," the NTSB points out one of the recurring problems with analysis of general aviation crash survivability. It states, "The Safety Board examined only air carrier operations performed under … Part 121 because the majority of the Board's survival factors investigations are conducted in connection with accidents involving Part 121 carriers. Therefore, more survivability data are available for Part 121 operations than are available for Part 135 and Part 91 (general aviation) operations." Looking at a 10-year average, GA still experiences about 2,000 accidents per year. In about 25 percent of these, serious injuries and/or fatalities occur. In most cases, there is little to no data relative to the specific injuries themselves or what may have caused the injuries. Without good data, it is difficult, if not impossible, to determine what hurts people, nor make changes to prevent injuries in the future. Two case examples illustrate the points, as well as examine the issues with crashworthiness.

The first of these accidents happened in 1989. The aircraft was a Cessna 172N, built in 1977, being flown by a 120-hour private pilot. The flight was intended to show the pilot's girlfriend (passenger) what aviation was all about. The pilot had not flown in 63 days and had had problems with landings. On his first touch-and-go attempt, the pilot was rushed, rounding the base to final turn and touching down at a high vertical velocity. The aircraft bounced off and flew horizontally down the runway about a wingspan above the surface. Witnesses indicated that the flaps appeared down (40 deg) at the initial contact, then retracted near the mid point of the runway. The aircraft then nosed over and hit the runway. It slid out in the infield area, hit a taxiway sign, and flipped to the left, with the landing gear all failed. The pilot experienced multiple displaced fractures of his lumbar vertebrae and is permanently paralyzed from the waist down. The passenger suffered factures of the thoracic and lumbar vertebrae, but at a lesser severity and without displacement.

Examination of the wreckage revealed why the injuries were differing in severity. During impact, the nose gear failed rearward and positioned under the pilot's seat area. This caused a reduction in collapsible space (stopping distance) of about 6 inches. It also projected upward and bent his inboard seat rail up through the leading edge. This caused about a 15-deg lateralization to the left and a 50 percent increase in the g-loads he experienced, as compared to the passenger. Further, the brittle nature of the seat frame undoubtedly increased the g-spike that both occupants experienced. The result was the injury patterns experienced by the two occupants. Without the basic data (distances, angles, and velocities) it would have been difficult to understand WHY the injury patterns were what they were. The investigation also revealed the inherent lack of crashworthiness of most older GA aircraft.

The second accident is a good illustration of how important crashworthiness investigation can be. It involved a new Cessna 172S, which was designed according to the modified Part 23 requirements specifying 22-g seats and dynamic testing.

The aircraft had two occupants, an instructor and a student. They were attempting a touch-and-go landing when the aircraft encountered a severe lateral wind gust or microburst. The right wing came up suddenly and violently, rolling them over to the left. The instructor's attempt to correct was unsuccessful and the aircraft cartwheeled to the left off the runway. The left wing failed at the root, and the fuselage broke apart at the aft cabin bulkhead frame. The aircraft came to rest inverted. The IP extracted the unconscious student and both were medevaced to the hospital. The student had suffered serious injuries as a result of the left wing root intruding into the cabin area and his head striking the structure. The instructor had minor injuries only. Examination of the wreckage showed that the restraint systems performed normally. Even though this was a severe impact sequence, both occupants survived. Contrasting the damage to the aircraft with the previous case example, the new S-model experienced a much more severe impact, with a much more complex impact situation than the older aircraft. Yet the injuries to the occupants of the new aircraft were much less.

Seat/restraint issues

The older GA seats had little to no crashworthiness built in. They were made of rigid, brittle materials and tended to fail in ways that increased injury severity. Further, the seat belt attachments were made to the floor, rather than to the seat. This results in a change to the belt pull-off angle if the seat positioned anywhere other than to accommodate a 50th percentile male mesomorph (5'9" tall with average arm leg torso proportions). A tall person moves the seat all the way back, resulting in a vertical lap belt pull-off angle. In a crash, this can dislocate the hips or break the femurs. A short person moves the seat all the way forward, resulting in a shallow pull-off angle, which may actually be positioned over the lower abdomen. In a crash, this person ruptures the spleen or intestines. The ideal pull-off angle across the pelvis is 45 deg—achievable only if the belt anchorage is attached to the seat frame itself. The newer 22-g GA seats incorporate this feature, as well as other changes, all learned through crashworthiness investigation.

There are several seat systems that are intentionally designed to attenuate energy in a crash. The SIMULA Corporation manufactures several energy-attenuating seats for use in a variety of military aircraft. The S-tube seat was originally designed in the 70s for use in some general aviation aircraft. The retro-fit can be accomplished in the Cessna 182 and C206 models, and has been incorporated in the Mission Aviation fellowship aircraft for years. This particular seat was installed in a C206 that crashed in South America a few years ago. All the occupants survived an extreme crash, with minimal injury. It is one further example of how applying the lessons learned through crashworthiness investigation can be applied to change aircraft designs and systems to improve survivability.

What the crashworthiness engineer needs from the field investigator is the right data necessary to DO a crashworthiness evaluation. For fire crashworthiness, we need evidence of fuel release points, fire origin and propagation, ignition sources, and fire effects. For impact analysis, we need angles…impact angles, attitude at impact, etc., velocities, impact airspeed, deceleration once on the surface, and a good description of the entire impact sequence and how non-linear decelerations might have happened. We also need distances. The vertical and horizontal ground scar measurements, as well as vertical and horizontal crush distances in front of and below the occupants. We also need good descriptions of deformations to the aircraft (photos work wonders) as they relate to the surrounding terrain. We also need good medical and pathologic information as to injuries and injury mechanisms as they relate to the victims. The old days of finding cause of death listed on the autopsy report as "airplane crash" just don't allow us to understand WHY the people got hurt or killed.

If we are truly going to improve survivability, crashworthiness investigation can provide the best data available to make those changes necessary. We CAN change the future, by learning from the past! You can now flip your safety switch back to "prevention" for the duration of this program. ◆

References

1. *Aircraft Crash Survival Design Guide, Vol. 1 – 5*, U.S. Army Aviation Systems Command, USAAVSCOM TR 89-D22A-E, SIMULA, Inc. Phoenix, AZ, 1989.
2. Chandler, Richard, "Seats, Restraints, and Crash Injury Protection," *Conference on Cabin Safety*, Flight Safety Foundation, Dec. 1984.
3. DeHaven, H., "Measures for Increasing Safety of Flying Personnel in Crashes: A Memorandum to the Committee on Aviation Medicine," National Research Council, Committee on Aviation Medicine, Report #34, November 14, 1941.
4. DeHaven, H., "The Relationship of Injuries to Structure in Survivable Aircraft Accidents,, National Research Council, Committee on Aviation Medicine, Report #440, July 9, 1945.
5. DeHaven, H., "Accident Survival—Airplane and Passenger Automobile", presented at the annual meeting of the Society of Automotive Engineers, Jan. 1950, as part of the SAE Symposium on "Packaging the Passenger."
6. DeHaven, H., "Development of Crash Survival Design in Personal, Executive, and Agricultural Aircraft," Crash Injury Research, Cornell University Medical College, May 1953.
7. Hasbrook, H., "The Historical development of the Crash-Impact Engineering Point of View," *Clinical Orthopaedics*, 8:268-274, 1956.
8. Hasbrook, H., "Crash Injury Study: Northeast Airlines CV240 Accident at La Guardia Airport on Jan. 14, 1952," Informative Accident Release #14, Crash Injury Research, Cornell University Medical College, August 1952.
9. Hasbrook, H., *Handbook for Aircraft Accident Investigators Cooperating in Crash Injury Research*, CIR-H-2, Cornell University Medical College, Jan. 1951.
10. Miller, C.O., "Aviation Crash Injury Prevention: Perspective 1981," *LPBA Journal*, Summer 1981.
11. NTSB, "SAFETY REPORT-The Status of General Aviation Aircraft Crashworthiness," NTSB SR-80-2, 1980.
12. NTSB, "Survivability of Accidents Involving Part 121 U.S. Air Carrier Operations, 1983-2000," NTSB SR-01-01, 2001.
13. Snyder, Richard, "Crashworthiness Investigation of General Aviation Accidents," SAE Pub. 750537, Society of Automotive Engineers, 1975.
14. Snyder, Richard, *General Aviation Aircraft Crashworthiness*, Aircraft Owners & Pilots Assn., May 1981.
15. Swearingen, John, "General Aviation Structures Directly Responsible for Trauma in Crash Decelerations," Special Report, Office of Aviation Medicine, Federal Aviation Administration, Jan. 1971.

Enhanced Occupant Protection Through Injury Pattern Analysis

By William T. Gormley

***William T. Gormley**, M.D., Ph.D.; colonel, USAF MC CFS (retired); Office of the Chief Medical Examiner, Commonwealth of Virginia; Department of Legal Medicine, Medical College of Virginia, Virginia Commonwealth University; Virginia Institute of Science and Medicine. Dr. Gormley received his Ph.D. in chemical and biomedical engineering from the University of California at Davis and his M.D. from the Medical College of Ohio at Toledo. He is certified in anatomic, clinical, and forensic pathology. During almost 20 years at the Armed Forces Institute of Pathology, he participated as an aviation pathology consultant in many hundreds of aircraft accident investigations and served as a consultant in aviation pathology and forensic pathology to the USAF Surgeon General.*

The victims of a fatal aviation mishap experience the same damaging events as the aircraft. Analogous to engineering analysis of the wreckage, medical examination of occupant injuries can provide important scientific data for mishap investigators. In fact, the human body is structurally more robust than any aircraft: aircraft structure will fragment under forces an order of magnitude less than it would take to produce the same result in an occupant.

When aircraft mishap investigations are conducted in the United States of America, federal regulations mandate postmortem examination of some, or all, occupants fatally injured in an aircraft mishap.

Postmortem Examination of aircraft mishap fatalities: U.S. civilian—pilots by federal law, crew and passengers by local jurisdiction. U.S. military—pilots, crew, and passengers.

For more than two decades, postmortem examinations of military aircraft mishap fatalities have been performed by specially trained military pathologists who directly support the mishap investigation board. In civilian mishaps, postmortem examinations are performed by civilian medical examiners, or pathologists, employed by elected coroners. While federal investigators can order postmortem examinations for civilian pilots, state or local regulations and policies determine the extent of postmortem examination for each occupant.

The legal purpose of postmortem examination by medical examiners or coroners is to scientifically identify the remains and certify the cause and manner of death. In aircraft mishaps, the cause of death is usually blunt force injury, fire injury, or both. For this purpose, the examination need only document lethal injuries and the absence of suspicious features such as bullets, stab wounds, or explosives. The manner of death is certified as an accident unless circumstances and findings suggest another manner of death such as suicide, homicide, or natural. Postmortem toxicology is also collected for analysis by the FAA laboratory, at least for pilots.

In the Commonwealth of Virginia, we perform complete autopsies on all fatalities in aircraft mishaps. As part of our death investigation, we routinely request information about the circumstances of death verbally and in writing. Unfortunately, we usually get little or no response from investigators.

With limited information about the circumstances of death, the postmortem examination will produce little more than a document that certifies the cause and manner of death.

The postmortem examination should be more than an administrative exercise to produce documents proving that the occupants are truly dead. For maximum investigational impact, postmortem medical examinations should function as an interdisciplinary effort, with the pathologist and mishap investigation team sharing of data on 1) flight history, 2) crash site data, 3) wreckage analysis, 4) occupant medical data, 5) postmortem examination results, and 6) other pertinent data. This will promote accurate, effective, and complete medical input for many concerns of accident prevention and occupant safety.

Document natural disease and evaluate role in mishap

A complete postmortem examination, in addition to documenting traumatic injuries, will identify pre-existing natural disease. Natural diseases of the heart, brain and lung are the most likely to be possible mishap factors because they can cause rapid incapacitation. Atherosclerotic cardiovascular disease is by far the most commonly identified natural disease in middle aged or older pilots. This disease may or may not have a significant role in the aircraft mishap. The flight history must be correlated with the specific anatomic disease to determine the role in a mishap.

In one mishap, a middle-aged pilot flew a single-engine private aircraft into a commercial airliner approaching an airport. Both aircraft crashed, and there were no survivors. Autopsy of the private pilot demonstrated severe atherosclerosis in the coronary arteries and local authorities announced that the mishap, and almost 100 deaths, were caused by the private pilot having a heart attack. While atherosclerosis can cause a heart attack, there are many people living quite well with similar disease. Investigative interviews, wreckage analysis, autopsy data from all occupants of the private aircraft, crash scene documentation, and radar data indicated that the pilot was mildly lost, navigating visually using a road map, unaware that he had wandered into an approach path to the commercial airport and inadvertently flew into the airliner. There was no evidence of pilot incapacitation prior to the collision, and the heart disease was not a factor in this mishap.

In another case, a small aircraft with two occupants crashed into trees near an airport on a dark and foggy night. Both occupants died instantly, and their bodies were fragmented with evisceration of most internal organs. A heart was recovered from the crash site and there was severe atherosclerosis in the coronary arteries. Since the pilot was 65 years old and the passenger was 45 years old, it was assumed that the heart was that of the pilot. While heart attacks are not uncommon in 65-year-old people with atherosclerosis, crashing while making an approach instead of finding an alternate airport is also not uncommon. While it is possible that both events occurred at the same time, such a coincidence would be unusual. There was no way to determine the true mishap factors with scientific certainty DNA analysis demonstrated that the diseased heart was from the passenger, not the pilot.

Mishap sequence reconstruction

Correlation of medical with other accident investigation data can help reconstruct the mishap sequence through injury pattern analysis. Such techniques often help identify and validate, or eliminate, proposed mishap sequences as shown in the following illustrative examples.

A medical evacuation helicopter crashed and burned with five occupants, including pilot, copilot, two medics and a patient. All died and the remains were sent for autopsy. The pilot was not burned but had multiple lethal injuries to the trunk, and amputation of the right arm. The other bodies had extensive burns and multiple lethal blunt force injuries, including skull and rib fractures and lacerations of lungs, liver, heart, aorta, and brain. There was no soot in the airways of any victim, and carboxyhemoglobin was not elevated in any victim. The patient had a fracture of his neck, with hemorrhage in the deep cervical muscles. All deaths were certified as due to blunt force injuries, and the manner of death was certified as accidental.

What more can we do? We can correlate the medical data with some information about the mishap. The crash scene shows that the helicopter hit a tree with a main rotor blade, then crashed and burned about 50 yards beyond the tree-strike. The post-crash fire incinerated most of the wreckage.

Since there were no thermal injuries, the pilot must have separated from the helicopter prior to impact. The amputation of the right arm was caused by a sharp, chop-like injury most consistent with a rotor strike. This injury suggests that the blade may have passed through the cockpit, damaging the tie-down-chain for the pilot's restraint system, and separating the pilot from the crashing helicopter. Engineering analysis of wreckage verified this correlation.

The patient was being transported to a hospital following an accident that may have involved neck injury. The documentation of bleeding in the neck muscles around the fracture provided scientific data that the neck fracture occurred before the helicopter crash. Why? With multiple blunt force injuries, there is very rapid loss of blood pressure and circulation. To form a bruise (contusion, intramuscular hemorrhage, etc.) requires both damage to blood vessels and pressure to propel blood through the torn vessels into the soft tissues. Thus, the patient was alive at the time of the neck injury and was not dying in the helicopter crash.

Another question that may be answered with data from examination of pilots and copilots involves who was controlling the aircraft at the time of the crash. When the hands and feet of a pilot or copilot are in firm contact with aircraft controls (yokes, sticks, throttles, rudder pedals, anti-torque pedals) crash forces may be mechanically transmitted to the hands and feet, causing characteristic injuries. Classic injuries of the hands may include palmar lacerations, fracture-dislocation of the thumb base, serial fractures of the metacarpals, and fractures of the wrists and lower arms. On the feet, plantar lacerations and fractures of the feet, ankles, and lower legs may be characteristic.

Survivability analysis

Incorporation of data from postmortem examination into survivability analysis can help provide improved design criteria to decrease deaths and injuries in those aircraft mishaps that occur. Throughout the mishap sequence, survival depends upon tolerable crash forces, maintenance of occupiable space, and a survivable post-crash environment.

Overall crash forces as experienced by the occupants in general must be less than 50 g to avoid lethal injuries (laceration of aorta). Crash forces can be estimated by engineering physics based on scene data, aircraft post-crash structural integrity, and occupant injuries. These three independent estimates should be of the same general magnitude if the crash sequence and dynamics are understood. General medical crash force indicators are shown below:

Injury	Forces	Survivability
Compression of Spine	20-25 Gz	Yes
Laceration of Aorta	50 Gxyz	Borderline
Transection of Aorta	100 Gxyz	No
Body Fragmentation	350+ Gxyz	No

If the overall crash forces are within survivable limits, then survivability depends on maintenance of occupiable space. If a human body must compete with environmental structures during a crash sequence for a place to be, tremendous equal and opposite forces may be exchanged with lethal results. When such interactions occur, the occupant may sustain patterned injuries, which can be correlated with structures and mechanisms. Such correlations naturally require significant consultation between physicians, engineers, and other mishap investigators. These correlations are also the most valuable for future survivability design.

If crash forces are tolerable and occupiable space in maintained, then mishap survival depends on the post-crash environment. Usually, post-crash fire and post-crash drowning are the hazards to prevent or remediate through engineering design. The success of crashworthy fuel system design in preventing fire deaths in otherwise survivable helicopter crashes is an obvious example.

Evaluation of safety systems—restraints, energy absorption

Postmortem injury pattern correlation is an important element in evaluating the safeguards provided by occupant protection systems. Examples include pattern injuries to determine restraint use and function. Bruises on the surface of the body may document the impact of restraint systems. Pattern injuries have also documented submarining failure of systems with less than five points of restraint and subsequent lethal damage to internal organs. They have also demonstrated lethal neck injuries associated with rotation of helmets around neck straps during crash sequences. Such observations are extremely important to avoid lethal protective equipment injuries.

Optimal medical consultation

The following steps will optimize collection, documentation, and incorporation of significant medical data into any aircraft mishap investigation:

- Contact the pathologist before autopsy to explain mishap history, crash site, and specific concerns.
- Attend the postmortem exam to share information, concerns, and questions.

(Contact pathologist after the autopsy with questions—sub-optimal but better than nothing.)

- Arrange a brief visit to the crash site (wreckage) by pathologist and medical consultants.
- Arrange meeting to review medical findings and correlation with other mishap investigation data.

Participants should include pathologist and representatives of Human Factors, Investigator-in-Charge, Structures, Engineering, and others depending on mishap specifics.

Sometimes, such active and interactive consultation cannot be arranged. Local medical examiners or coroner's pathologists may not have the time or interest to fully participate in the investigation. When this occurs, the following elements from the autopsy examination can provide a basis for later consultation with aviation pathologists if necessary:

- Diagnosis list including all significant injuries and disease.
- Complete autopsy report.
- Toxicology report.
- Photographs of all external body surfaces, clothed and unclothed.
- Total body X-rays with special attention to hands and feet of pilots.

Such documentation, especially the photographs and X-rays, may severely tax the budget and resources of many civilian death investigation systems. Mutual respect, friendly persuasion, and financial reimbursement for additional expenses are key to effective incorporation of injury pattern analysis in the aircraft accident investigation process. ◆

Forensic Aspects of Occupant Protection: Victim Identification

By Mary Cimrmancic, D.D.S., Associate Staff, Transportation Safety Institute, Oklahoma City, Okla., Adjunct Assistant Professor, Marquette University, Milwaukee, Wisc.

__Dr. Mary Cimrmancic__ received her D.D.S. from Marquette University and completed a residency in general dentistry at the Zablocki Veterans Administration Medical Center in Milwaukee, Wisc. A general dentist, she is in private practice with Greenbrook Den-tistry, in Brookfield, Wisc. An Adjunct Assistant Profes-sor at Marquette University, she teaches gross anatomy in the College of Health Sciences, as well as instructs in the preclinical fixed prosthodontics laboratory and directs a graduate head and neck anatomy course in the School of Dentistry. She is a faculty member at the Armed Forces Institute of Pathology's Annual Course in Forensic Identification and Emerging Technologies. She has trained law enforcement personnel and death investigators in forensic dental evidence and forensic photography. As associate staff at the Transportation Safety Institute in Oklahoma City, Okla., she lectures on medical factors in aircraft accident investigation in the National Aircraft Accident Investigation School.

On Sept. 17, 1908, the first fatal mishap of a powered aircraft in the United States occurred at Ft. Myer, Va. Orville Wright was at the controls of the Wright Flyer being tested for the U.S. Army Evaluation Board, with Board member Lieutenant Thomas Selfridge as his passenger. The propeller struck a guy wire, breaking the blade and causing subsequent loss of control. The machine pitched and fell 75 feet to the ground. Held in their seats at impact by wires braces crossing in front of their bodies, their positions were noted, and were recovered for medical attention. Wright survived, with fractured ribs, femur, and injuries to the eye area and lip. Lieut. Selfridge died that evening, having sustained a fatal skull fracture as he struck a wooden support or one of the wires. He was buried with full military honors at Arlington Cemetery on September 25th.

Investigation of the accident involved collection of witness accounts, examination of the damage to the aircraft and the injuries to the occupants, and correlation of these data. The investigation of fatal aviation mishaps has evolved into a multi-agency effort, encompassing a wide range of disciplines. Although conducted independently, the parallel investigations carried out by air safety personnel and local authorities, such as the coroner or medical examiner (ME), can provide mutual support.

Humanitarian mission

Urgently needing to know the fate of their loved ones, it is the surviving families of the victims who are served by the identification (ID) effort. Certification of death is essential for the legal purposes of settling estate matters, collection of life insurance benefits, and spousal remarriage. Along with the return of identified remains, the death certificate provides tangible evidence of death, fulfilling the humanitarian role of helping surviving families to commence grieving.

Death investigation

Responsible for accounting for fatalities and certifying their deaths, the ME conducts a medicolegal death investigation. To fulfill the requirements for establishing cause and manner of death, and determining victim identity, the ME directs a diverse team of forensic personnel to recover and examine the remains. The identification procedures are carried out in three phases

- Postmortem data collection from the site and remains.
- Antemortem data collection from family and health care providers.
- Comparison of postmortem and antemortem data for establishing identity.

At the mortuary, a set flow of procedures is carried out: remains are assigned case numbers, personal effects and other items are documented and removed for security, and the bodies are systematically moved to stations for standard autopsy examinations and collection of toxicology and DNA specimens. Remains also proceed to fingerprinting, dental examination and X-rays, anthropologic examination, and embalming. With the arrival of antemortem medical/dental records and the collection of postmortem findings, an extensive collection of data is produced, requiring a skilled records librarian to manage the information. Automated databases speed the tedious process of sorting through postmortem and antemortem files, permitting examiners to compare individual features with references most likely to identify them. Finally, with evidence compiled from the various examinations and analyses, the ME assigns identity to the individual remains. The time frame for this process can be significantly extended by difficulties with recovery, extreme fragmentation, sheer numbers of fatalities, or delays with obtaining antemortem records. Identifications based on DNA profiles can take weeks or months.

When a major aviation mishap overwhelms local and state response capabilities, federal level response teams in the United States can be deployed to function under local jurisdictional authorities to supplement emergency medical response, family assistance, and mortuary support. Access to these resources is facilitated by legislation that assigns the NTSB Office of Transportation Disaster Assistance with the responsibility for coordinating federal resources with local and state authorities.

Safety investigation

The postmortem examination process may at first seem unrelated to the mishap investigation itself. On a broader scale, however, examination of the occupants can serve the goals of the safety investigation: prevention of death and injury. In order to allow the medical evidence to best contribute to the overall investigation, the fatalities need to be identified. This can facilitate placement of individuals into the sequence of events surrounding the crash. Once identified, the flight crew can be examined for pre-existing disease and incapacitation, as well as evidence of control injuries. If detected, these data can be correlated with the events of the mishap. Also of interest is evidence of criminal activity and passenger interference with the operation of the aircraft.

Criminal investigation

Criminal investigators search for evidence that demonstrates who was present, what their actions were, and who was responsible for the criminal activity. Physical evidence is essential to link or exclude a suspect and crime scene. In the following case, when correlated with preflight events and inflight recordings, physical evidence had demonstrated the presence of the suspect aboard the flight and confirmed his actions: On the day he was dismissed from his position, a disgruntled former airline ticket agent smuggled a revolver aboard a commuter flight taken by his former supervisor. In flight, he wrote a threatening note to the supervisor on an airsickness bag, passed it to him, and subsequently fired the gun at him. The gunman then proceeded to invade the flight deck, shooting the captain and first officer, and then himself. The aircraft went into a steep, high-velocity dive and impacted on a granite hillside, killing all 43 occupants. The scene was widely scattered, with severe fragmentation of the aircraft and its occupants. The investigation was carried out in cooperation with law enforcement authorities.

Although rain complicated the search, field personnel located a gun frame with six expended rounds. Skin recovered from the trigger area revealed a friction ridge pattern matching that of a print recorded on the former employee's fingerprint card at the airline. The barrel of the gun was found separately, and was found to fit the gun frame. A test bullet fired from the barrel revealed a rifling pattern that matched a bullet found imbedded in a section of the instrument panel. Even more remarkably, the airsickness bag was also found. Handwriting analysis concluded that the writing was that of the gunman himself. Despite the extreme destruction of the aircraft and occupants, sufficient evidence was collected to identify the gunman, demonstrate that he wrote the note and discharged the firearm in the aircraft, causing incapacitation of the flight crew and the resultant crash.

Identification

In the 1908 Wright Flyer crash, the identity of Lieut. Selfridge was not in question. Strong circumstantial evidence supported his identity: people knew who he was, and witness accounts confirmed his participation in the flight. His physical features and clothing were relatively intact.

The methods by which fatalities are identified depend upon, in part, what materials are recovered from the scene, and the extent of damage incurred. Facial features, clothing, jewelry, and other personal effects are useful, particularly when there is strong evidence indicating the presence of the individual at the mishap. However, these methods need to be used cautiously, as they can be misleading.

Items worn or carried aboard by an individual, or found on or near a body at the site may not necessarily belong to them. However, these items are to be kept with the body until it is recovered and transported to the mortuary facility. There, the items are carefully documented, also noting where at the scene, and with which body, they were found. Furthermore, when asked to view the facial features of a body resembling the general description of their loved one, a distraught family member or friend may erroneously conclude that those remains are that of the person they had lost. In spite of these drawbacks, personal effects and visual features, can form the basis for a provisional or tentative identification (ID), establishing whom the remains might represent. When this evidence is sufficiently strong, a body may be positively identified on this basis.

Scientific methods can confirm or refute a provisional ID, based upon unique physical features of the body that have been documented in some form during the individual's life. Postmortem X-ray and photographic images, fingerprints, and DNA profiles are collected from remains, and the documented features are compared with those present in analogous antemortem reference exemplars.

For example, a photograph or portrait may serve as a reference, provided that the features being compared are sufficiently distinctive. For example, the contour and position of the teeth, the shape of ears, moles, and scars can be useful. To some extent, tattoos, piercings, and other body modifications can provide supporting information, depending upon their uniqueness. The unique anatomical features of the teeth, fingerprints, and skeleton, as well as DNA and artifacts of surgery, and disease, provide more substantial evidence.

Directed by information from the flight manifest, data gathered from surviving family members by family affairs personnel, and provisional ID, the challenging search for antemortem records can proceed. A variety of sources, ranging from personal items and photographs, to dentists, physicians, and hospitals, and fingerprint databases, for example, can provide these materials.

The strength of confidence for identification is reflected by the following terms: positive; possible/presumptive (tentative/provisional); insufficient evidence; exclusion. A positive ID is developed from comparison of antemortem references with postmortem data that demonstrate whom the remains actually represent. Features exhibited by the remains are determined to be essentially the same as those in the antemortem reference, with no unexplainable differences. Insufficient evidence to support an identification by one means or another may be subsequently combined with other evidence to identity. An exclusion refutes a provisional ID when differences in the evidence demonstrates whom the remains do not represent.

Background

One of the earliest recorded forensic identifications in American history involved two patriots of the Revolutionary War: silversmith Paul Revere and physician Joseph Warren. While fighting in the ranks with his men, Major General Warren sustained a fatal bullet wound to the head in the Battle of Breed's Hill in 1776. Buried in a shallow grave by British soldiers alongside another casualty, his body was recovered several months later by friends. Having been stripped of his uniform, the identity of his remains was confirmed by his friend and practicing dentist, Paul Revere. He recognized a fixed bridge that he had placed the previous year, consisting of what was likely to have been a sculpted piece of hippopotamus tooth affixed with silver wire, replacing a missing cuspid.

Used alone and in combination, dental features and fingerprints have comprised the majority of identifications in mass fatality incidents, particularly where there has been significant tissue destruction due to fire, fragmentation, and decomposition.

Additional classic scientific methods of identification include radiographic examinations and anthropologic analyses.

With the arduous disaster scenarios of recent years, DNA has emerged as a primary means of identification. Instead of replacing classic methods, DNA has supplemented them, extending to those remains not identifiable by other means. Where in years past, those remains may have been buried in a common grave and recognized by a memorial, the standard has now been raised to where DNA analysis of every fragment is not unheard of. These materials now provide a source from which DNA profiles can be derived, greatly increasing the potential for establishing whom these remains represent.

Methods employed to identify remains primarily depend upon the materials recovered from the scene, and secondarily, the available reference materials. With every mishap being distinctive in its causation and presentation, the condition of remains will vary accordingly; therefore, the nature of the mishap determines the evidence that is available for examination. Air transport disasters involving explosion, fire, and high-velocity impacts have presented as mass fatality incidents (MFIs), involving severe fragmentation and burning of the aircraft and its occupants. Identifications using classic methods can be completed typically within days or weeks (sometimes hours) of recovery. IDs based upon DNA profiles may take weeks or months to process.

A number of crash sites have presented exceedingly challenging recovery situations: mountainside, tropical rainforest, muddy field, swamp, open ocean, and urban environments. The demands of these scenarios have necessitated advances in technology and protocols to facilitate recovery of remains, making possible their identification. In all, identifications are based upon the nature of the remains recovered as a result of the mishap, and the availability of antemortem references. This can result in an individual being identified by more than one method.

Scientific methods

Fingerprints

The fingers, palms, and soles exhibit distinctive patterns of friction ridge details forming the basis for what can be a fair proportion of identifications in aviation disasters. These patterns can be recorded from remains that have been exposed to fire or undergone fragmentation and decomposition. In fire, contraction of major muscle groups causes the decedents arms, hands, and fingers to curl inward, forming fists. To an extent, this protects the finger pads from the effects of the fire.

Fingerprint experts can print postmortem friction ridge details and compare them with recorded antemortem prints on file with the individual's employer, fingerprint databases, or other sources. In the absence of recorded prints, latent prints can be lifted from items frequently handled by the individual. Identifications are a product of comparison between the postmortem and antemortem patterns.

For 60 years, the FBI Disaster Squad has responded to the requests of local authorities to assist with disaster victim identification. agents and latent fingerprint specialists from the Forensic Analysis Branch of the FBI Laboratory have served a humanitarian role in obtaining fingerprints, palm prints, and footprints from decedents. They search for recorded prints in various databases, obtain latent prints, and make comparisons for identification. Advances in technology, such as the Integrated Automated Fingerprint Identification System (IAFIS), have significantly expedited the search through civil and criminal fingerprint databases. Additional sources for fingerprint records now include driver's license applications in California and Texas.

Radiographic identification

Medical X-ray images are useful for comparison with postmortem full-body radiographs. Useful medical radiographs include view of the skull, chest, abdomen, spinal column, and extremities. Normal anatomical variations of the skeleton, abnormal bone formation, evidence of disease, and surgical artifacts can serve as identifying features. When viewed on radiographs, the configuration of surgical plates, wires, implants, pacemakers, and defibrillators can provide identifying data. What is more convenient is that the last three items typically have serial numbers that can be traced to the manufacturer, and to the recipient.

X-ray scanning of body bags can reveal not only remains and their injury patterns, but also personal effects, aircraft parts, and items potentially hazardous to morgue personnel. Fractured bones, displaced teeth, and jewelry can be located and documented for subsequent identification procedures.

Anthropology

While we are on the subject of bones, the expertise of forensic anthropologists is key to search-and-recovery efforts as well as the identification process, particularly in scenarios involving extensive fragmentation, commingling, and burning. They can direct excavation of difficult recovery sites and distinguish human skeletal materials from those of animal origin. Their familiarity with the distinctive anatomical features of the human skeleton allows them to locate, sort, and reassociate fragmented remains, fundamental to establishing how many individuals are represented. Some patterns of damage to bone are amenable to anthropologic interpretation as to mechanisms of injury, be it mechanical trauma or heat fractures produced in a fire.

Depending upon materials available, anthropologists can reconstruct and analyze the individual bones and skull to make estimates of stature, age range, muscularity, and determine the gender of an individual. The compiled data forms a biological profile, an approximate physical description of an individual. The profile can be compared with physical descriptions of persons listed on the flight manifest, forming the basis for a provisional ID.

Age at time of death can be estimated, based upon the stages of development of the skeleton and dentition during infancy, childhood, and adolescence. For example, the crash of an aircraft into swamp presented a challenging recovery site: difficult access, associated environmental hazards, and sunken fragmented materials. A number of hands were recovered and subsequently X-rayed. Anthropologists estimated approximate ages for each hand, based on the development of specific bones of the fingers, hand, and wrist. Age estimates were calculated from statistics derived from a normal reference population represented in an atlas of hand-wrist development. Age estimates were valuable in associating most of the hands with specific juveniles listed on the flight manifest. Fingerprints and other features were also important factors in identification.

Estimates of age at death are generally based upon areas where many structures are developing: hands and wrists, knees, feet, and ankles and jaws with developing permanent teeth. Narrower age ranges can be derived from younger individuals who still exhibit numerous areas of growth As growth processes cease in adults, degenerative changes are used for making broad age range estimates.

Portions of bone lacking soft tissues or distinctive anatomy can still serve the identification effort as part of a reconstructed skeleton, or as a source of DNA. For purposes of reassociating other fragments with the same DNA profile, samples may be taken for DNA analysis from already-identified structures, such as hands or teeth.

DNA

DNA analysis is based upon examination of specific segments of human genetic material that can distinguish one individual from another. These molecular variations are processed and viewed as a distinctive graphic pattern, or DNA profile. This technology offers a means of establishing identity for remains that could not otherwise be identified. DNA profiles generated from remains already identified by other means, such as teeth or hands, can be utilized to reassociate other fragments from the same individual. Environmental insults can damage the DNA molecule and hamper identification.

Molecular biologists have developed methods of extracting DNA from a variety of biologic samples: bone, teeth, whole blood, saliva, muscle tissue, as well as a variety of cell-containing tissues and fluids. Small yields of DNA can be copied to amplify its volume. Suitable quantities of DNA are processed to generate a profile that reflects the sequence or the length of the components of the molecular reference points being examined.

As with classic forms of identification, the pattern of a DNA profile generated from a postmortem sample is compared with those derived from direct or indirect reference samples from known sources. A direct reference sample is taken from the decedent sometime during life, such as a blood sample, biopsy specimen, or it can be provided by a hair sample, biological residues from a toothbrush, clothing, or other personal items. An indirect reference, such as a blood sample or cheek swab obtained from a close relative, can also be used. The patterns of the subject and reference profiles are examined for consistencies. When the profile derived from the subject matches that of a known reference, two conclusions can be drawn: Either the remains represent the individual in question, or there is another individual with the same genetic profile. Population statistics provide the analyst with probabilities indicating the likelihood of the remains representing the subject in question.

Interestingly, human X and Y chromosomes, present in cell nuclei throughout the body, contain a gene that codes for amelogenin, a protein involved in the production of tooth enamel. The length of the gene that codes for this protein is shorter in females than it is in males, which makes it a convenient marker for gender determination.

DNA is present within the teeth, contained within cells of the pulp and porous dentin comprising the greater part of the crown and root structure. Teeth are excellent vessels for DNA, offering protection from damaging environmental conditions. The contours of the internal and external aspects of the teeth make them inherently unique. When altered, teeth become even more distinctive. Methods for accessing DNA from teeth have been developed to preserve the anatomic contours that make teeth excellent identifiers.

Dental identification

Teeth have been used for identification since ancient Roman times. Variations in shape, position, color, alterations, and patterns of loss are distinguishing characteristics readily seen. Teeth are durable, which allows them to retain their fundamental characteristics through the effects of fire, decomposition, immersion, and impact. Their internal and external contours can be unique enough to allow a jaw fragment with a couple of teeth, or a displaced single tooth, to form the basis for identification.

The outline of the crown, root(s), pulp chamber, and root canals are visible on dental radiographs. The internal and external outlines of restorations, root canal treatments, and other alterations are unique themselves, and are also examined on X-ray images. Antemortem X-ray images document these landmarks and are compared with analogous postmortem X-rays to reveal consistencies or differences that would confirm or refute whom the remains in question represent.

Postmortem dental examinations, photographs, and radiographs are conducted in a standard manner to gather the same data that would be compiled in a clinical setting. The presence and absence of teeth, their restorations and replacements, orthodontic appliances, and other features are documented. The same types of data are compiled from antemortem dental records, X-rays, and other materials, and a composite chart is constructed, depicting the existing dental conditions of an individual at the most recent visit to the dentist. These postmortem and antemortem data are entered into a computer database. When a dentist queries the database regarding a specific postmortem case file, for example, the computer quickly sorts the available data and directs the dentist to the most likely antemortem files that fit the case description. Dentists then compare the X-rays and data from those files to determine whether the remains in question represent one of those individuals. Among dealing with many other issues in dental identification, additional analyses and inquiries are also carried out, dealing with dental appliances, specific restorative materials, and thermal damage to name a few.

While untreated teeth and jaw structures are already distinctive, alterations can further differentiate one individual from another. With 32 possible permanent teeth, the potential combinations of missing and present teeth are considerable. Add five surfaces per tooth that can be restored, and categorize restorations as either metallic or tooth colored, the potential combinations for present/missing/filled teeth are vast.

Individual teeth can be restored with a variety of materials: metal alloys comprised of silver, tin, copper, and mercury; gold alloys; cast semi-precious or base metal alloys; tooth-colored resins; and all-porcelain restorations. Each of these materials exhibit specific physical properties that influence their clinical application and damage sustained in a fire.

Single displaced teeth that are not restored can provide information about metallic restorations that may be present on adjacent teeth. Scanning electron microscopy (SEM) and energy-dispersive X-ray fluorescence (EDS) can allow high magnification visual examination of a tooth surface and provide elemental microanalysis of trace materials. Traces of elemental gold can indicate that the adjacent tooth was restored with a gold alloy, while the detection of silver, mercury, or tin can indicate an adjacent silver amalgam restoration. This data can be sorted through the computer database to reveal which antemortem records contain the same information for those specific teeth.

Replacements for missing teeth can be removable, fixed, or supported by implants. Many permanently cemented fixed bridges are cast in a strong metal alloy, with porcelain fused to the surface for esthetics, while some are constructed entirely of porcelain. As with natural dentition, these structures possess unique contours useful for identification, even when displaced from the oral cavity. Fabricated under high temperatures, they can begin to distort as a fire nears their specific fusing temperatures, giving an indication as to the temperature of the fire they were exposed to in the mishap.

Like Cinderella's glass slipper, removable appliances fit the person for whom they are made. Required by law in many states, removable dentures and partials discretely bear the name of the patient for whom they are made. Constructed of various combinations of acrylics, resins, and metal alloys, removable prostheses can, to various extents, resist the effects of fire and impact.

Implants function as artificial tooth roots, supporting a single replacement tooth, or a larger prosthesis. Many are manufactured of pure titanium of specific design and dimensions. Their appearance on X-ray, and the restorations they support, can be useful in identification.

As with aircraft components, fire can produce characteristic thermal damage to teeth, bone, and dental restorations. With increasing duration and temperature, teeth can change color, dry out, develop cracks, and enamel can separate from the underlying tooth. The outer layer of bone that surrounds the teeth can be destroyed and teeth can be lost, and eventually the remaining teeth and bone become ashed. Posterior teeth are afforded some protection from fire by surrounding jaw muscles, cheeks, and tongue.

Burned teeth and bone can be very fragile and can crumble if handled. These materials require careful handling by forensic personnel, who may document them at the site with photographs and portable X-rays before stabilizing them for transport. When remains are highly fragmented as well as burned, they can be significantly reduced, including teeth and bone. Recovery is difficult, and there are fewer materials with which to make identifications. Despite the challenging situation, the humanitarian mission served by personnel at the scene and mortuary encourages their best effort.

Considerations

In difficult field situations, on-scene personnel may encounter remains yet to be recovered. As materials in these scenarios can be greatly reduced, seemingly insignificant fragments become increasingly necessary for identification. Field investigators can facilitate the recovery and identification process by recognizing and protecting these materials at the scene, perhaps documenting them, and notifying the ME of their presence and position. In assisting this effort, air safety investigators can ultimately help to serve the surviving families. ◆

References

1. Lahm FP, *First United States Military Aircraft Accident; Mr. Orville Wright and Lt. Thomas E. Selfridge 17 September 1908*, Signal Corps, USA, February 9, 1909; Directorate of Aerospace Safety, Deputy Inspector General for Inspection and Safety USAF.
2. Office of Emergency preparedness, National Disaster Medical System, www.ndms.dhhs.gov/NDMS/ndms.html.
3. Disaster Mortuary Operational Response Team, www.dmort.org.
4. *Federal Family Assistance Plan for Aviation Disasters*, National Transportation Safety Board, August 1, 2000.
5. Public Law 104-264, Title VII, Aviation Disaster Family Assistance Act of 1996, October 9, 1996.
6. Public Law 105-148, Foreign Air Carrier Family Support Act, December 16, 1997.
7. Public Law 106-181, Title IV Sec. 401-404 – Family Assistance, April 5, 2000.
8. Transportation Disaster Assistance, www.ntsb.gov/Family/family.htm.
9. Luntz LL, Luntz P, *Handbook for Dental Identification; Techniques in Forensic Dentistry*, Lipincott, Philadelphia, 1973.
10. Froede RC, etal, *Investigation of Multiple Fatality Incidents*, In Handbook of Forensic Pathology, 2nd, Froede RC, ed. College of American Pathologists, Northfield IL, 2003.
11. Cimrmancic MA, Gormley WT, Cina SJ, Aviation Pathology, In Handbook of Forensic Pathology, 2nd, Froede RC, ed. College of American Pathologists, Northfield IL, 2003.
12. USDOJ FBI Handbook of Forensic Services www.fbi.gov/hq/lab/handbook/examds.htm.
13. FBI Disaster Squad www.fbi.gov/hq/lab/disaster/disaster.htm.
14. Warren MW, etal, *Use of Radiographic Atlases in a Mass Fatality*, J Forensic Sci, 1999;45:467-470.
15. Rudin N, Inman K, *An Introduction to Forensic DNA Analysis, 2nd*, CRC Press, Boca Raton, 2002.
16. Smith BC, *Introduction to DNA Analysis*, Dental Clinics of North America, Vol. 45, No. 2, April 2001, pp. 229-235.
17. Gaytmenn R, Sweet D, *Quantification of Forensic DNA from Various Regions of Human Teeth*, J Forensic Sci, May 2003, Vol. 48, No. 3.
18. Avery JK, *Essentials of Oral Histology and Embryology: A Clinical Approach, 2nd*, Steele PF ed., Mosby Inc., and St. Louis, 2000.
19. Brannon RB, Morlang WM, *Tenerife Revisited: The Critical Role of Dentistry*, J Forensic Sci, 2001; 46(3):722-725.
20. Ludes B. etal, *Medico-Legal Investigations of the Airbus A320 Crash upon Mount Ste-Odile, France*, J Forensic Sci, Vol. 39, No. 5, September 1994, pp. 1147-1152.
21. American Board of Forensic Odontology, Inc., ABFO Guidelines and Standards, In Manual of Forensic Odontology, 3rd, Bowers CM, Bell GL, eds., American Society of Forensic Odontology, 1995.
22. Smith BC, A Preliminary Report: Proximal Facet Analysis and the Recovery of Trace Restorative Materials from Unrestored Teeth, J Forensic Sci, Vol. 35, No. 4, July 1990, pp. 873-880.
23. Myers SL, Williams JM, Hodges JS, *Effects of Extreme Heat on Teeth with Implications for Histologic Processing*, J Forensic Sci, 1999; 44(4):805-809.
24. Carr RF, Barsley RE, Davenport Jr., WD, Postmortem Examination of Incinerated Teeth with the Scanning Electron Microscope, J Forensic Sci, Jan 1986, Vol. 31, No. 1, pp. 307-311.

Aircraft Accident Investigation— The Role of Aerospace and Preventive Medicine

By Allen J. Parmet, M.D., M.P.H., F.A.C.P.M.

***Dr. Allen Parmet** received his B.S. in chemical engineering from the United States Air Force Academy and served on active duty with tours in Vietnam and NORAD before going to medical school. He received his M.D. from the University of Kansas and masters in public health from the University of Texas and completed a residency in aerospace medicine at the USAF School of Aerospace Medicine in San Antonio, Tex. After numerous assignments, he retired from the Air Force in 1992. He was the medical director of Trans World Airlines and currently is in private practice at Midwest Occupational Medicine in Kansas City, Mo.*

Prevention of future mishaps has long been the primary goal of aircraft accident investigation. The secondary purpose for conducting an inquiry is to derive causes of death and injury, with the objective of modifying those factors and improving mishap survivability. Thirdly, the facts of the mishap are essential for purposes of establishing cause and subsequent action in the litigation and regulatory arenas. Since the earliest days of flight, physicians have played an integral role in the progress of aviation safety.

Experts in a diverse array of disciplines, ISASI members are united in their pursuit of the advancement of aviation safety. Amid the multidisciplinary working groups focused upon structures, systems, and operational data, an effective member of an accident investigation team is the human systems maintenance engineer, also known as the aerospace medicine physician (AMP), flight surgeon, or aviation medical examiner (AME). While the AME is designated by the Federal Aviation Administration to perform flight examinations, the training requirements are basic and consist of a week-long course taught in Oklahoma City. This physician is responsible for the most important part of the aircraft: the pilot. Malfunction of the pilot has from the very beginning of flight been the cause of most aviation accidents.

The AMP is a medical specialist who functions within in the areas of preventive medicine and its subspecialty, aerospace medicine. One of the 24 recognized medical specialties recognized in the United States, aerospace medicine is the smallest of all specialties, with about 1,000 physicians completing the 3 years of residency training and becoming certified in the United States over the past 50 years. They differ from most of their medical colleagues in that prevention of illness and injury is the goal rather than therapy after one is already sick. Their job, then, is to prevent accidents of aircraft and other forms of vehicles, for prevention is much more effective than treatment after the accident.

While not all accidents can be prevented, the AMP can use the information derived from accident investigations to derive the causes of injury and help modify those factors. This leads to addition of engineering changes for both active and passive protection of occupants, reduction of crash-related environmental factors, and providing for survival and rescue in the post-crash phase.

The lessons learned from accidents are also translated into training to help prevent future accidents, design safer aircraft, and improve crash/rescue operations. The information may also find its way into the courtroom as the AMP may become an expert witness in helping derive forensic and legal conclusions.

Customarily, there is no separate Medical Factors Working Group in U.S. civil aviation mishap investigations, aside from the participation of the local medical examiner or coroner, who may provide trauma data to the Survival Factors/Crashworthiness Working Groups. However, U.S. military aviation mishap investigations have a flight surgeon as a member of every board. In civil accidents, when the AMP is called to participate, it is usually through invitation of the safety investigators or after the investigation closes and when litigation starts. Although a considerable proportion of aviation mishap causation is human related, the specialist of the human aspect is not a proportionately routine participant in aircraft accident investigations.

The primary causes of accidents have always been human factors. Even before the Wright brothers flew in 1903, there had been numerous aviation accidents and deaths. Probably the first true accident occurred in 1785 when Pilâtre de Rozier, a French physician who had been on board the very first flight of a Montgolfier brothers balloon in 1783, sought to be the first to fly a balloon from France to England, westbound across the English Channel. He was preceded by the American physician John Jeffries, on January 7 of that year, but Jeffries had the advantage of much stronger prevailing winds and needed to spend less time aloft in a hot air balloon. De Rozier decided to combine Charles' invention of a hydrogen balloon with the Montgolfier's hot air balloon. Hot hydrogen, however, proved to be a very dangerous combination, and de Rozier died in the fiery crash. One might say then that physicians invented the aviation accident.

Over the next hundred years, ascents to higher and higher altitudes were made with safer methods of handling hydrogen, and high-altitude ballooning came into being. Soon, the problems of cold and hypoxia became apparent. In 1862 the English aeronauts Glaisher and Coxwell ascended to 9,480 m (29,388 ft), but they were unconscious above 8,833 m (27,382 ft) due to hypoxia. Following this, the French physician Paul Bert began experiments that determined that humans could not live at oxygen pressures below 45 mmHg (equivalent to air at 33,000 ft/10,000 m), which would ultimately be proven a century later when Austrian Reinhold Messner climbed Mt. Everest without oxygen in 1980. Just behind him was an American physician with a team of

Sherpas carrying a bicycle ergometer to the base of the Hillary Step in order to replicate Bert's work.

Bert was also the medical advisor to a team of French aeronauts, Crocé-Spinelli, Sivel and Tissandier. In the summer of 1874, they attempted to set a new altitude record of 10,000 m using a primitive oxygen supply system, which consisted of three bags of 72 percent oxygen and simple tubes that were held in the mouth. Bert warned them that this was inadequate, but on April 15, 1875, the trio ascended. While they probably did exceed their goal, all were unconscious and only Tissandier survived. The accident was a national tragedy that shook France as much as the Challenger disaster would rock America. As a result, high-altitude attempts would come to a halt until the 1930s.

Physiologic issues had become established as one factor in the cause of aviation accidents. Hypoxia would remain a challenge until oxygen supply systems were perfected and pressurized cabins came into use in the 1940s. Other physiologic issues remain with low barometric pressure at altitudes over 50,000 feet, toxic gases both in the systems and in the event of crashes and fires. Finally the problem of acceleration forces would not become evident until the U.S. Navy invented dive bombing and a plane capable of 5-g pullouts in the 1930s. Soon fighter aircraft were beginning to dogfight in the realm above 5 gs and acceleration-induced loss of consciousness (G-LOC) became an additional cause of accidents.

The first fatal accident of an airplane occurred on Sept. 17, 1908, at Ft. Myer, Va. The starboard propeller failed on a demonstration flight, seriously injuring Orville Wright and killing his passenger, Army Lt. Thomas Selfridge. An Army surgeon conducted the autopsy and found that Selfridge was thrown out of the aircraft on impact and died of a skull fracture. His army colleagues, such as Lt. Henry (Hap) Arnold, were later encouraged to wear their West Point football helmets while flying. It would not be until the 1940s that Dr. John Paul Stapp would lead design changes in helmet safety.

Within a few years, aviation was an important part of world military activities, and most militaries developed medical standards—particularly after early studies of Britain's Royal Flying Service in 1915 found that the life expectancy of a pilot was a mere 2 weeks. Of the deaths, 90 percent were due to what we would today call human factors. What has changed, however, is the mixture.

In 1915, medical conditions were the cause of 60 percent of accidents, spatial disorientation another 30 percent. Mechanical problems accounted for 8 percent and combat a mere 2 percent. Pilots were entering training and often dying there. Medical conditions such as asthma (German Oswald Boelcke), skull fracture and epilepsy (Manfred von Richtoffen), tuberculosis (Georges Guynemer), blindness (William Thaw, Edward Mannock), bleeding ulcers (Roy Brown), and psychosis (Frank Luke) were considered unsuitable for such military arms as the infantry or cavalry. Aviation was deemed to be much like an office job; after all, the pilot just sat there. Medical regulations were soon in place and a military doctor, known as a surgeon, was assigned to flight units. In the United States, Major Theodore Lyster became the head flight surgeon for the Army flying and established standards that would screen out nearly 30 percent of all U.S. flying applicants. In 1926 Dr. Louis Bauer would be reassigned from the Army to become the first federal air surgeon. Dr. Bauer would begin the training program of AMEs that is the standard today. The medical standards for civil pilots were also established at this time.

The presence of AMEs would not do much to affect the first-high profile aircraft accident, the 1931 crash of a Fokker Trimotor in Chase County, Kans., that killed Notre Dame coach Knute Rockne. There was no national system for investigating accidents. Spectators drove around the site, taking souvenirs and destroying evidence. Bodies were barely identified by their clothing. In contrast, the investigation of the 1950s crashes of the Comet IA were directed by an AMP, who noted that the deaths were due to explosive decompression, not terrorist bombs. As the AMP during the loss of TWA 800, the author's role fell to providing identification data to the local medical examiner, crew medical information to the NTSB, support for disaster response and family assistance, as well as counseling and helping company employees affected by such a catastrophe. The loss of space shuttle Columbia was complicated by the hazards to people on the ground from toxic chemicals used for propulsion and power. The author had trained the military flight surgeons who deployed and cared for the military personnel involved in wreckage search and recovery.

The imposition of medical standards on pilots effectively minimized medical conditions as the primary cause of accidents. However, human factors still comprise 80-90 percent of all aircraft accidents. Today medical accounts for 2 percent of accidents, spatial disorientation 36 percent, controlled flight into terrain 38 percent, drugs and alcohol are 6-9 percent, midair or ground collisions 6 percent, and mechanical problems only 2 percent. Hostile actions such as terrorism are still 2 percent.

Spatial disorientation accidents began to occur as soon as pilots began to fly into clouds, bad weather, and at night. The first real solution to this problem was the Sperry turn-and-bank indicator, but it met with resistance from pilots who distrusted it. Dr. Ocker developed a combination of a rotating chair equipped with a turn and bank indicator to train pilots in the effects of vertigo while on the ground and to instill in them the confidence they needed to use their instruments. The "Ocker Box" was the forerunner of instrument simulators, later brought into its common form by Lear.

AMP physicians continued their work improving vision, life support and escape, as well as crashworthiness. High-altitude bailouts were researched by Dr. Randall Lovelace, who discovered the high opening shock forces, cold, and hypoxia and recommended free fall to lower altitudes. After World War II, Dr. John Paul Stapp began his impact acceleration work on the Corum ranch in California, using Muroc dry lake bed for sled testing (now known as Edwards Air Force Base). His research team developed the limits of human tolerance to impact accelerations and all modern energy absorption limits are derived from his work. Stapp's team would develop the standards for ejection seats, shock absorbers, passive restraints, crash helmets, air bags, and seating arrangements. Stapp's chief engineer, Ed Murphy, also discovered that whatever can go wrong, eventually will.

The discoveries in aviation safety were to eventually be applied to many other areas of safety including automobiles and highways and motorcycle and football helmets.

Accidents still occur due to psychological factors. Judgment and drugs are the main issues. It is difficult to evaluate a pilot's judgment, but many factors come into play including learning ability, rate, experience and transfer. Attention, boredom, complacently, task saturation, fatigue, and complacency all have roles to play. Personality states of self-discipline, motivation, supervisory pressures and cumulative workload interact with outside psychosocial factors of job satisfaction, career expectations, family, and community conflicts. Within the operating environment there are supervisory and management issues as well as crew coordination and cockpit resource management. Organizational issues of aircraft systems, transitions, maintenance, weather, and air traffic control all interact.

Analysis of these factors is known as the "Swiss Cheese Model" after Drs. Shappell and Weigman, in their article "The Human Factors Analysis and Classification Stytems in 2000." An accident is inevitably the end result of a chain of errors. These are classified into latent and active issues. Latent issues consist of organizational and supervisory preconditions. These may include pressure to perform to schedules and ignore crew rest, fuel reserves, or mechanical problems. Active issues include preconditions such as medical problems, weather or traffic, and finally unsafe acts. The unsafe act is a decision made by the pilot to arrive first at the scene of an accident.

Drugs and alcohol are common in society and contribute significantly to aviation accidents. Their use is rare in commercial and military aviation. However in general aviation, the use of prescription and non-prescription drugs as well as illicit drugs is a growing problem. The detection and deterrence of their use is a societal problem as well as an aviation safety issue. Drug testing does serve to deter use by casual illicit drug users, but not those who are addicted. Treatment works. The HIMS program, originated by the FAA and ALPA in the 1960s ,successfully returns to duty 90 percent of pilots with alcohol problems and 50 percent of those with illicit drug problems.

The AMP should participate in the aircraft accident investigation and help determine the cause of the accident, as well as the causes of death/Injury along with the forensic pathologist/medical examiner. Medical examiners may not necessarily be attuned to the specific needs of the accident investigator, such as determining who was at the controls of a multipilot aircraft. Nor should it be assumed that the medical examiner would automatically turn that information back to prevent the next accident. It is important to determine if the pilot and passengers were incapacitated prior to, during, or after the crash. Pre-crash incapacitation may be due to medical causes such as cardiac disease, carbon monoxide poisoning, or hypoxia. Crash-related injury is analyzed using CREEP: Container, Restraints, Environment, Escape, and Post-crash factors. As a result of this accident analysis, the AMP will help in recommending remedial actions to prevent the next accident from occurring and reducing injury.

The aerospace medicine physician can be a resource to assist the medical triage teams and should be involved in mass-casualty issues. Leaving out the preventive medicine physician means that the disaster responders may themselves become ill or injured during the response phase and recovery. Their care and feeding is a basic public health function. Finally, there are preventive measures needed for both rescuers and accident investigators. The environment of the accident site may represent a human health hazard.

Environmental issues such as clean water and food, sleeping arrangements, and thermal protection need to be addressed. Sometimes a hazardous chemical, high-altitude, or underwater environment exists and additional protective measures must be taken to prevent the investigating team from becoming additional casualties. Finally, there is the problem of infectious diseases. Disease can spread to the investigators through four methods.

First is blood and body fluids. Any area where there has been spillage of blood and human body products represents a biological hazard. Personal protective equipment must be worn by investigators to avoid contamination by such diseases as hepatitis B and C or HIV, the AIDS virus. A vaccine exists only for hepatitis B.

Food and water supplies must be secured to avoid the spread of contamination. Such diseases as hepatitis A, typhoid fever, and polio can be prevented by vaccination. Airborne spread of disease from person to person is unlikely at the accident site but may be an issue due to the surrounding social conditions. Illnesses such as tuberculosis and SARS are real risks in some areas.

Last is the problem of vector-borne diseases. Mosquitoes, ticks, and fleas carry illnesses such as malaria, West Nile virus, yellow fever, dengue, Lyme, and plague. The best protection is to know what areas are at risk and use insect repellants. Medications and vaccinations are also of use. Always consult the Centers for Disease Control and Prevention website at http://www.cdc.gov and check Travelers' Health for the latest area assessment.

The aerospace medicine physician has the role of preventing future accidents and illness in everyone involved in aviation, including pilots, passengers, rescuers and investigators. This role will continue as long as there are airplanes and people who fly them. Most AMPs are members of the Aerospace Medical Association and can be contacted, along with other aeromedical professionals, at http://www.asma.org. ◆

References

DeHart RL, *The Atmosphere*, in Fundamentals of Aerospace Medicine, 3rd Ed, DeHart & Davis, 2002.

Gibbons HL, Snyder RG, *Aircraft Accidents*, in Fundamentals of Aerospace Medicine, 3rd Ed, DeHart & Davis, 2002.

McMeekin R. *Aircraft Accident Investigation*, in Fundamentals of Aerospace Medicine, 3rd Ed, DeHart & Davis, 2002.

Parmet AJ, Gillingham K, *Spatial Orientation in Flight*, in Fundamentals of Aerospace Medicine, 3rd Ed, DeHart & Davis, 2002.

Sheffield PJ, Heimbach RD. *Respiratory Physiology*, in Fundamentals of Aerospace Medicine, 3rd Ed, DeHart & Davis, 2002.

Whinnery, JE. *Biodynamics: Sustained Acceleration*, in Fundamentals of Aerospace Medicine, 3rd Ed, DeHart & Davis, 2002.

Expansion of the ICAO Universal Safety Oversight Audit Program to Include Annex 13—Aircraft Accident And Incident Investigation

By Caj Frostell (MO3596), Chief, Accident Investigation and Prevention, ICAO

***Caj Frostell's** educational background includes basic flight training in the Air Force in Finland, a degree in aeronautical engineering from the Technical University in Helsinki, Finland, and a master of applied science degree from the Institute of Aerospace Studies, University of Toronto, Canada. From 1967 to 1980, he was Chief of Accident Investigation with the Board of Aviation in Finland and investigated some 300 accidents. In 1980, he joined the Accident Investigation and Prevention Section in Montreal. In 1996 he was appointed Chief of the section. Frostell's special assignments include the following: 1997—A technical cooperation assignment as accident investigator, assigned to the Republic of Korea, for the investigation of the accident to the Korean Air Boeing 747 in Guam on Aug. 6, 1997. 1996—A technical cooperation assignment as accident investigator, assigned to Saudi Arabia, for the investigation of the mid-air collision between the Saudi Arabian Airlines Boeing 747 and the Kazakhstan Airlines IL-76 near New Delhi, India, on Nov. 12, 1996. 1996—Team leader for the ICAO team investigating and reporting on the shooting down of two civil aircraft by Cuban military aircraft on Feb. 24, 1996. 1993—Team leader for the ICAO team completing the investigation (December 1992-June 1993) on the destruction of Korean Air Lines Flight 007, a Boeing 747 on Aug. 31, 1983.*

1. General

1.1 An expansion of the ICAO universal safety oversight audit program (USOAP) to include Annex 13—*Aircraft Accident and Incident Investigation* is feasible as Annex 13 is in a format suitable for auditing. Its provisions clearly define actions required to be taken by a State which directly relate to the investigation and prevention of accidents and incidents. In addition, ICAO guidance material in the form of an accident investigation manual has been in existence for more than 30 years, thus providing States that procedures and guidance to assist with the establishment of national accident investigation and prevention programs.

1.2 The concept of an Annex 13 audit would be to assess and evaluate a State's ability to conduct effective aircraft accident and incident investigations through an evaluation of the State's regulatory framework and its organizational structure (for accident investigations) including the availability of appropriately trained and qualified experts and the availability of other resources which would enable the State to implement and adhere to the Standards and Recommended Practices contained in Annex 13, as well as guidance material and procedures contained in Doc. 6920—*Manual of Aircraft Accident Investigation*, Doc. 9756—*Manual of Aircraft Accident and Incident Investigation, Part I: Organization and Planning* , and Doc. 9422—*Accident Prevention Manual*.

1.3 The preparatory work for the Annex 13 audits is focussed on developing relevant auditing documentation, including pre-audit questionnaires, audit protocols, auditors' training courses, and related guidance material. The pre-audit questionnaire is an essential auditing tool, designed to solicit the information required for audit scheduling and planning purposes. In addition, it will assist States in ascertaining the status of their implementation of the Annex 13 Standards and Recommended Practices (SARPs) in their national legislation and to identify any differences which may exist between their national regulations and the Annex 13 provisions. All information provided by States will be subject to verification during the actual audit.

1.4 Preparatory activities such as the development of the pre-audit questionnaire, audit protocols, training courses for auditors, and an amendment of the ICAO Safety Oversight Audit Manual have been initiated. Administrative actions such as the development of the memorandum of understanding, the recruitment of required personnel, and the development of an audit schedule are planned for late 2003. The conduct of the actual Annex 13 audits is envisaged to commence in the first half of 2004.

2. Content of Annex 13 audits

2.1 It is envisaged that the Annex 13 audits will focus on the following aspects of aircraft accident investigation:

- Implementation of the Standards and Recommended Practices (SARPs) in Annex 13
- The agency responsible for aircraft accident investigation
- Legislation
- Policy and/or procedures manual(s)
- Funding
- Personnel
- Equipment
- Review of the investigation of some recent accidents
- Accident prevention measures

2.2 Implementation of the SARPs in Annex 13. It is essential that the implementation of the SARPs covers all aspects of Annex 13, i.e., the definitions, the applicability, the notification process, the investigation, the developments of the final report including the safety recommendations, the reporting to the ICAO Accident/Incident Data Reporting (ADREP) System, and the accident prevention measures called for in Chapter 8 of Annex 13.

2.3 The agency responsible for aircraft accident investigation. In conformity with Article 26 of the Convention on International Civil Aviation, it is incumbent on the State in which an aircraft accident occurs to institute an inquiry into the circumstances of the accident. This obligation can only be met when appropriate legislation on aircraft accident investigation is in place. Such legislation must establish a process for the investigation of aircraft accidents and designate an appropriate agency such as an accident investigation authority, commission, board, or other body to undertake the investigations.

2.4 The essential functions of the agency responsible for aircraft accident investigation are to

- identify aviation safety deficiencies by the investigation of accidents and incidents so that accidents may be avoided in future;
- maintain the confidence of the aviation industry and the public that accidents and incidents are thoroughly investigated; and
- fulfil the States' obligations under Annex 13 to the Convention on International Civil Aviation (and the EU Council Directive 94/56/EC).

2.5 The accident investigation agency must have independence in the conduct of the investigation and must have unrestricted authority over its conduct. Independence is seen as essential because any investigation may result in the identification of safety deficiencies and the development of findings that could be considered critical of the regulatory organizations that provide safety oversight of the aviation system. Accident investigators should not feel constrained to consider and address apparent flawed policymaking or failings in the setting and policing of safety standards. Many States have achieved this objective by setting up their accident investigation authority as an independent statutory body or by establishing an accident investigation organization that is separate from the civil aviation administration. In these States, the accident investigation authority usually reports to Congress, Parliament or a ministerial level of government.

2.6 In many States, it may not be practical to establish a permanent accident investigation authority. These States generally appoint a separate accident investigation commission for each major accident to be investigated, the members of which are often seconded from the civil aviation administration. It is essential that such a commission report direct to a ministerial level of government so that the findings and safety recommendations of the investigation are not diluted during passage through regular administrative channels.

2.7 Legislation. It is apparent that not all Standards in Annex 13 are suitable for legislative material (perhaps only 20 to 30 percent of the Standards are). It would appear evident that the objective and the scope of the investigations would be covered by the legislation, as well as the rights and responsibilities of the accident investigators (and the investigation agency) to have unrestricted access to all evidence and witnesses. The non-disclosure of certain records (Paragraph 5.12 of Annex 13) would also constitute legislative material. To effectively discharge their duties, accident investigators should be granted suitable statutory powers, including authority over an accident site, possession of evidence, the right to test anything seized, and the right to obtain relevant documents. These powers should, however, only be used when necessary and with the utmost discretion.

2.8 Policy and Procedures Manual(s). Those SARPs in Annex 13 that are not suitable for inclusion in legislation should be covered by regulations or be included in policy and procedures manual(s) issued by the investigation authority.

2.9 Funding. The accident investigation agency should have ready access to sufficient funds to enable it to properly investigate those accidents and incidents that fall within its area of responsibility. Since it is impossible to accurately forecast annual budget requirements for accident investigation, provision should be made for supplementary funding as required. An airline accident is a rare event, and such a major investigation would normally not be expected to be covered by an annual budget in smaller States.

2.10 Personnel. The accident investigation agency would be expected to have a core staff, competent and trained in accident investigation, as well as a procedure in place to acquire additional investigators if required on a secondment basis. Normally, the core staff would have a professional pilot background and aeronautical engineer/aircraft maintenance engineer background. The accident investigation agency would need to make arrangements for the coverage of other essential areas in an investigation (air traffic services, meteorology, airports, human factors, etc.).

2.11 Equipment. The investigation field kit should contain sufficient equipment to enable examination of the wreckage, the plotting of impact points and wreckage patterns, parts identification, and the recording of observations. The availability and the content of investigation field kit(s) would be part of an audit. Accident investigators should have their investigation field kits and essential personal items packed and ready so that they can proceed without delay to the accident site. Advance consideration should also be given to such details as inoculations, passport requirements, and travel facilities. Investigators who work among wreckage are advised to have a valid anti-tetanus serum inoculation and hepatitis immunization, as well as the necessary personal protective equipment against biological hazards, such as bloodborne pathogens.

2.12 Review of the investigation of some recent accidents. In the preparation for an audit, the ICAO audit team would use the ICAO Accident/Incident Data Reporting (ADREP) System to obtain a list of the accidents to aircraft over 2,250 kg in the last 3-5 years in the State to be audited. In accordance with paragraph 6.7 of Annex 13, the Final Reports shall be available and the audit team would review the final reports on some recent accidents in advance of the audit. The audit team may also wish to interview the investigator-in-charge for one or more of these investigations in order to ensure compliance with Annex 13 and appropriate investigation procedures.

2.13 Accident prevention measures. Chapter 8 of Annex 13 covers accident prevention measures and calls for a mandatory incident report system, a voluntary incident reporting system that is nonpunitive in nature and provides protection of the information sources, and an accident/incident data system. It may be of interest to note that the European Union (EU) has established an accident and incident database system, the European Co-ordination Centre for Aviation Incident Reporting System (ECCAIRS), which is fully compatible with the ICAO ADREP system. It is envisaged that either through EU or ICAO, the ECCAIRS database system can be made available to other States on request.

3. New challenges

3.1 Although there may not be any noticeable upward trend in the number of accidents, it should be noted that the challenges and tasks faced by accident investigators are continually changing with the increasing complexity of aviation. As a result, the workload is increasing although the number of investigations stays constant. In the last 10 years, many new considerations have become part of the investigation process and have increased the workload considerably. These include

- The international requirements (Annex 13 and the EU Directive 94/59/EC) to investigate serious incidents, as well as accidents;
- Advances in technology and the complexity of modern aircraft and their systems have added new challenges to the task of accident investigation;
- International and domestic procedures and processes have increased in complexity; for example, investigators are required to consult interested parties on draft reports before their publication; and
- Health and safety requirements have increased the workload of investigators. Health and safety considerations are now an important element in the conduct of investigations.

3.2 There are also a number of non-investigative areas that need to be addressed by investigators.

- There is an increasing legal dimension (both civil and criminal) to investigation work. Investigators are required to attend coroner's courts and inquests and to appear in courts of public inquiries. There is also the question of management of inquiries from legal representatives of victims' families seeking information to pursue compensation claims.
- The task of family liaison requires careful and appropriate attention. It is not a task that can be rushed and, as such, has resource implications. Also, the awareness and expectations of family assistance programs are rapidly increasing worldwide.
- Emergency planning is also an area that has developed and requires an increase in liaison with the local emergency planning authorities.
- There is an increasing requirement for investigators to have the necessary skills and competencies to use information technology efficiently and effectively in conducting investigations and preparing accident reports.

3.3 All these factors indicate a growing workload for the accident investigation authorities and are likely to have an impact on target dates for completion of final reports of investigations. ◆

SESSION V

The CFIT and ALAR Challenge: Attacking the Killers in Aviation

By Jim Burin (M04448), Director of Technical Programs, Flight Safety Foundation

***Jim Burin** has 35 years of aviation experience and 27 years of experience in the aviation safety field. His work in aviation safety includes controlled flight into terrain, approach and landing accidents, human factors, safety program organization, accident investigation, safety education, and organizational influences on safety. He is a retired Navy captain, having commanded an attack squadron and a carrier air wing during his 30-year career. Prior to joining the Flight Safety Foundation, he was the director of the School of Aviation Safety in Monterey, Calif.*

Eleven years ago the Flight Safety Foundation embarked on a project to reduce the risk of controlled flight into terrain (CFIT) and approach and landing accidents (ALA). Many might ask "Why CFIT and ALA?" Why not study runway incursions or uncontained engine failures? Aren't bird strikes important? Yes, runway incursions, uncontained engine failures, and bird strikes are all important safety issues, but the chart in Figure 1 shows why this effort was initiated. In 1992 CFIT was the leading cause of fatalities in commercial aviation, and ALA was the most common type of accident. Everyone knew there were problems in these areas; there was a lot of qualitative information to confirm that. However, there was no study, nothing quantitative to base interventions on. Figure 2, showing current numbers, makes it evident that the challenge of CFIT and ALA still exists.

In 1996, after 3 years of work by more than 150 international aviation experts, recommendations concerning CFIT prevention were released. In addition to recommendations, there were also products. These included the CFIT training aid, which consisted of the CFIT checklist, a video, and two volumes of information on CFIT. The Foundation sent out thousands of the training aids, won some awards for its CFIT work, and the CFIT rate started to come down. Then came 1998. There were seven commercial jet CFIT accidents in 1998, a real shock and setback to the CFIT prevention effort. As a reminder, approach and landing is a phase of flight while CFIT is a type of accident that can happen during any phase of flight. In fact, I am sure it is no surprise that over the last 10 years, 96 percent of the commercial jet CFIT accidents happened during approach and landing. As you can see from Figure 3, there was only one commercial jet CFIT accident in 1999. However, of the 28 commercial turboprop accidents in 1999, 14 were CFIT, accounting for 80 percent of their fatalities for the year. Despite a focus on training, efforts to increase awareness, and some new and exciting technologies, there have been an average of four commercial jet CFIT accidents a year for the

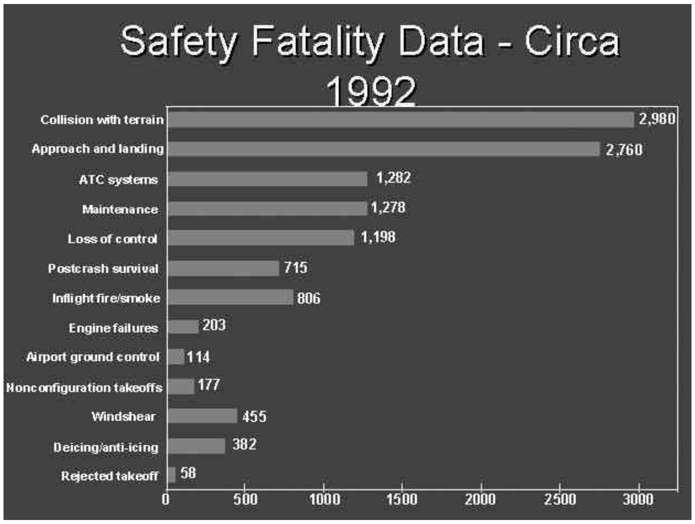


Figure 1

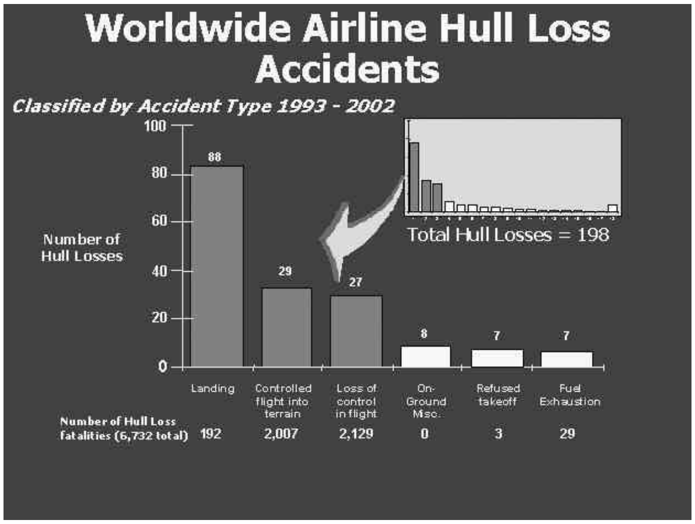


Figure 2

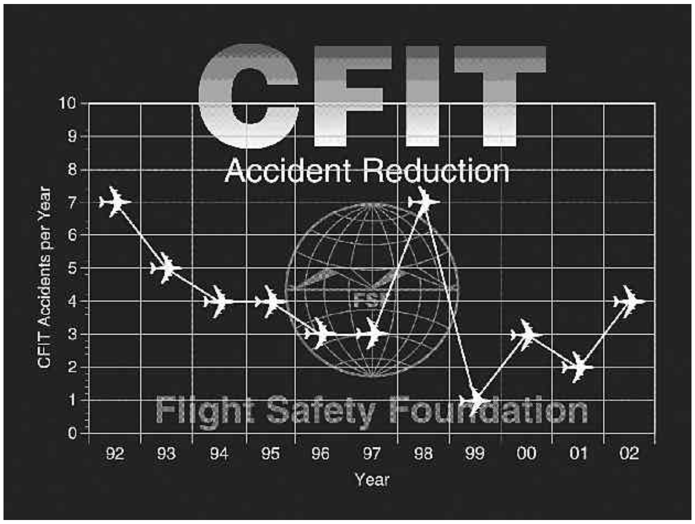


Figure 3

CFIT Accidents
Worldwide Commercial Jets (>60,000 lbs, non-CIS)
25 November 2001 to 1 September 2002

Date	Operator	Aircraft	Location	Phase of Flight	Total Fatal
25 Nov	Crossair	RJ-100	Zurich, Switzerland	Approach	24
27 Nov	MK Airlines	B747-200F	Port Harcourt, Nigeria	Approach	1
28 Jan	TAME	B727-100	Ipiales, Colombia	Approach	92
15 Apr	Air China	B767-200	Pusan, South Korea	Approach	128
7 May	Egyptair	B737-500	Tunis, Tunisia	Approach	14
26 July	Federal Express	B727-200F	Tallahassee, Fl, USA	Approach	0

6 Commercial Jet CFIT Accidents
In 8 Months !

Figure 4

last 10 years. As shown in Figure 3, there were only two commercial jet CFIT accidents in 2001 and four in 2002. This may seem about average, but the table in Figure 4 shows it is far from it. From Nov. 25, 2001, to July 27, 2002, there were six commercial jet CFIT accidents in 8 months. That is almost one CFIT accident a month for 8 months!! The good news is there were none from July 27 to the end of 2002. The bad news is that there were four CFIT accidents in the first month of 2003. The data tell us that no segment of aviation—from turboprop commuters to international widebodies—is immune to CFIT accidents. In 2002, in addition to four of 15 commercial jet accidents being CFITs, one of every three turboprop accidents were CFITs. Here are some numbers to think about 65 percent, 4 percent, and 0. Sixty-five percent of the commercial jets in the world are equipped with terrain awareness warning systems (TAWS). Only 4 percent of the regional aircraft (10-30 seats) have TAWS. And 0—well, that's the number of CFIT accidents that have happened to aircraft equipped with TAWS. That doesn't mean there won't be one—even Don Bateman, the inventor of GPWS and TAWS, admits that one will happen at some point. However, remember risk equals probability times severity. We can't do much about the severity of a CFIT accident, but TAWS greatly reduces the probability, and thus the risk of a CFIT accident.

As we evaluated the lack of success of our CFIT prevention program, the Approach and Landing Accident Reduction (ALAR) Task Force was already under way. It included much of the CFIT work. The ALAR study was based on 287 fatal approach and landing accidents that occurred between 1980 and 1996. These included all jet and turboprop aircraft with a maximum takeoff weight over 12,500 pounds. The top five ALA types from this study were CFIT (including landing short), loss of control, landing overrun, runway excursion, and non-stabilized approaches. In December of 1998, the ALAR Task Force report titled "Killers in Aviation" was released. This report has become the reference book on CFIT and ALA. More than 48,000 copies of this 278-page report have been downloaded from the FSF website. The report has been used as a reference by NTSB (who reprinted an entire section in the KAL/Guam accident report), by TSB Canada, and by the Netherlands Transportation Safety Board, to name just a few. It replaced a lot of qualitative ideas with quantitative facts.

Figure 5

- ***Flight Safety Digest*: "ALAR Briefing Notes":** A collection of 34 documents on a variety of topics to help prevent approach and landing accidents (ALAs), including those involving controlled flight into terrain (CFIT).
- ***Flight Safety Digest*: "Killers in Aviation: FSF Task Force":** Presents facts about approach and landing and controlled flight into terrain accidents" conclusions and recommendations of the FSF ALAR Task Force, and the accident/incident data on which they are based. Selected FSF publications related reading on approach and landing accidents and CFIT.
- ***Approach and landing Risk Awareness Tool:*** A supplement to the normal approach briefing for increasing flight crew awareness of hazards, includes elements of a stabilized approach.
- ***Approach and landing Risk Reduction Guide:*** Guidelines to help chief pilots, line pilots, and dispatchers evaluate training, standard operating procedures, and equipment.
- ***Standard Operating Procedures Template:*** Recommended elements for company-standard operating procedures and training procedures.
- ***Business & Commercial Aviation* Posters:** Four posters illustrate lessons learned about approach and landing accidents.
- ***CFIT Checklist:*** Guidelines in several different languages for assessing risk in specific flight operations and for increasing pilot awareness of factors that contribute to CFIT.
- ***CFIT Alert:*** Procedure for immediate response to a warning from a ground proximity warning system (GPWS) or a terrain awareness and warning system (TAWS).
- ***Flight Operations and Training:*** A presentation of data, procedures, and recommendations for aircraft operators and pilots. Speaker's notes included.
- ***Equipment for Aircraft and Air Traffic Control:*** A presentation of equipment and methods for optimum use of existing equipment. Speaker's notes included.
- ***Air Traffic Control:*** A presentation about improving pilot-controller communication and understanding of each other's operating environments. Speaker's notes included.
- ***Pilot Guide to Preventing CFIT:*** A presentation of CFIT accident data, lessons learned, and a review of approach obstruction-protection criteria.
- ***Approach and landing Accident Data Overview:*** A presentation of approach and landing accident data and lessons learned.
- ***An Approach and Landing Accident: It Could Happen to You:*** A 19-minute video presentation of the causes of approach and landing accidents and strategies for avoiding them.
- ***CFIT Awareness and Prevention:*** A 32-minute video presentation of several CFIT accidents and strategies by which they could have been avoided.
- ***Links to Aviation Statistics on the Internet:*** Aviation statistical data sources available on the Internet as of January 2001.

In 2000 a new group was formed and tasked with finding a way to implement the interventions of the ALAR effort. This group was known as the CFIT and ALA Action Group (CAAG). The CAAG was to utilize the lessons learned from the CFIT experience to more effectively implement the ALAR recommendations. The first goal the CAAG set was to conduct a regional ALAR implementation effort on a global basis. One of the keys to the regional implementation plan the CAAG proposed was the cre-

ALAR Tool Kit Workshops

Completed

Location	Host/Region	Date
Miami	PAAST/Latin America	Nov 2000
Mexico City	PAAST/Latin America	Jun 2001
Bangkok	AAPA/Asia-Pacific	Sept 2001
Nairobi	AFRASCO/Africa	Nov 2001
Johannesburg	SAA/South Africa	Nov 2001
Cairo	ICAO/AACO Middle East	Mar 2002
Reykjavik	Iceland FSF/Icelandair	May 2002
Perth/Melbourne	ASFA/ Australia	Sept 2002
Beijing	CAAC/China	Sept 2002
Dakar	ASECNA/IATA/ W. Africa	May 2003
Moscow	FSFI/Russia	July 2003
	Planned	
Brussels	Eurocontrol/ERA/Europe	Dec 2003

Figure 6

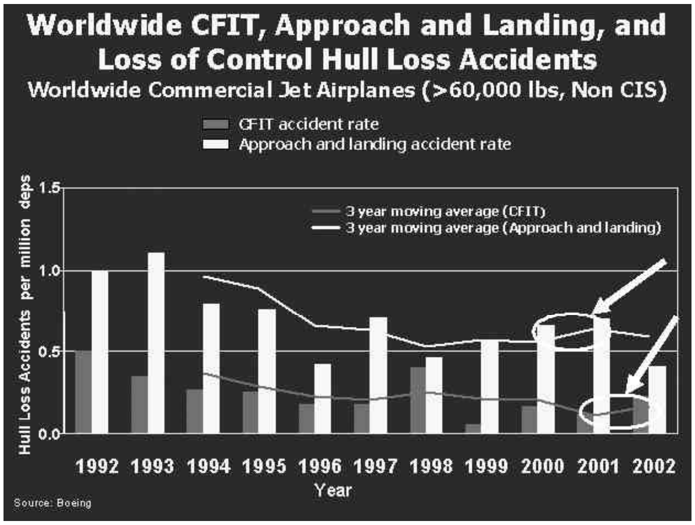


Figure 7

ation of the position of Regional Team Leader (RTL). This was to be an individual or organization that was a native speaker of the predominant language of the region, was active in the region's aviation community, and had contacts and creditability within the region. We wanted the RTLs to run the implementation of the ALAR interventions for their region. The RTLs would know who to go to, and what had to be done to make the plan work for their region. The second goal of the CAAG was to create a user friendly tool kit that would assist in implementing the interventions of the ALAR effort. The CAAG wanted the tool kit to address commercial, cargo, and corporate operators as well as ATC, regulators, and airports. These goals would enable the CAAG to implement the ALAR interventions globally on a regional basis with a focused, user friendly product.

The culmination of the CFIT/ALAR effort is the ALAR Tool Kit. This CD consolidates the data, products, findings, conclusions, and recommendations of 9 years of work by almost 300 aviation experts. The CAAG utilized lessons learned from the CFIT effort to produce this self-contained and ready-to-use product. The Tool Kit contains19 different elements, each designed to help prevent CFIT and ALA accidents. One of the primary elements of the Tool Kit is the briefing notes. There are 34 of these 3-7 page documents, each on a specific topic. Some sample briefing note topics include SOPs, managing interruptions/distractions, being prepared for a go-around, and energy management during approach. Each briefing note has statistical data to support it, a discussion section, a summary, and references. The references are not only listed by name, but by selecting a reference you get the entire reference document. There are more than 2,500 pages of reference material in the Tool Kit. In addition to the briefing notes, the Tool Kit also contains CFIT information (the CFIT checklist, a CFIT brief, and a CFIT video) and ALA information (several briefings, the ALAR risk assessment tool, and a video). All the briefings contained in the Tool Kit are PowerPoint briefings with speakers notes included. There are also ALAR posters, an SOP template, and the entire "Killers in Aviation" publication contained in the tool kit. Figure 5 gives a complete listing of the Tool Kit elements.

Of course the key to getting full benefit from the Tool Kit is the Regional Team Leader and the regional implementation plan. The job of the RTL is to ensure the information in the Tool Kit gets to every aviation organization (commercial, cargo, corporate operators, ATC, regulators, and airports) in the region. The CAAG supports the RTLs with workshops on the Tool Kit or any other requirements they may have. In addition, ICAO, IATA, IFALPA, ALPA, and IFATCA have all provided support in assisting the RTLs in implementing the ALAR interventions. The first regional effort was started in December 2000 in Latin America. The Regional Team Leader is the Pan American Aviation Safety Team (PAAST), which has done an impressive job. More than 15,000 pilots and 300 ATC controllers in Latin America have received ALAR training from the Tool Kit. In addition, a 4-hour ALAR course based on the Tool Kit is an annual requirement to renew your pilot license in Mexico. Of course, we know and expect each region will be different in its approach and planning for implementation, but that is the strength of the regional approach. Each region can tailor its program to ensure that implementation in the region is done most efficiently.

Figure 6 shows the completed and future ALAR regional workshops. These have been very successful in not only getting the ALAR message out, but also in establishing a safety network that can be used for other safety initiatives such as runway incursion. The ICAO 33rd Assembly reported that "the ALAR Tool Kit has been assessed as containing extremely valuable accident prevention material which will greatly assist accident programs.…" IATA and the U.S. CAST team have also endorsed the Tool Kit and encouraged its use. So with 11 ALAR workshops complete, more than 28,500 tool kits in circulation, and these impressive endorsements, things should look promising. However, here is a question for all safety professionals—Is anyone out there listening? One look at Figure 7 shows that things have not improved. In 2001 the ALA rate increased. In 2002, as you have seen, CFIT came back with a vengeance. None of the causes of any of these accidents were new, or were outside the scope of the ALAR Tool Kit—non-precision approaches, weather, non-radar environment, unstabilized approaches, lack of go-arounds, etc. This clearly shows that we must continue our efforts to disseminate, educate, and communicate the ALAR recommendations on a global level to hopefully reduce the risk of these killers in aviation. ◆

Flightdeck Image Recording on Commercial Aircraft

By Pippa Moore, CAA, UK

__Pippa Moore__ worked for GEC-Marconi Avionics prior to joining the UK CAA. While with this organization, she worked on a range of safety-critical flight control computers in both the military and civil fields. She has been an Avionic Systems Design Surveyor with the CAA for 7 years, working on civil aircraft certification projects as a CAA and JAA systems specialist. She is now a member of multinational JAA teams including the Boeing 737 and 767 and Airbus A330/340 and A380. She is currently Secretary of the Certification Authorities Software Team (CAST) and the JAA Flight Recorder Study Group.

Background/introduction

There have been a number of accidents where the accident investigation agencies have suspected that the causes stemmed from a series of human-factors-related incidents, but they have been unable to prove this from the flight recorder data currently available to them. As a result of this accident, investigators have postulated that flightdeck image recorders may provide useful information.

In contrast with this, flight crews have expressed the concern that flightdeck image recording would constitute a significant invasion of their privacy.

The purpose of this research project is to compare the data provided by flightdeck image recording against the data provided by FDRs and CVRs and determine what, if any, additional information is provided and whether the benefits associated with the additional information justify the potential invasion of flight crew privacy.

This research project has not yet been completed; however, this paper details the progress made to date. The conclusions contained within this paper may be supplemented by further conclusions as the research draws to a close.

Research principles

The research project was divided into several distinct stages as detailed below:

Stage 1

- Static simulator work with camera manufacturer and BALPA representative to determine
—appropriate camera locations for the trial.
—whether it is possible to use camera locations and angles to protect flight crew privacy.
- Draft a series of representative accident scenarios.

Stage 2

- Scenario evaluation meeting to determine
—whether the scenarios covered a broad enough range of accident types to avoid skewing the results of the trial.
—whether there were any health and safety issues related to the planned scenarios.
—whether is was possible to replicate the accident scenarios with the simulator equipment available.
—whether the proposed camera layout was appropriate for the planned scenarios.
—whether the proposed scenarios posed any additional unforeseen difficulties.

Stage 3

- Fly the agreed scenarios to provide voice parameter and image data for analysis by independent investigation agencies.

Stage 4

- Replay of the flight recorders. This occurred in three distinct parts as follows:
—Part 1: BFU analyzed the FDR and CVR data and submitted an interim report and BEA analysed the image recorder data and submitted an interim report.
—Part 2: On receipt of the two interim reports, the data packs were swapped.
—Part 3: BFU analyzed the image data and submitted a final report and BEA analyzed the FDR and CVR data and submitted a final report.

Note: Both investigation agencies were provided with the usual supporting data (e.g., radar plots, etc.) to support their analysis.

Stage 5

- Wash up meeting to
—present the analyses of the flight recorders and establish what information was gained from each and how it was gained.
—determine exactly how much additional information is gained from the image recording system.
—establish whether camera location can be used as a means of protecting pilot privacy without compromising the benefit to accident investigation.
—establish the limitations of the proposed system in both technical and political terms.
—establish the limitations of the trial's output.

Trial limitations known at the start

The following limitations of this trial were identified prior to commencing this research:

- Simulators are not capable of providing genuine light conditions and, therefore, the effects of changes in ambient light on a flightdeck image recorder cannot be established during this trial.
- The simulator provided cannot accurately represent parts of the aircraft becoming detached and so scenarios including events like this are not possible.
- The simulator provided is not equipped with a CVR. This

meant that a CVR would have to be temporarily installed, which may result in a non-standard equipment installation. It was not anticipated that this would have a significant effect on the outcome of the trial.

- The FDR data were not completely representative of normal FDR data in that they were sampled at a higher rate and were subject to the limitations of the simulator. This implied that some of the FDR data would not be entirely realistic.

Protection of flight crew privacy using camera location

Intrusion of pilot privacy has been a major issue in the debates around flightdeck image recording, particularly with respect to general flightdeck area views. Various solutions to this problem have been discussed, including data encryption and image distortion.

Although it was agreed that some form of data encryption may be useful, it was concluded that it was not a complete solution to the problem.

Discussions on image distortion concluded that this methodology could not be used, as it was not technically feasible to avoid accidentally distorting images of the flightdeck instruments while trying to distort the explicitly identifying images of the crew.

EUROCAE Working Group 50 agreed that in order to protect unnecessary invasions of privacy image recording systems should, where practicable, be developed to avoid recording images of the head and shoulders of the flight crew when seated in their normal flying positions.

Previous discussions on flightdeck image recording have assumed that a general flightdeck area view would be recorded using a single camera, probably located toward the rear of the flight deck. Although this method has been shown to provide a general view of the flight deck, it has also been shown to provide explicitly identifying images of the flight crew, thus limiting its acceptability as a solution. This research proposed that a general area view of the flight deck could equally be generated using two corner-located cameras instead of one centrally located camera.

It was further proposed that the cameras be located such that their viewing angle excluded the head and shoulders of the crew member they were directed towards (while in the normal seated position) while providing as great a general view of the flight deck as possible.

Once the images had been recorded, a post-processing exercise could then "stitch" the two sets of image data together, providing a view of the general flightdeck area that was equivalent to that which would be produced by a single, centrally located camera, without providing explicitly identifying images of the flight crew.

This dual-camera location was believed to make it easier to avoid identifying images of the crew as they moved around the flight deck. It was, however, accepted by all parties that if the crew were to look directly toward the camera, it would be impossible to avoid recording an explicitly identifying image.

It was agreed that this concept would be tested during the course of the "flight trials."

Progress to date

This research project has not yet been completed; however, the following progress has been made to date.

The accident scenarios have been drafted and flown and both BEA and BFU have evaluated all the data.

An initial "wash up" meeting was held to discuss the results; however, although that meeting did produce some useful results, it also highlighted the need to discuss some of the issues further.

This being so, this paper represents the current conclusions of the research. Although these are unlikely to change significantly, further conclusions may need to be added once the research is complete.

Work to be completed

The following tasks need to be completed before a final set of conclusions can be reached:

- Analysis of the issues raised in the initial wash-up meeting.
- Investigation of whether it would be practical to install a similar camera set up in real aircraft.
- Analysis of what specific considerations should be addressed to avoid mistaken conclusions based on insufficient analysis of image recording data.
- Completion of final, agreed research paper.

Note: This research is limited to determining whether an image recording system can provide additional information to accident investigators and so does not address the potential cost of installing this equipment. It is, however, noted that a cost-benefit analysis would be required before any final conclusions could be drawn about the installation of image recorders.

Initial research findings

Although the research project has not yet been completed, some initial conclusions have been drawn. These are discussed below.

Protection of flight crew privacy using camera location

The initial proposal put forward by this research was that a general area view of the flight deck could be obtained using two corner-located cameras. However, extensive experimenting during the static simulator trial revealed that four cameras provided adequate coverage of the flightdeck instruments and a general area view of the flight deck once their images were viewed next to each other. It was further shown that this combination of four cameras excluded images of the head and shoulders of the flight crew while they were seated in their normal positions. This addressed both the concerns raised by various pilot associations and the requirements of EUROCAE ED-112.

Despite this, the team working in the static simulator was concerned that there may be some accident scenarios that could be missed by this combination of camera views so a series of experiments were carried out to determine whether the cameras would provide images of the following types of incident:

- Aggressive intrusion in the flight deck (e.g., from a passenger/terrorist).
- Flightcrew members changing seats.
- Non-flightcrew members being invited to fly the aircraft.
- More than one person in any flightdeck seat.
- Inter-flight crew aggression.
- Physical incapacitation of the flight crew.

In all cases of aggression (including inter-flight crew aggression), the image recorder provided a clear view. This was largely because the camera angle was such that

- anyone attacking the flight crew from behind would be seen.

- if a member of the flight crew were to wield a weapon, either the weapon would be seen or the action itself would result in a sufficiently different pattern of behavior on behalf of the aggressor and their victim that it could be picked up by an image recorder.

The image recorder also provided clear views of anyone changing seats in the flight deck, and the camera angle was such that should the seat be occupied by more than one person that too would be visible.

The assessment of whether an image recorder could pick up information about physical incapacitation of the flight crew required the assessment of two different issues:

- A member of the flight crew becoming incapacitated and falling forward on to the stick.
- A member of the flight crew becoming incapacitated and falling backward in the seat.

In the first instance, the cameras provided a clear image of the flight crew because they had fallen forward from their normal seated position and into the view of the instrument panel.

The second case was not so clear-cut. Because the camera angles were designed to avoid identifying images of the flight crew while in their normal seated positions, it did not provide direct information about flight crew incapacitation. However, during the normal course of flying, the flight crew are seen to move their hands over the instruments, thus providing evidence that they are not physically incapacitated. The inference of this is that the absence of movement for a prolonged period (e.g., several minutes) would provide evidence to suggest the physical incapacitation of a member of the flight crew.

Note: This assessment was limited to physical incapacitation of the flight crew as image recorders are unlikely to be able to provide information on any other form of flight crew incapacitation.

Human factors and flight crew workload

It has been suggested that flightdeck image recording systems could provide invaluable data relating to a range of flight crew human factors issues, including some that result from high workload.

The analysis of this issue can be split in to two areas

- Flight crew human factors
- Flight crew workload

Flight crew human factors

The results of the analysis relating to the ability of flightdeck image recorders to provide information about flight crew human factors have, so far, been mixed.

It is true to say that, with the exception of the types of aggressive intrusion discussed above, flightdeck cameras will not be able to provide meaningful information relating to distraction of the flight crew by cabin crew or passengers. This is due to two factors:

- Flightdeck doors are now locked, which means that cabin crew interruptions are usually via some form of interphone system. As image recorder systems provide images not sound; this information would not be provided by an image recording system.
- Even if the cabin crew did enter the flight deck, flight crews are trained to keep looking forward to avoid losing situational awareness, and supposing they did look back, all an image recording system could show was that they had been disturbed. The absence of sound means that they would be unable to determine the scale of the interruption (e.g., the difference between "Would you like a cup of coffee sir" and "Captain, there is an uncontained fire in the rear galley and the passengers are panicking").

This research clearly shows that the most meaningful information relating to flight crew distraction comes from CVR systems. Although image recording systems would provide some information showing the crew's reaction to the disturbance (e.g., whether they turned to face the disturbance or consulted a checklist), the reason for their reaction can only be determined from a CVR.

Although image recorder systems have not been shown to provide useful information about distraction of the flight crew, it has shown that image recorders can provide two very important pieces of information that are unlikely to be provided by any other recording system. These are

- loss of flight crew displays that is not detected by the FDR.
- unsuccessful flight crew actions.

Loss of flight crew displays

It has been suggested that, where aircraft data are supplied via an electronic display, information that has been recorded on an FDR may not actually be displayed to the flight crew. This has been postulated as possible cause for inappropriate flight crew responses in a range of investigation reports.

The reason for this is that although FDR systems get their flight crew display data from the same source as the relevant electronic displays, the FDR usually gets the data first. If the data should be lost at a point after the FDR (e.g., through fire/electrical failure, etc.) or the displays themselves fail, the flight crew will never receive the information that has been recorded on the FDR, and, consequently, may not react the expected manner. It is also worth noting that FDR systems get raw, unsmoothed data while electronic displays are provided with smoothed data. This process of "smoothing" may also result in the flight crew being given different information to that which is recorded on the FDR.

This research has shown that image recorder systems can provide clear evidence of the failure of aircraft electronic displays. It has also been shown that the image recorder systems provide images of sufficient resolution to enable investigators to see both missing data and data fail flags. This implies that the use of flightdeck image recording systems could result in a reduction in the number of incident/accidents attributed to pilot error.

This research has also shown that image recording systems may provide some information as to whether the data displayed to the flight crew has been smoothed. However, the effectivity of image recording systems in this area will depend on the resolution of the images provided.

Unsuccessful flight crew actions

It was found that image recording systems can provide information about unsuccessful attempts to resolve problems. This is a potential use of image recorders that has not been discussed before.

FDRs and CVRs can only provide certain types of data. FDRs can only record system status (i.e., what was done and what was not done). They cannot provide information about actions that did not occur.

CVRs can only provide information on flight crew discussions and aircraft environmental noise. One of the major issues faced by accident investigators is that commercial flight crews are so highly trained that they frequently act in unison without the need for discussion. This can be particularly true when the flight crew workload is very high. A clear example of this occurred when the first officer's displays failed during one of the scenarios. Although the image recorder showed that this had happened, the flight crew did not discuss it at all.

This research showed that flight crews can sometimes attempt to solve a problem and fail to do so without any audible discussion. If their workload is particularly high they may well resort to visual communication (e.g., looking or pointing) rather than actually saying anything.

If there is no audible discussion relating to a failed attempt to solve a problem and the attempt does not result in a change in environmental noise, the CVR will not provide any information to supplement the lack of FDR information.

This absence of data could result in the flight crew being censored for not taking appropriate action when, in fact, they tried to take the appropriate action but were unable to do so.

Image recording systems have been shown to be capable of providing information about failed attempts to solve problems. This, again, could result in a reduction of the number of accidents/incidents that are attributed to pilot error.

Flight crew workload

The ability of image recorder systems to provide information relating to flight crew workload needs to be assessed in three ways:

- Cognitive versus manipulative workloads.
- Flight crew response to workload/stress.
- Accident investigator assessment of the flight crew reaction.

Cognitive versus manipulative tasks

In general terms, flight crews have two types of work, manipulative tasks and cognitive tasks. Manipulative tasks are physical actions performed by the flight crew, and cognitive tasks are mental, problem-solving activities.

In simplistic terms, the following statements are true:

- An excessive number of manipulative tasks, or a set of manipulative tasks that require great strength or dexterity, may make even a small number of the simplest cognitive tasks very difficult for a flight crew.
- An excessive number of cognitive tasks, or a set of particularly complex cognitive tasks, may make simple manipulative tasks very difficult.
- Either one of these combinations could result in an accident or incident.

Although image data could provide evidence of manipulative workload, it would be difficult to make any positive statements about cognitive workload.

It should also be noted that there are "gradients" of workload, and there may be situations where, due to fatigue or distraction, the crew are less able to combine cognitive and manipulative tasks than usual. This is something that would be almost impossible to determine from any flight recorder data.

Flight crew response to workload/stress

Although it is possible to determine that the flight crew are under stress from the CVR, it is not possible to determine the cause of the stress (i.e., the crew could be stressed due to workload, communication difficulties, simple concern about the situation they are in, system malfunctions, etc).

It has been suggested that the image data could provide further information about the possible causes of flight crew stress. However, this research has shown that the ability of an image recording system to provide this information is actually dependent upon the personalities of the flight crew concerned.

Image recorders can only record visual data and if the flight crew make no visual response that suggests that their workload is affecting their ability to manage the situation (e.g., facial expressions, obvious physical exertion, etc.), an image recorder cannot provide any information that indicates the effect of workload or stress.

Although excessive physical exertion should be apparent (see "Accident Investigator Assessment of Flight Crew Reaction" below), the personality of the individual flight crew members will determine whether they look or sound stressed.

Note: Type Ia or IVa flight data recorder installations will record input forces thus providing further indications of physical exertion.

Accident investigator assessment of flight crew reaction

This research also found that the ability of either a CVR or an image recording system to provide information about flight crew workload/stress depends upon how an investigator perceives the data.

Even if there is evidence that suggests high workloads or stress, if an investigator does not get the perception that the flight crew sound or look as if they are under pressure, this is unlikely to be reported as a contributory factor.

It is true that careful analysis of CVR data may provide further substantiating evidence of workload or stress (e.g., heart rate indications and breathing rates equating to physical stress); however, to obtain this information investigators would need to perform a very detailed analysis. If a preliminary investigation of either CVR or image data has led to the perception that the flight crew are coping, the human factors associated with accident investigation may result in an analysis that is not of sufficient depth to detect other indicators. This has led to the CAA conclusion that careful procedures need to be developed if image recorder data are to be useful to an accident investigation.

This implies that the accurate assessment of flightcrew workload, and the associated human factors issues, depends upon two other sets of human factors; flight crew personality and investigator perception. Given this fact, it is unlikely that either a CVR or an image recording system can be guaranteed to provide accurate and useful information relating to flightcrew workload.

Smoke in the flight deck

It has been suggested that flightdeck image recording would provide the ability to detect smoke in the flight deck.

This research determined that if the flight crew could see smoke, image recorder cameras would also be able to see smoke. It may not be immediately apparent that there is smoke in the flight deck (particularly if the smoke is not dense); however, if a flight crew sees smoke in the flight deck, their reaction will be to don smoke hoods, and it is reasonable to presume that investigators will look back through the image recording to determine the reason for this action. This being so, the CAA believes that image recording will enable investigators to discover the presence of any smoke that is visible to the flight crew.

There are, however, some caveats to this.

A flight crew may well don oxygen masks because they can smell smoke without actually being able to see smoke. The use of oxygen masks could equally imply a drop in cabin air pressure (if at high altitude). This means that crew action cannot be taken to provide definitive evidence of smoke, and investigators need to subject the image data to an appropriate level of investigation and to refer to other FDR data relating to altitude, etc., before drawing any conclusions.

As the presence of smoke should result in the flight crew donning smoke hoods, it would also result in a change of communication systems, which can readily be detected by a CVR. Although this may imply that the use of an image recorder is superfluous, the CAA considers that, at the very least, image recording systems could provide additional information about the reason for donning smoke hoods and, in the absence of an functional CVR, they could be the only source of information about smoke or fumes in the flight deck.

One further point that should be addressed is the ability of an image recorder system to provide a representative idea of the visibility the flight crew has of their environment when there is smoke in the flight deck.

If there is smoke in the flight deck, the flight crew will don oxygen masks. Although the oxygen masks will protect them from the worst physiological effects of the smoke, they will partly obscure their vision. Image recorder system cameras will not have this additional impedance to “vision.”

Inversely, it is also true to state that the flight crew will be closer to the instrument panel than the image recorder system cameras and, as such, have a better chance of seeing what is happening than the image recording system cameras.

These inverse facts lead to the inevitable conclusion that in the event of smoke, an image recorder’s view of the flight deck is not completely representative of the flight crew’s view.

Additional considerations

This research has identified a range of additional considerations that apply to the investigation of image recorder data. These include

- additional information required for image data analysis.
- the need for careful procedures related to image recorder analysis.

Additional information

Image data analysis requires some items of information that would not be required to analyze CVR or FDR data. These include a detailed knowledge of the flightdeck layout and knowledge of the flight crew personalities.

A detailed knowledge of the flightdeck layout is essential to enable accident investigators to successfully interpret flight crew actions and flightdeck alerts.

This information can be obtained from a range of sources including OEM technical manuals and the Internet, and the CAA believes that any procedures relating to the interpretation of image recorders should require that acquisition of this information prior to performing the investigation. It is also noted that the support of an appropriately type-rated pilot would be beneficial.

Knowledge of the flight crew personalities would assist investigators in their appraisal of flight crew reactions. However, accurate information on this subject would be very difficult to obtain, and since complete assessment of the flight crew reaction would need to account for the cognitive workload and the workload gradient (as discussed earlier), the CAA does not believe that the absence of this information would significantly affect the investigation of image recorder data in terms of the accuracy of the results. However, some knowledge of the personalities involved is deemed to provide a useful balance to purely technical information.

The need for careful procedures for image recorder analysis

The CAA has concluded that although all types of flight recorder data can be misinterpreted, the compelling nature of image data makes it more prone to precipitate judgement. This may lead to misinterpretation of the information provided and the absence of investigation into other causal factors.

As a result of this concern, the CAA has concluded that particular care should be taken with the analysis of image data to avoid mistaken conclusions.

The CAA has not completed its research into this issue but it is likely that, due to the occasionally ambiguous nature of image data, it will conclude that image recorders should not be used as the sole flight recorder for any aircraft.

Note: This concern is demonstrated by the presence of several factual errors in the analysis of image data. Examples of this include

- In one of the dynamic simulator trials an investigator concluded that the first officer’s instrument panel was blank before takeoff, whereas other information demonstrated that the instrument panel blanked 18 seconds after takeoff.
- In another of the dynamic simulator trials, the first officer was incorrectly identified as the handling pilot during takeoff.

Interim conclusions

As the CAA has yet to complete its research into this subject, no final conclusions can be drawn, however, the following statements can be made at this point.

It is possible to install image recording systems that provide general area views of the flight deck without the need for either explicitly identifying images of the flight crew or post processing.

Image recording systems can provide useful data that are not available from other flight recorder systems (e.g., loss of flight displays and failed flight crew attempts to solve problems).

They can also provide valuable confirmation of facts suggested by other recorders (e.g., smoke in the flight deck).

There are still, however, some types of events that image recorder systems can provide little information about (e.g., the reason for flight crew actions or reactions).

The CAA expects to finish their research by the end of the year and then a full report will be issued. ◆

Acknowledgements

The CAA would like to extend its grateful thanks to the following organizations for their assistance in this research:
BALPA
UK AAIB
BEA France
BFU Germany
AD Aerospace (for supplying, installing, and providing technical support for the image recorder system and cameras)
GECAT Training Facilities

Flightdeck Image Recording On Commercial Aircraft

By Mike Horne, Managing Director, AD Aerospace, Ltd., Manchester, UK

***Mike Horne**, Beng, Ceng, MIEE, is Managing Director of AD Aerospace Ltd. He graduated from the University of Bradford with an honors degree in electrical and electronic engineering, including a student apprenticeship with Marconi Avionics in 1983. He has worked extensively in video camera systems for a wide variety of purposes from missile guidance and fire control to pipe inspection and commercial security. His work has also included image intensifying and thermal imaging systems. In 1995 he joined the successful video security systems company Dedicated Microcomputers to form DM Aerospace, which later split off as the independent company, AD Aerospace, specializing in the design and manufacture of video systems for aerospace. During his time at the company, Horne has overseen the development of the first "digital video network server" compatible with aerospace requirements, which is now being offered to the world's airlines. From 1996 to 2002, he was an active member of the EUROCAE Working Group 50, and was secretary of the sub-group that wrote the Image Recording section of the final specification, ED-112. He is a Chartered Engineer and a full member of the Institution of Electrical Engineers.*

Introduction

The recent moves toward datalink systems, where air traffic control radio messages are being replaced with text uplinks, has made communication between aircraft and the ground more reliable and less subject to misinterpretation and error. However, the removal of the voice link also makes one of the most important tools of the air accident investigator, the cockpit voice recorder (CVR), which gives the accident investigator details about the cockpit environment, crew interaction, and the pressures that the flightdeck crew are under, almost redundant. Modern glass cockpits are now the primary flight displays on which the pilots rely; however, their displays are only graphical interpretations of the instruments that they have replaced, and any anomalies in the translation of electronic data to visual presentation can give the pilot incorrect information and lead to disaster.

Image recording

Accident Investigators have looked to video recording as a solution to getting extra data on the cockpit environment, and picking up datalink data, while for the first time showing just what the pilot actually sees, rather than the data that defines the instrument text.

The European Organization for Civil Aviation Equipment (EUROCAE) recognized in 1995 that modern video technology could meet this need and set up Working Group 50 (WG50) to report.

In 1996, EUROCAE WG50 was formed with the remit to address the requirements for the recording of datalink data. By meeting two, this had broadened to the consideration of image recording and to a general update of the current accident investigation recorder requirements.

EUROCAE WG50

The members of EUROCAE WG50 are voluntary and come from a balance of regulators, airline pilot unions, accident investigators, airlines, and avionics manufacturers. The members of the group came from the United States, UK, France, Germany, Canada, Sweden, and the Netherlands among others. Meetings were held three times per year, alternatively in North America and in Europe, as far and wide as London, Paris, Brussels, Ottawa, Annapolis, Sarasota, Memphis, Kiev, and Venice. Each meeting was hosted by a member of the group, either at their own premises or at nearby hotels. The meetings also covered tours of air traffic control facilities in the UK, ARINC facilities, and Kiev University. Over the 22 meetings and 7 years of the Working Group more than 150 people sat on the panel, with around 85 people attending more than three meetings and having their names recorded as authors of the final document.

ED-92 MASPS

Five years after the start of the Group the first document was published. This was a minimum aircraft system performance specification, or MASPS, which defined the "end to end" performance characteristic of the system. Work could then start on more detailed specifications. This work started with the accident investigators discussing and debating the "fundamental needs" of accident investigation recording, bearing in mind the sensitivities of the pilot community.

ED-111 MOPS

In 2002, ED-111 was published as a minimum operational performance Specification for the ground recording portion of the datalink recording system.

ED-112 MOPS

Finally, in March 2003 the final MOPS was published, defining the systems to be used on board the aircraft.

ED-112 Requirements of an Imaging System

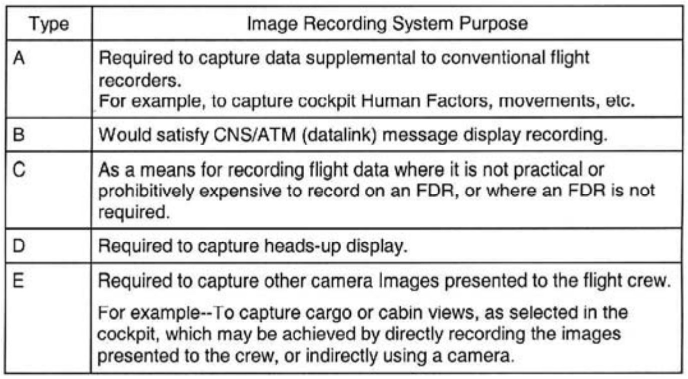
ED-112 details five separate requirements for imaging systems, which results in very different technical solutions.

a) General flightdeck area

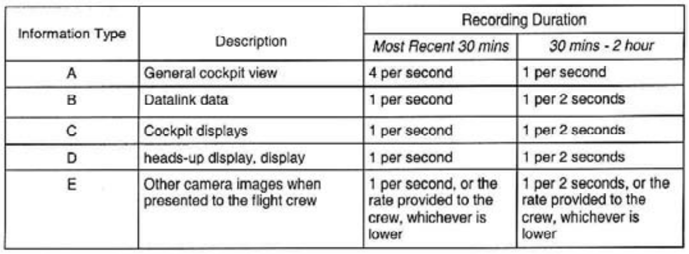
Coverage areas—All flight crew stations work areas including instruments and controls.

Purpose—To determine the following:

- Ambient conditions on the flight deck (smoke, fire, lighting, etc.).
- General crew activities such as use of checklists, charts, etc.,



Type	Image Recording System Purpose
A	Required to capture data supplemental to conventional flight recorders. For example, to capture cockpit Human Factors, movements, etc.
B	Would satisfy CNS/ATM (datalink) message display recording.
C	As a means for recording flight data where it is not practical or prohibitively expensive to record on an FDR, or where an FDR is not required.
D	Required to capture heads-up display.
E	Required to capture other camera Images presented to the flight crew. For example--To capture cargo or cabin views, as selected in the cockpit, which may be achieved by directly recording the images presented to the crew, or indirectly using a camera.



Information Type	Description	Recording Duration	
		Most Recent 30 mins	*30 mins - 2 hour*
A	General cockpit view	4 per second	1 per second
B	Datalink data	1 per second	1 per 2 seconds
C	Cockpit displays	1 per second	1 per 2 seconds
D	heads-up display, display	1 per second	1 per 2 seconds
E	Other camera images when presented to the flight crew	1 per second, or the rate provided to the crew, whichever is lower	1 per 2 seconds, or the rate provided to the crew, whichever is lower

and health and well-being of crew.

- Non-verbal communications (hand signals, pointing, etc.).
- Cockpit selections within crew reach while seated at duty station (switch/throttle/flight controls, etc.).

Resolution—Sufficient to determine status of instrument displays and ambient conditions.

Frame recording rate—Sufficient to determine significant crew actions.

Color—Required.

b) Instruments and control panels

Coverage areas—Forward instrument panel, overhead panel, center pedestal, and video displays presented to the crew (where installed).

Purpose—To determine the following:

- Information (including crew selections) not explicitly recorded on the flight data recorder.
- Status of instrument displays and display modes (blank screen, partial display, automatic display mode changes, etc.).

Resolution—Sufficient to

- Determine instrument display status and operational mode of the displays.
- Determine parameter values whose recording requirements can only be met by image recording.

Frame recording rate—As shown in table above.

Color—Required.

The general flightdeck area requirement is for a wide-angle view, covering the flightdeck crew. The instrument panel requirement is for a high-resolution camera specification, directed solely at the flightdeck instrument panel.

General requirements of an airborne camera system

To withstand the harsh aerospace environment, all components need to be designed and manufactured specifically for use in that environment. Taking standard off-the-shelf cameras and recorders designed for the office environment and using them in the air, while economically attractive, will result in early problems and many failures. Specifically, cameras need to be small, light, and reliable using solid-state electronic shuttered light control. They need to take into account the following, which leads to a highly specialized video solution.

Within an aircraft environment, the light range is very wide, even within a single picture, with the brightest scenes, above the clouds, for instance, being up to 100,000 times brighter than in a dimmed passenger cabin. For the camera designer, this leads to either a mechanically driven iris or to a wide-ranging electronic light control system.

The exterior of an aircraft in flight can be down to –60 degrees Celsius, and just as importantly the interior of an aircraft left parked on an apron can drop far below zero. Any moving parts will be subject to a great deal of stress and wear, which really leads to a purely electronic solution, using no moving parts, and therefore inevitably to electronic shuttering.

With the intense radiation of the sun during a flight, or within a constrained avionics bay in an aircraft parked in the desert, temperatures can rise to well over 50 degrees Celsius. Heating effects within a camera can lead to "thermal noise" being injected into the picture, which leads to a deteriorating picture, and loss of resolution.

Standard CCTV video cameras "scan" at a field rate of 60Hz. When used to view instruments, this can lead to "beating effects" caused by the scan rate of the tube or LCD display being similar, but out of phase, with the camera scan rate. Even more off-putting can be a variable scan rate like those used in radar displays, which can lead to a whole range of different beating effects depending on the phase difference between the signals.

CAA trial

In 2002, the CAA approached AD Aerospace for assistance with a trial that it was setting up at the GEC Capital Aviation Training (GCAT) 737-300 simulator section in Gatwick.

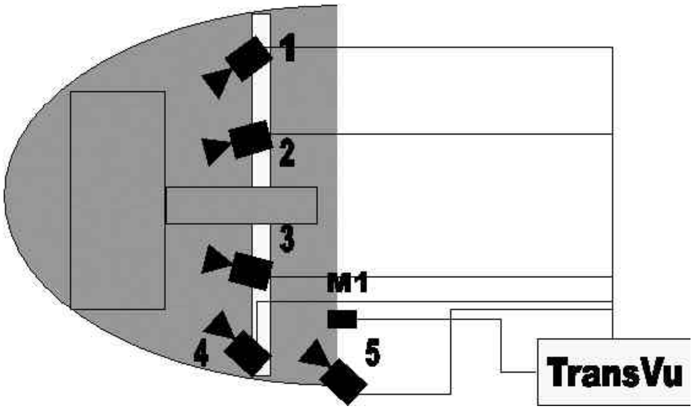
AD Aerospace was to design and supply the video camera and recording system, to be as far as was practical in line with the ED-112 specification.

A "set up" day was held in August 2002, when equipment and angles were tried out. It was decided that, in order to meet the instrument panel recording requirements of ED-112 set out above, a system of four standard resolution (600 pixel horizontal) CCTV cameras could be used, with either 6 mm or 8 mm lenses. The alternative to this, which would probably be adopted in practice, would be to use one very-high resolution camera with a stabilized lens to replace the multiple standard cameras. This would be a highly specialized piece of equipment, and is certainly not readily available for a trial of this kind.

The four cameras were suspended from an aluminum bar, which was screwed onto the overhead instrument panel, just above and behind the pilots' heads.

Cameras from the extreme right and left of the bar were angled to view across the instrument panel and onto the primary flight displays (PFDs) of the pilot on the opposite side of the aircraft. In this way a clear view of the PFDs could be seen, without giving a "recognizable view of the pilots," as was required by the ED-112 specification.

The two central cameras were angled to cover the central console and the middle section of the instrument panel, covering the engine instruments and autopilot controls.



1 8 mm lens pilot main displays
2 6 mm lens engine instruments
3 6 mm lens throttles and center panel
4 8 mm lens copilot main displays
5 3.5 mm lens cockpit general view

All Cameras WATEC 201 PAL standard, color, approx. 350 TV lines horizontal resolution. Cameras mounted on a bar, just behind and above the pilot position.

One further wide-angle camera was installed, to give an overall view of the flightdeck environment.

The cameras, plus a small microphone, were recorded using an AD Holdings "TransVu" digital recorder, using modified JPEG compression to record the video and audio on a hard disk drive. The recording rate was set to be around four frames per channel per second, with a target resolution of 640 x 256, and a target frame size of 30 kB. This is more or less in line with the ED-112 specification.

Conclusions

Following the trial, several lessons were learned.

a) We underestimated the vibration levels that occurred during the trial. An actual installation would, of course, be hard mounted; however, there was noticeable movement in the "aluminum bar" arrangement, which led to some difficulties in the interpretation of the resulting pictures.

b) We expected to see distracting "beating effects" when viewing scanned LCD and tube displays. While the effects were certainly there, there did not seem to be any problems caused by this in the interpretation of the results.

c) While we set up the cameras in good lighting conditions, the low light levels imposed by the simulator operating conditions caused several problems, including "blooming" of lighted instruments, which in some cases made the instruments quite unreadable. In other cases, lack of lighting, and the subsequent loss of signal to noise ratio in the video picture caused the data (readable in daylight) to be lost.

d) One of the most interesting conclusions was the depth of knowledge of the cockpit layout that was required from the accident investigators. In several instances the investigators could not locate, or distinguish, the readings of the instruments on the flightdeck, while qualified pilots had no problem in identifying indicators, switch positions, and reading pointers on gauges. It is certainly true that a similar amount of training was necessary in the early days of CVR and FDR and this finding, while interesting in itself, should not be surprising.

Summary

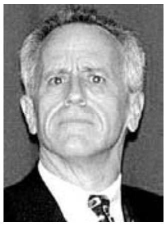
The trials carried out by the United Kingdom CAA and AD Aerospace in late 2002 showed that the image recording system envisaged by ED-112 would be a useful additional tool to the accident investigator. This trial should be seen as part of ongoing work, and further trials should not be ruled out.

While not giving the full solution to the accident scenarios presented, there were several factors that were only picked up by the image system. This was the same conclusion as with the CVR and the FDR analyses.

Throughout this trial, it was apparent that the complete picture of an accident or incident can only be built up using data, voice, and image recording, and that any single recording could lead to erroneous conclusions. ◆

An Analysis of the Relationship Of Finding-Cause-Recommendation From Selected Recent NTSB Aircraft Accident Reports

By Michael Huhn (MO3689), Senior Safety Investigator, Air Line Pilots Association, International. This paper was presented by Chris Baum, Manager of ALPA's Engineering and Accident Investigation Department.



***Michael Huhn** is the Senior Safety Investigator of the Engineering and Air Safety staff at the Air Line Pilots Association, International. He has a B.S. in aeronautical engineering and came to ALPA in 1994 after 16 years at various aerospace companies, including Douglas Aircraft, Rockwell, Northrop, and Fairchild. His primary background is aircraft performance and flight test, but he also has nearly 4 years of design and manufacturing experience. He attended the USC Aircraft Accident Investigation School, holds a private pilot certificate with an instrument rating, and is a licensed A&P mechanic. In addition, he has participated in a number of accident investigations, including Air Midwest 5481, Emery 17, Swissair 111 and TWA 800.*

Abstract

Note: This paper reflects the personal views of the author and is not intended to represent any official positions or opinions of the Air Line Pilots Association, International.

The intent of this study was to evaluate a selected group of recent National Transportation Safety Board (NTSB) aircraft accident reports in an effort to determine the quality of the reports, and, by inference, the quality of the investigations. This study examined the NTSB accident reports ("Blue Covers") from two accidents each year during the period from 1990 to 1997. The basic methodology consisted of examining the quantities of and correlations between each report's findings, causes, and safety recommendations. The data were compiled, analyzed, and summarized, and conclusions and recommendations were drawn regarding these results.

This study shows that the NTSB accident reports infrequently exhibit strong correlation between their findings, causes, and recommendations. Since the report is an integral part of the accident investigation process, these results indicate that this is an area for potential improvement in the NTSB's accident investigation process.

Introduction

The purpose of an aircraft accident investigation is to prevent recurrences through the development of viable and effective safety recommendations. In the same sense that analysis of an accident affords the opportunity to improve design and operations, analysis of accident reports affords the opportunity to improve the accident investigation process. In the United States, the National Transportation Safety Board ("NTSB" or "Board") is the agency charged with conducting and reporting on the investigations of major civil airline accidents. Normally, the Board's safety recommendations are issued in its final report on each accident. While there is no doubt that the U.S. air transportation system is extremely safe, can one necessarily infer from that that the quality of NTSB investigations is commensurate with the expense and effort put into them? Using the premise that the quality of the final report is one means to evaluate the quality and effectiveness of the investigation, this paper examined a selected group of recent National Transportation Safety Board aircraft accident reports in an attempt to develop a general assessment of their quality, and, by inference, the quality of the investigations.

The underlying concept in this effort is that a high-quality accident report will exhibit a strong correlation between its findings, causes, and recommendations. In other words, the recommendations should be directly related to and substantiated by the facts, conditions, and circumstances of the accident. Chapter 38 of Wood and Sweginnis (1995) provides the rationale for this concept, and a means of determining how well it has been embodied by the report. In this chapter, they discuss the "F.A.C." method of treating topics of discussion. These letters stand for fact, analysis and conclusion, respectively, and the method advocates a logical, building-block approach to developing the arguments in the accident report. Sub-chapter 5 is entitled "Report Quality Control," and this section utilizes and expands on the F.A.C. concept as a means to ensure that the accident report flows logically and contains the appropriate information and discussions. Wood and Sweginnis state that if the report is constructed properly and in this F.A.C. manner, the analysis should lead directly to, as well as substantiate, the conclusions. Similarly, the conclusions should lead directly to, as well as substantiate, the safety recommendations. Finally, as a means of auditing the report, the authors suggest reviewing the report backwards to ensure that the recommendations are supported by the conclusions, the conclusions by the analysis, and so on.

If the above-described relationships are prevalent in the accident report, one can conclude that these results are a strong indication of robust investigative and analytical processes, and could only have been the product of a high-quality accident investigation. This study utilized the method described by Wood and Sweginnis as the primary means of determining the quality of the subject NTSB accident reports, and both quantitative and qualitative methods were used in this analysis. This paper includes detailed discussions of the methods (including limitations), conclusions, and recommendations of this study, as well as a comparison with some results from the RAND Corporation's recent study of the NTSB.

Methodology

Selection of study accidents

The selection of the final subject accident reports was a multiple-step process. Since one goal of this study was to assess the quality of the accident investigations, it was decided to limit the scope to investigations that utilized large amounts of NTSB's personnel, time and financial resources. Typically, but not always, these are the "Major Investigations," which initially involve a significant manpower response by personnel from NTSB headquarters in Washington, D.C. However, while some NTSB regional office investigations initially involve only a limited number of NTSB personnel, the follow-on investigative activities sometimes expand to the point where they command significant NTSB resources, and a few of these accidents have been included in the final selection. In summary, the initial qualifier for inclusion of an accident in this study was that the investigation resulted in a full NTSB aircraft accident report, which is known throughout industry as the "Blue Cover." The other parameters used to initially limit the scope of accidents for this study were as follows:

- Date of Accident: Accident occurred between 1990 and 1997
- Type of Operation: Limited to FAR Part 135 or 121 operations

It should be noted that the type of aircraft and whether or not fatalities resulted were not explicit factors in the initial or final selection process.

The preliminary selection process yielded a group of 44 candidate accidents. Since it was recognized that the critical and thorough analysis of such a large group of reports was beyond the resource constraints of this author, it was decided to limit the study to two accidents from each year of the original scope. In order to select these final accidents, certain defining characteristics of each accident and corresponding report were tabulated. This original tabulation appears in Appendix 1. An explanation of the column headers and the data is also included in Appendix 1.

Inspection of the data in the "ACCIDENT CATEGORY" column of the tabulation in Appendix 1 reveals a significant number of repeat accident types, and it was decided that there might be some additional benefit in possibly comparing the NTSB results from these repeat accidents types over the period in question. Using this criterion, the study scope was reduced to 16 accidents. These 16 accidents included five runway collisions, four controlled flight into terrain (CFIT), three uncontrolled flight into terrain (UC FIT), one inflight fire, and three icing events. These final 16 accidents, along with their previously tabulated characteristics, are presented in Table 1.

Preliminary data analysis

In all cases, the findings, causes, and recommendations analyzed by this study *only* include those explicitly listed in the "Conclusions" section of each NTSB report. Although many findings may appear in the text of the NTSB reports and yet not be explicitly enumerated as formal findings, no attempt was made during this study to identify or quantify those findings. While it is recognized that accounting for these discrepancies would provide another metric for judging the quality of the NTSB reports, the workload associated with this was beyond the resources of the author.

While most of the information in Accident Summaries (Table 1 and Appendix 1) is objective data, there is one significant exception. The quantities of the findings of safety deficiencies (column "FNDNG DEF") are necessarily subjective, because unlike several non-U.S. transportation safety agencies, the NTSB does not explicitly categorize or even always state its findings as safety deficiencies. Therefore, some judgment by the author was necessary to determine which findings represented safety deficiencies. Generally speaking, a finding that addresses an intentional or "manmade" event, and that seems to be correctable, was considered to be a finding of a safety deficiency. As an example, the hypothetical finding of "The thunderstorm produced a strong microburst that resulted in significant low-level windshear" would not be categorized as a finding of a safety deficiency, but a finding of "Presence of the microburst-induced windshear was not relayed to the flight crew" would qualify as a safety deficiency.

Primary data analysis

Once the final accidents were selected, the quantitative and qualitative analyses were conducted. Initial quantitative analysis consisted of computing a number of derived values from the raw data. These derived values include the duration of the investigation, the percentage of findings of safety deficiencies to total findings, and similar calculated values. These derived values are presented in the tables in this paper.

The qualitative analysis consisted of the effort to determine the specific relationships existing between each accident report's findings, causes, and safety recommendations. For each accident, two two-dimensional matrices (tables) were created. Each large matrix lists all the findings and safety recommendations by number as they appear in the NTSB accident report. The Findings are listed across the top row of the matrix, and findings of safety deficiencies (as determined by the author) are denoted by bold outline boxes. The safety recommendations are listed in the left-most column of the matrix. For each accident, any correspondence between each individual finding and safety recommendation was determined, and this correspondence is noted by a "1" in the respective matrix. Safety recommendations that do not have corresponding Findings are denoted by horizontal lines in the boxes. Similarly, findings of safety deficiencies that do not have corresponding safety recommendations are denoted by diagonal lines in the boxes. These matrices of the raw data correlation are presented in Appendix 2.

Also for each accident, a much smaller matrix correlates the probable and contributing causes with both the findings and safety recommendations. In this case, the goal was to determine whether each probable and contributing cause was supported by a finding, and whether each probable and contributing cause resulted in a safety recommendation. In this matrix, a "1" denotes the defined relationship, and a "0" denotes a lack of that defined relationship. These raw data matrices are presented in Appendix 3.

Analysis results

NTSB findings

The first step in the primary analysis consisted of summarizing the NTSB findings from the 16 subject accident reports. These 16 reports contained a total of 401 findings (refer to Table 2). The ValuJet 592 report had the most findings (47), while the

Eastern 111 report had the least (12). The average number of findings was 25, but the standard deviation of 11 indicates that the number of findings for each accident was widely scattered.

Examination of the findings of safety deficiencies shows a similar distribution. In this case the author identified a total of 215 findings of safety deficiencies. Again ValuJet 592 had the most (27), but the Eastern 111 report (7) was edged out by the TWA 427 report for the least (6). The average number of findings of safety deficiencies was 13, and again the standard deviation (6) was approximately half of the average, indicative of a widely scattered distribution. However, when the findings of safety deficiencies are presented as a percentage of the total findings, the results are much more consistent. Ranging between a high of 78 percent and a low of 38 percent, an average of 54 percent of the total findings were findings of safety deficiencies and yielded a standard deviation of only 10 percent.

Correlation of findings of safety deficiencies and safety recommendations

This analysis is considered to be the most important part of the study, since it quantifies how many of the identified safety deficiencies were addressed by safety recommendations. Ideally, a one-to-one (or better) correspondence between safety deficiencies and safety recommendations would be expected from a high-quality accident investigation and report. Such ideal correlation was not observed, and the results displayed very wide scatter. The tabulations of this correlation are presented in Table 3.

As noted previously, the number of findings of safety deficiencies ranged from a high of 20 (VJ 592) to a low of six (TWA 427). Twenty of these 27 VJ 592 Findings were addressed by safety recommendations, for a correlation value (“hit ratio”) of 74 percent. However, although VJ 592 had the highest absolute number of “hits,” this ratio was significantly bettered by the CMR 3272 hit ratio of 93 percent. At the extreme opposite end of this scale was the AIA 808 accident, which yielded eight findings of safety deficiencies, and no corresponding safety recommendations.

The average hit ratio for the study accidents was 54 percent, and the standard deviation was 24 percent. In simple terms, based on these results, this means that approximately only half of the identified safety deficiencies in any given accident will even be addressed by a corresponding safety recommendation. The large standard deviation indicates that the NTSB investigative and reporting process does not ensure high correlation between the safety deficiencies that it identifies and the safety recommendations that it issues. This observation is echoed in the RAND report (Lebow, C., et al, p. 41), which noted, “The preparation of recommendations could also be more consistent.”

Correlation of causes supported by findings or addressed by recommendations

Perhaps stated best by the RAND report (Lebow, C., et al, p. 42) are the following remarks regarding the probable cause: “The most controversial result of the NTSB’s investigation process is the statement of probable cause….This statement reflects the cumulative fact-finding and analysis of the NTSB investigative process. However, probable cause reverberates far beyond the halls of the NTSB. In terms of the assignment of fault and blame for a major aviation accident, by the media or in a legal proceeding, the NTSB’s probable cause finding is the “ball game.”

However, most safety professionals agree that the NTSB’s continued practice (which is legislated by Congress) of issuing “probable causes” draws the focus from the real safety issues, and in fact, it is counterproductive. C.O. Miller (Weir, 1999, p. 227) notes that “…causes are merely convenient cubby holes…. Further analysis is needed to identify the most practical remedial actions.” In the same book, Ira Rimson is quoted stating, “Assigning causes is passive…. Preventing recurrence requires action.”

A review of Table 4 shows that the NTSB does a thorough job of ensuring that the probable and contributing causes are substantiated in its findings. An average of 97 percent of the probable causes and 93 percent of the contributing causes are supported by NTSB findings. However, when the correlation between causes and safety recommendations (Table 5) is examined, the continuity has diminished significantly. Only 76 percent of the probable causes and 63 percent of the contributing causes are addressed by formal NTSB safety recommendations.

Additional observations

This section briefly discusses several observations that were made during the gathering and analysis of the subject NTSB information, but which fell outside the stated scope of the analysis process being employed. These observations provide several qualitative examples of some of the variations present in the individual NTSB reports. While these variations made the analysis slightly more difficult and slightly less rigid, the author does not believe that meticulously accounting for these items would significantly alter the quantitative analytic results of this study. Nevertheless, they have been included here because they do provide some additional insights into the overall quality and consistency of the NTSB accident reports.

Multiple findings listed as a single finding

Some findings listed by individual numbers in the NTSB report actually contained multiple findings. Most frequently these seemed to be statements of cause and effect, but occasionally two separate, unrelated findings were listed as a single finding in an accident report.
Example: NTSB finding number 19 from the USAir Flight 1493 accident states, “The propagation of the fire…was accelerated by the release of oxygen from the flightcrew oxygen system that was damaged in the initial collision…. The accelerated fire significantly reduced the time available for a successful emergency evacuation.”

Conditional findings

Some findings were of a conditional nature, frequently beginning with the words “if” or “had.” Most commonly, these conditional findings were also of a cause-and-effect nature, and typically referred to equipment not installed or procedures not followed.
Example: NTSB finding number 11 from the TWA Flight 427 accident begins with “Had the Cessna 441 pilot volunteered….”

Findings in the form of recommendations

Several NTSB reports contained findings that were stated as suggestions or imperatives. These findings were not worded consistently with the wording of the bulk of the NTSB’s findings, and usually contained the word “should” or the phrase “it is essential.” In essence, these findings were safety recommendations. On a positive note, such findings almost always also appeared as formal NTSB safety recommendations.
Example: NTSB finding number 23 from the Atlantic Southeast

Flight 529 accident states, “There should be standards governing the design of crash axes required to be carried aboard passenger-carrying aircraft.”

Conclusions

This study shows that the NTSB accident reports infrequently exhibit strong correlation between their findings, causes, and recommendations. Furthermore, the reports included in the study exhibited a relatively large degree of inconsistency, both within each report, as well as across all the reports. While these results indicate that the NTSB investigative and reporting process does not ensure high correlation between the safety deficiencies that it identifies and the safety recommendations that it issues, the study did not attempt to determine the underlying reasons for these results.

Unless the NTSB has significantly changed the way it develops and writes its accident reports since the study period, approximately only half of the identified safety deficiencies in any given accident will likely even be addressed by a corresponding safety recommendation. Since the report is an integral part of the accident investigation process, these results indicate that this is an area for potential improvement in the NTSB’s accident investigation process.

Recommendations

The NTSB should evaluate, and modify as necessary, the accident investigation, analysis, and safety recommendation process to ensure that the results comply with the following guidelines:

- Identify all contributing and ancillary safety deficiencies.
- Develop one or more safety recommendations for each identified causal or ancillary safety deficiency.
- Ensure that each safety recommendation is substantiated by an identified causal or ancillary safety deficiency.

The NTSB should evaluate, and modify as necessary, the accident report writing and review process to ensure that the reports comply with the following guidelines:

- Structure findings so that they are clear declarative statements, and not either conditional or imperative in nature.
- Establish a separate category for findings of safety deficiencies.
- Sequence findings in as close to chronological order as possible.
- Ensure that probable and contributing causes are substantiated by findings and also addressed by safety recommendations (or some other means of remedial action).

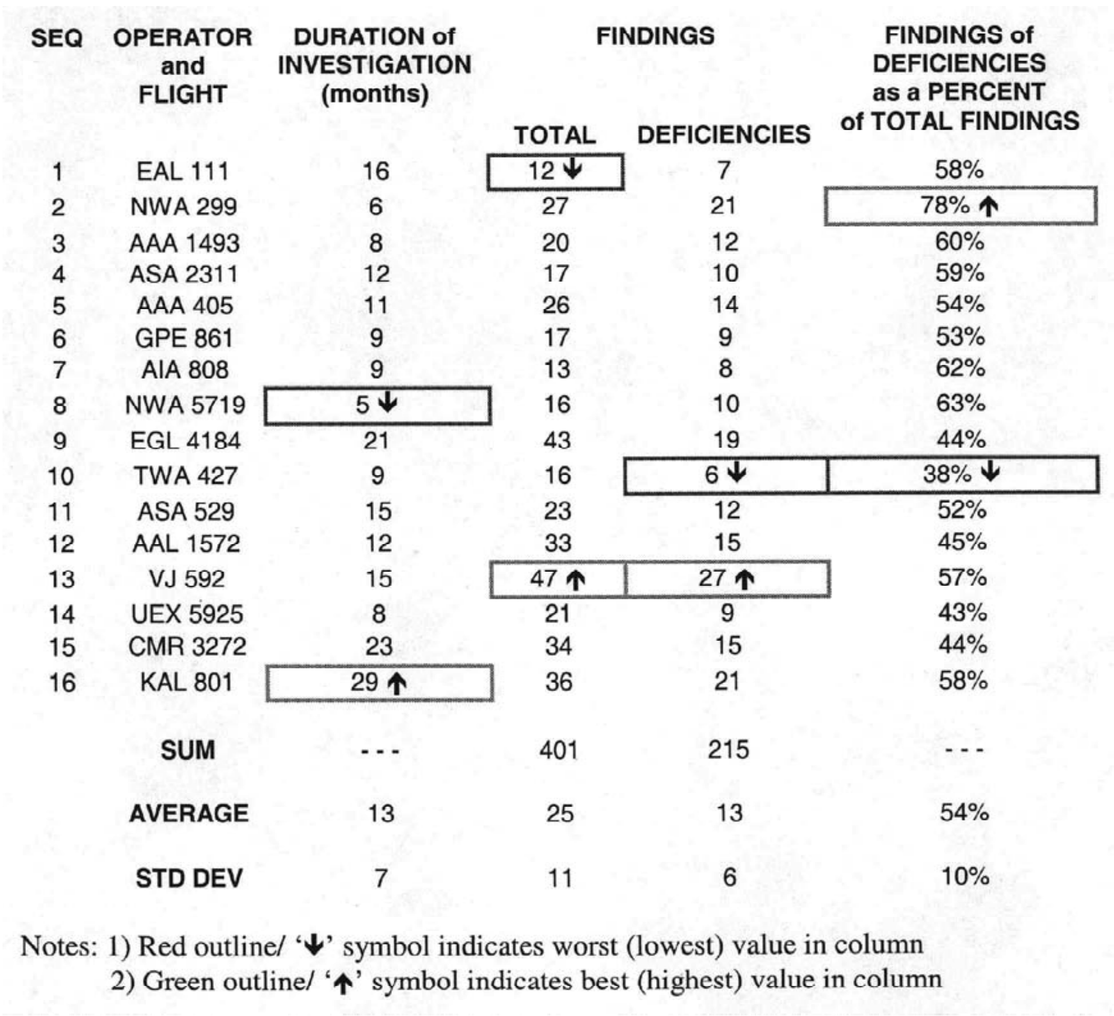
The NTSB should engage the participation of industry to encourage the U.S. Congress to modify the NTSB legislation with the aim of removing the mandate for finding of Probable Cause. ◆

TABLE 1: FINAL LIST OF STUDY ACCIDENTS

SEQ	OPERATOR FLIGHT	ACCIDENT CATEGORY	TYPE A/C	LOC	FAR	MODE	DATE AX	DATE RPT	# FATAL	FNDNG TTL	FNDNG DEF	CAUSE PROB	CAUSE CONTR	RECS TTL
1	EAL 111	Rwy Collision	B727	ATL	121	Pax	1/18/90	5/29/91	1	12	7	2	2	5
2	NWA 299	Rwy Collision	B727 DC-9	DTW	121	Pax	12/3/90	6/25/91	12	27	21	2	5	16
3	AAA 1493	Rwy Collision	B737	LAX	121	Pax	2/1/91	10/22/91	34	20	12	3	1	17
4	ASA 2311	UC FIT Mech	EMB-120	Brunswick	135	Pax	4/5/91	4/28/92	23	17	10	1	2	6
5	AAA 405	Icing T/O	F-28	LGA	121	Pax	3/22/92	2/17/93	27	26	14	2	2	16
6	GPE 861	CFIT	B-99	ANN	135	Pax	6/8/92	3/2/93	4	17	9	1	4	5
7	AIA 808	UC FIT	DC-8	Cuba	121	Cargo	8/18/93	5/10/94	0	13	8	4	5	6
8	NWA 5719	CFIT	J-31	Hibbing	135	Pax	12/1/93	5/24/94	18	16	10	3	3	5
9	EGL 4184	Icing LOC	ATR-72	IND	121	Pax	10/31/94	7/9/96	68	43	19	3	2	35
10	TWA 427	Rwy Collision	MD-80	STL	121	Pax	11/22/94	8/30/95	2	16	6	2	2	12
11	ASA 529	UC FIT Mech	EMB-120	Carrollton	135	Pax	8/21/95	11/26/96	8	23	12	2	3	8
12	AAL 1572	CFIT	MD-80	BDL	121	Pax	11/12/95	11/13/96	0	33	15	1	2	13
13	VJ 592	Inflt Fire	DC-9	MIA	121	Pax	5/11/96	8/19/97	110	47	27	3	3	27
14	UEX 5925	Rwy Collision	B-1900	Quincy	135	Pax	11/19/96	7/1/97	14	21	9	2	3	7
15	CMR 3272	Icing LOC	EMB-120	Monroe MI	135	Pax	1/9/97	12/4/98	29	34	15	3	2	21
16	KAL 801	CFIT	B747	GUM	121	Pax	8/6/97	1/13/00	228	36	21	2	4	15

Note: See Appendix 1 for key to columns

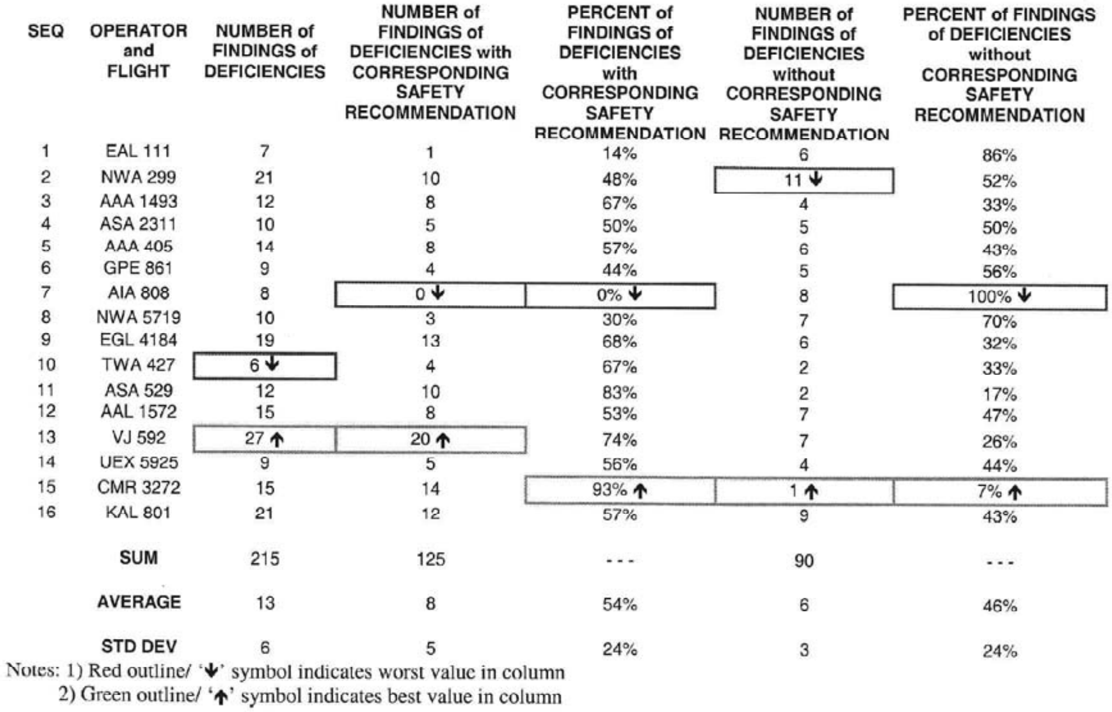
TABLE 2: SUMMARY OF FINDINGS



SEQ	OPERATOR and FLIGHT	DURATION of INVESTIGATION (months)	FINDINGS TOTAL	FINDINGS DEFICIENCIES	FINDINGS of DEFICIENCIES as a PERCENT of TOTAL FINDINGS
1	EAL 111	16	12 ↓	7	58%
2	NWA 299	6	27	21	78% ↑
3	AAA 1493	8	20	12	60%
4	ASA 2311	12	17	10	59%
5	AAA 405	11	26	14	54%
6	GPE 861	9	17	9	53%
7	AIA 808	9	13	8	62%
8	NWA 5719	5 ↓	16	10	63%
9	EGL 4184	21	43	19	44%
10	TWA 427	9	16	6 ↓	38% ↓
11	ASA 529	15	23	12	52%
12	AAL 1572	12	33	15	45%
13	VJ 592	15	47 ↑	27 ↑	57%
14	UEX 5925	8	21	9	43%
15	CMR 3272	23	34	15	44%
16	KAL 801	29 ↑	36	21	58%
	SUM	- - -	401	215	- - -
	AVERAGE	13	25	13	54%
	STD DEV	7	11	6	10%

Notes: 1) Red outline/ '↓' symbol indicates worst (lowest) value in column
2) Green outline/ '↑' symbol indicates best (highest) value in column

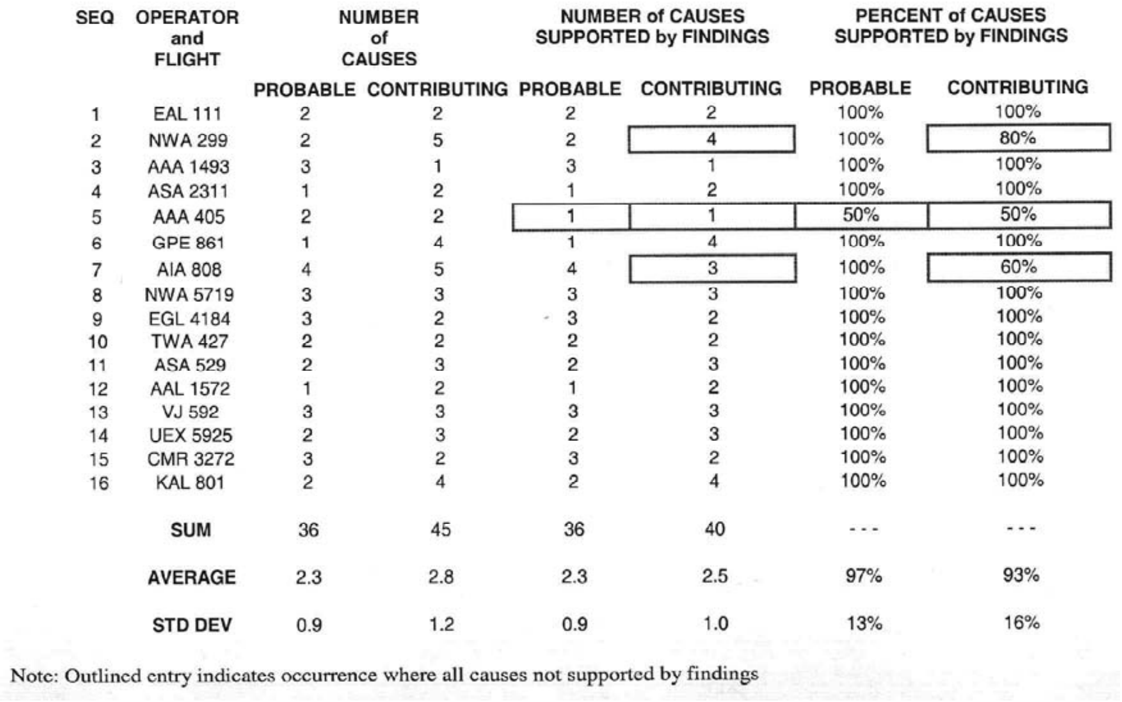
TABLE 3: CORRELATION OF FINDINGS OF DEFICIENCIES WITH SAFETY RECOMMENDATIONS



SEQ	OPERATOR and FLIGHT	NUMBER of FINDINGS of DEFICIENCIES	NUMBER of FINDINGS of DEFICIENCIES with CORRESPONDING SAFETY RECOMMENDATION	PERCENT of FINDINGS of DEFICIENCIES with CORRESPONDING SAFETY RECOMMENDATION	NUMBER of FINDINGS of DEFICIENCIES without CORRESPONDING SAFETY RECOMMENDATION	PERCENT of FINDINGS of DEFICIENCIES without CORRESPONDING SAFETY RECOMMENDATION
1	EAL 111	7	1	14%	6	86%
2	NWA 299	21	10	48%	11 ↓	52%
3	AAA 1493	12	8	67%	4	33%
4	ASA 2311	10	5	50%	5	50%
5	AAA 405	14	8	57%	6	43%
6	GPE 861	9	4	44%	5	56%
7	AIA 808	8	0 ↓	0% ↓	8	100% ↓
8	NWA 5719	10	3	30%	7	70%
9	EGL 4184	19	13	68%	6	32%
10	TWA 427	6 ↓	4	67%	2	33%
11	ASA 529	12	10	83%	2	17%
12	AAL 1572	15	8	53%	7	47%
13	VJ 592	27 ↑	20 ↑	74%	7	26%
14	UEX 5925	9	5	56%	4	44%
15	CMR 3272	15	14	93% ↑	1 ↑	7% ↑
16	KAL 801	21	12	57%	9	43%
	SUM	215	125	- - -	90	- - -
	AVERAGE	13	8	54%	6	46%
	STD DEV	6	5	24%	3	24%

Notes: 1) Red outline/ '↓' symbol indicates worst value in column
2) Green outline/ '↑' symbol indicates best value in column

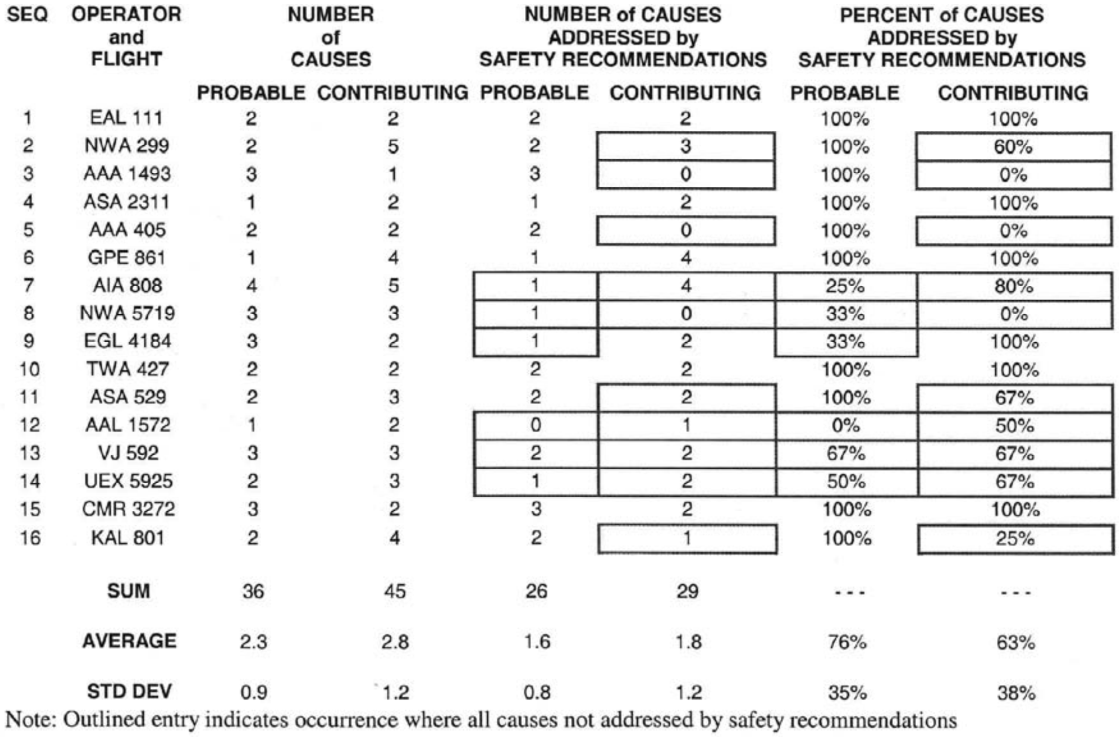
TABLE 4: CORRELATION OF CAUSES SUPPORTED BY FINDINGS



SEQ	OPERATOR and FLIGHT	NUMBER of CAUSES		NUMBER of CAUSES SUPPORTED by FINDINGS		PERCENT of CAUSES SUPPORTED by FINDINGS	
		PROBABLE	CONTRIBUTING	PROBABLE	CONTRIBUTING	PROBABLE	CONTRIBUTING
1	EAL 111	2	2	2	2	100%	100%
2	NWA 299	2	5	2	4	100%	80%
3	AAA 1493	3	1	3	1	100%	100%
4	ASA 2311	1	2	1	2	100%	100%
5	AAA 405	2	2	1	1	50%	50%
6	GPE 861	1	4	1	4	100%	100%
7	AIA 808	4	5	4	3	100%	60%
8	NWA 5719	3	3	3	3	100%	100%
9	EGL 4184	3	2	3	2	100%	100%
10	TWA 427	2	2	2	2	100%	100%
11	ASA 529	2	3	2	3	100%	100%
12	AAL 1572	1	2	1	2	100%	100%
13	VJ 592	3	3	3	3	100%	100%
14	UEX 5925	2	3	2	3	100%	100%
15	CMR 3272	3	2	3	2	100%	100%
16	KAL 801	2	4	2	4	100%	100%
	SUM	36	45	36	40	- - -	- - -
	AVERAGE	2.3	2.8	2.3	2.5	97%	93%
	STD DEV	0.9	1.2	0.9	1.0	13%	16%

Note: Outlined entry indicates occurrence where all causes not supported by findings

TABLE 5: CORRELATION OF CAUSES ADDRESSED BY SAFETY RECOMMENDATIONS



SEQ	OPERATOR and FLIGHT	NUMBER of CAUSES		NUMBER of CAUSES ADDRESSED by SAFETY RECOMMENDATIONS		PERCENT of CAUSES ADDRESSED by SAFETY RECOMMENDATIONS	
		PROBABLE	CONTRIBUTING	PROBABLE	CONTRIBUTING	PROBABLE	CONTRIBUTING
1	EAL 111	2	2	2	2	100%	100%
2	NWA 299	2	5	2	3	100%	60%
3	AAA 1493	3	1	3	0	100%	0%
4	ASA 2311	1	2	1	2	100%	100%
5	AAA 405	2	2	2	0	100%	0%
6	GPE 861	1	4	1	4	100%	100%
7	AIA 808	4	5	1	4	25%	80%
8	NWA 5719	3	3	1	0	33%	0%
9	EGL 4184	3	2	1	2	33%	100%
10	TWA 427	2	2	2	2	100%	100%
11	ASA 529	2	3	2	2	100%	67%
12	AAL 1572	1	2	0	1	0%	50%
13	VJ 592	3	3	2	2	67%	67%
14	UEX 5925	2	3	1	2	50%	67%
15	CMR 3272	3	2	3	2	100%	100%
16	KAL 801	2	4	2	1	100%	25%
	SUM	36	45	26	29	- - -	- - -
	AVERAGE	2.3	2.8	1.6	1.8	76%	63%
	STD DEV	0.9	1.2	0.8	1.2	35%	38%

Note: Outlined entry indicates occurrence where all causes not addressed by safety recommendations

References

Lebow, C., Sarsfield, L., Stanley, W., Ettedgui, E., & Henning, G. (undated). *Safety in the Skies Personnel and Parties in NTSB Aviation Investigations.* Santa Monica, CA: RAND Institute for Civil Justice.

National Transportation Safety Board. (1991). *Runway Collision of Eastern Airlines Boeing 727 Flight 111 and Epps Air Service Beechcraft King Air A100 Atlanta Hartsfield International Airport Atlanta, Georgia January 18, 1990* (NTSB/AAR-91/03) Washington, D.C.: NTSB.

National Transportation Safety Board. (1991). *Northwest Airlines Inc. Flights 1482 and 299 Runway Incursion and Collision Detroit Metropolitan/Wayne County Airport Romulus, Michigan December 3, 1990* (NTSB/AAR-91/05) Washington, D.C.: NTSB.

National Transportation Safety Board. (1991). *Runway Collision of USAir Flight 1493, Boeing 737 and Skywest Flight 5569 Fairchild Metroliner Los Angeles International Airport Los Angeles, California February 1, 1991* (NTSB/AAR-91/08) Washington, D.C.: NTSB.

National Transportation Safety Board. (1992). *Atlantic Southeast Airlines Inc Flight 2311 Uncontrolled Collision with Terrain An Embraer EMB-120, N270AS Brunswick, Georgia April 5, 1991* (NTSB/AAR-92/03) Washington, DC: NTSB.

National Transportation Safety Board. (1993). *Takeoff Stall in Icing Conditions USAir Flight 405 Fokker F-28, N485US LaGuardia Airport Flushing, New York March 22, 1992* (NTSB/AAR-93/02) Washington, D.C.: NTSB.

National Transportation Safety Board. (1993). *Controlled Collision with Terrain GP Express Airlines Inc Flight 861 A Beechcraft C99 N118GP Anniston, Alabama June 8, 1992* (NTSB/AAR-93/03) Washington, D.C.: NTSB.

National Transportation Safety Board. (1994). *Uncontrolled Collision with Terrain American International Airways Flight 808 Douglas DC-8-61 N814CK U.S. Naval Air Station, Guantanamo Bay Cuba August 18, 1993* (NTSB/AAR-94/04) Washington, D.C.: NTSB.

National Transportation Safety Board. (1994). *Controlled Collision with Terrain Express II Airlines Inc/Northwest Airlines Flight 5719 Jetstream BA-3100 N334PX Hibbing, Minnesota December 1, 1993* (NTSB/AAR-94/05) Washington, D.C.: NTSB.

National Transportation Safety Board. (1995). *Runway Collision Involving Trans World Airlines Flight 427 and Superior Aviation Cessna 441 Bridgeton, Missouri November 22, 1994* (NTSB/AAR-95/05) Washington, D.C.: NTSB.

National Transportation Safety Board. (1996). *Inflight Icing Encounter and Loss of Control Simmons Airlines d.b.a. American Eagle Flight 4184 Avions de Transport Regional (ATR) Model 72-212 N401AM Roselawn, Indiana October 31, 1994* (NTSB/AAR-96/01) Washington, D.C.: NTSB.

National Transportation Safety Board. (1996). *Collision with Trees on Final Approach American Airlines Flight 1572 McDonnel Douglas MD-83 N566AA East Granby, Connecticut November 12, 1995* (NTSB/AAR-96/05) Washington, D.C.: NTSB.

National Transportation Safety Board. (1996). *Inflight Loss of Propeller Blade Forced Landing and Collision with Terrain Atlantic Southeast Airlines Inc Flight 529 Embraer EMB-120RT N256AS Carrollton, Georgia August 21, 1995* (NTSB/AAR-96/06) Washington, D.C.: NTSB.

National Transportation Safety Board. (1997). *Runway Collision United Express Flight 5925 and Beechcraft King Air A90 Quincy Municipal Airport Quincy, Illinois November 19, 1996* (NTSB/AAR-97/04) Washington, D.C.: NTSB.

National Transportation Safety Board. (1997). *Inflight Fire and Impact with Terrain Valujet Airlines Flight 592 DC-9-32 N904VJ Everglades Near Miami, Florida May 11, 1996* (NTSB/AAR-97/06) Washington, D.C.: NTSB.

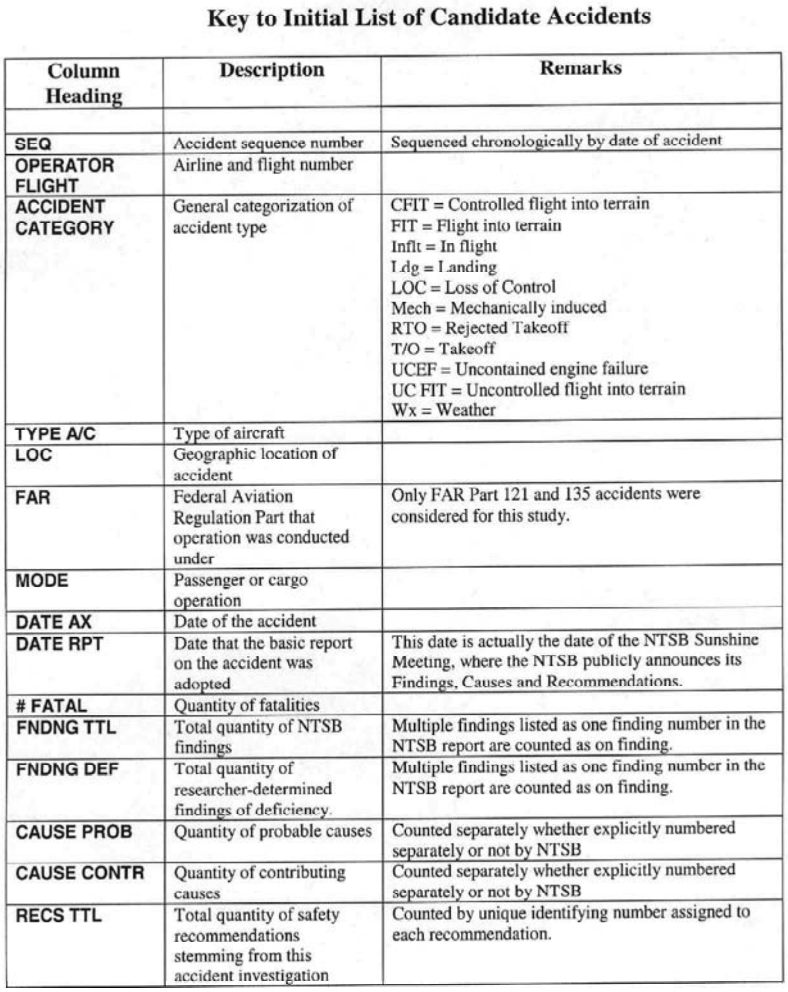
National Transportation Safety Board. (1998). *Inflight Icing Encounter and Uncontrolled Collision with Terrain Comair Flight 3272 Embraer EMB-120RT N265CA Monroe, Michigan January 9, 1997* (NTSB/AAR-98/04) Washington, D.C.: NTSB.

National Transportation Safety Board. (2000). *Controlled Flight into Terrain Korean Air Flight 801 Boeing 747-300 HL7468 Nimitz Hill, Guam August 6, 1997* (NTSB/AAR-00/01) Washington, D.C.: NTSB.

Weir, A. (1999). *The Tombstone Imperative The Truth About Airline Safety* London, UK: Simon & Schuster.

Wood, R. & Sweginnis, R. (1995). *Aircraft Accident Investigation* Casper, WY: Endeavor Books.

APPENDIX 1



Key to Initial List of Candidate Accidents

Column Heading	Description	Remarks
SEQ	Accident sequence number	Sequenced chronologically by date of accident
OPERATOR FLIGHT	Airline and flight number	
ACCIDENT CATEGORY	General categorization of accident type	CFIT = Controlled flight into terrain FIT = Flight into terrain Inflt = In flight Ldg = Landing LOC = Loss of Control Mech = Mechanically induced RTO = Rejected Takeoff T/O = Takeoff UCEF = Uncontained engine failure UC FIT = Uncontrolled flight into terrain Wx = Weather
TYPE A/C	Type of aircraft	
LOC	Geographic location of accident	
FAR	Federal Aviation Regulation Part that operation was conducted under	Only FAR Part 121 and 135 accidents were considered for this study.
MODE	Passenger or cargo operation	
DATE AX	Date of the accident	
DATE RPT	Date that the basic report on the accident was adopted	This date is actually the date of the NTSB Sunshine Meeting, where the NTSB publicly announces its Findings, Causes and Recommendations.
# FATAL	Quantity of fatalities	
FNDNG TTL	Total quantity of NTSB findings	Multiple findings listed as one finding number in the NTSB report are counted as on finding.
FNDNG DEF	Total quantity of researcher-determined findings of deficiency.	Multiple findings listed as one finding number in the NTSB report are counted as on finding.
CAUSE PROB	Quantity of probable causes	Counted separately whether explicitly numbered separately or not by NTSB
CAUSE CONTR	Quantity of contributing causes	Counted separately whether explicitly numbered separately or not by NTSB
RECS TTL	Total quantity of safety recommendations stemming from this accident investigation	Counted by unique identifying number assigned to each recommendation.

LIST of INITIAL CANDIDATE ACCIDENTS

SEQ	OPERATOR FLIGHT	ACCIDENT CATEGORY	TYPE A/C	LOC	FAR	MODE	DATE AX	DATE RPT	# FATAL	FNDNG TTL	FNDNG DEF	CAUSE PROB	CAUSE CONTR	RECS TTL
1	EAL 111	Rwy Collision	B727	ATL	121	Pax	1/18/90	5/29/91	1	12	7	2	2	5
2	Avianca 052	Fuel Exhaust	B707	JFK	121	Pax	1/25/90	4/30/91	73	24	16	2	4	9
3	MarkAir	CFIT	B737	AK	121	Pax	6/2/90	1/23/91	0	11	6	4	0	4
4	NWA 299	Rwy Collision	B727 DC-9	DTW	121	Pax	12/3/90	6/25/91	12	27	20	2	5	16
5	AAA 1493	Rwy Collision	B737	LAX	121	Pax	2/1/91	10/22/91	34	21	12	3	1	17
6	Ryan 590	Icing LOC	DC-9	CLE	121	Cargo	2/17/91	12/16/91	2	17	8	2	0	6
7	UAL 585	UC FIT	B737	COS	121	Pax	3/3/91	12/8/92	25	12	1	0	0	7
8	ASA 2311	UC FIT Mech	EMB-120	Brunswick	135	Pax	4/5/91	4/28/92	23	17	10	1	2	6
9	LEX 508	UC FIT Wx	B-99	BHM	135	Pax	7/10/91	3/3/92	13	13	4	1	0	3
10	ATI 805	UC FIT Mech?	DC-8	TOL	121	Cargo	2/15/92	11/19/92	4	8	4	1	0	0
11	AAA 405	Icing T/O	F-28	LGA	121	Pax	3/22/92	2/17/93	27	26	14	2	2	16
12	GPE 861	CFIT	B-99	ANN	135	Pax	6/8/92	3/2/93	4	17	9	1	4	5
13	TWA 843	RTO	L1011	JFK	121	Pax	7/30/92	3/31/93	0	19	8	3	0	10
14	China 012	Inflt Upset Wx	MD-11	Japan	121	Pax	12/7/92	2/15/94	0	17	5	1	1	3
15	JAL 46E	Inflt Upset Wx	B747	AK	121	Cargo	3/31/93	10/13/93	0	14	5	1	1	7
16	China 583	Inflt Upset Mech	MD 11	AK	121	Pax	4/6/93	10/27/93	2	15	6	2	3	13
17	AAL 102	LOC Landing	DC-10	DFW	121	Pax	4/14/93	2/14/94	0	21	7	1	0	11
18	AIA 808	UC FIT	DC-8	Cuba	121	Cargo	8/18/93	5/10/94	0	13	8	4	5	6
19	NWA 5719	CFIT	J-31	Hibbing	135	Pax	12/1/93	5/24/94	18	16	10	3	3	5
20	UEX 6291	UC FIT	J-41	CMH	135	Pax	1/7/94	10/6/94	5	15	7	4	2	4
21	CAL 795	RTO	MD-80	LGA	121	Pax	3/2/94	2/14/95	0	18	5	2	0	7
22	AAA 1016	UC FIT Wx	DC-9	CLT	121	Pax	7/2/94	4/4/95	37	18	8	4	4	20
23	AAA 427	UC FIT Mech	B737	PIT	121	Pax	9/8/94	3/24/99	132	34	8	2	0	10
24	EGL 4184	Icing LOC	ATR-	IND	121	Pax	10/31/94	7/9/96	68	43	19	3	2	35
25	TWA 427	Rwy Collision	MD-80	STL	121	Pax	11/22/94	8/30/95	2	16	6	2	2	12
26	EGL 3379	UC FIT	J-32	RDU	135	Pax	12/13/94	10/24/95	15	18	12	2	4	7
27	ATI 782AL	UC FIT Mech	DC-8	KCI	121	Cargo	2/16/95	8/30/95	3	16	10	3	2	6
28	VJ 597	UCEF	DC-9	ATL	121	Pax	6/8/95	7/30/96	0	20	13	1	2	12
29	ASA 529	UC FIT Mech	EMB-120	Carrollton	135	Pax	8/21/95	11/26/96	8	23	12	2	3	8
30	AAL 1572	CFIT	MD-80	BDL	121	Pax	11/12/95	11/13/96	0	33	15	1	2	13
31	TWR 41	RTO	B747	JFK	121	Pax	12/20/95	1/2/96	0	25	19	2	3	16
32	VJ 558	Hard Ldg	DC-9	NSH	121	Pax	1/7/96	12/11/96	0	18	11	3	3	8
33	CAL 1943	Gr Up Ldg	DC-9	HOU	121	Pax	2/19/96	2/11/97	0	17	8	1	4	8
34	VJ 592	Inflt Fire	DC-9	MIA	121	Pax	5/11/96	8/19/97	110	47	27	3	3	27
35	DAL 1288	UCEF	MD-80	PNS	121	Pax	7/6/96	1/13/98	2	30	17	3	1	15
36	TWA 800	Inflt Explos	B747	JFK	121	Pax	7/17/96	8/23/00	230	25	8	1	2	16
37	FDX 1406	Inflt Fire	DC-10	SWF	121	Cargo	9/5/96	7/22/98	0	18	12	1	0	10
38	DAL 554	CFIT	MD-80	LGA	121	Pax	10/19/96	8/25/97	0	27	16	2	2	13
39	UEX 5925	Rwy Collision	B-1900	Quincy	135	Pax	11/19/96	7/1/97	14	21	9	2	3	7
40	ABX 827AX	UC FIT	DC-8	Narrows	91	Mech	12/22/96	7/15/97	6	23	13	3	2	7
41	CMR 3272	Icing LOC	EMB-120	Monroe	135	Pax	1/9/97	12/4/98	29	34	15	3	2	21
42	FDX 14	Hard Ldg	MD-11	EWR	121	Cargo	7/31/97	7/25/00	0	27	8	1	1	12
43	KAL 801	CFIT	B747	GUM	121	Pax	8/6/97	1/13/00	228	36	21	2	4	15
44	Fine Air 101	UC FIT	DC-8	MIA	121	Cargo	8/7/97	1/16/98	5	36	26	2	2	15

Notes: 1) Shading in 'SEQ' column indicates accident included in final list for study
2) See next page for key to columns

APPENDIX 2

CORRELATION OF FINDINGS AND SAFETY RECOMMENDATIONS (RAW DATA)

KEY

	FINDINGS									
REC	1	2	3	4	5	6	7	8	9	← BOLD OUTLINE INDICATES A FINDING OF A DEFICIENCY
	▨	← DIAGONAL LINES INDICATES A FINDING OF DEFICIENCY WITHOUT A CORRESPONDING RECOMMENDATION								
91-27										
91-28										
91-29	← HORIZONTAL LINES INDICATES NO CORRESPONDING FINDING(S)									
91-30										
91-31			1	← A '1' INDICATES A CORRELATION BETWEEN A FINDING AND A RECOMMENDATION						

EAL 111

	FINDINGS											
REC	1	2	3	4	5	6	7	8	9	10	11	12
						▨		▨	▨	▨	▨	▨
91-27							1					
91-28												
91-29												
91-30												
91-31							1					

NWA 299

	FINDINGS																										
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
			▨	▨		▨	▨											▨	▨		▨	▨	▨	▨			▨
91-54					1																						
91-55					1			1																			
91-56					1																						
91-57																	1										
91-58																											
91-59																											
91-60																											
91-61																											
91-62														1	1												
91-63																1											
91-64																										1	
91-65																										1	
91-66									1				1				1										
91-67																											
91-68					1																						
91-69										1	1	1	1														

AAA 1493

	FINDINGS																			
REC	1	**2**	3	4	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	14	**15**	16	17	18	**19**	**20**
									▨	▨	▨								▨	
91-104																				
91-105							1													
91-106								1												
91-107							1	1												
91-108													1							
91-109													1							
91-110						1									1					
91-111																				
91-112																				
91-113																				
91-114																				
91-115												1								
91-116																				
91-117																				1
91-118		1																		
91-119																1				
91-120																				
91-121																				

ASA 2311

	FINDINGS																
REC	**1**	2	3	4	5	**6**	7	8	**9**	**10**	**11**	12	**13**	**14**	**15**	**16**	**17**
						▨				▨	▨				▨	▨	
92-25	1												1	1			
92-26									1								
92-27																	
92-28																	1
92-29																	1
92-30																	1

AAA 405

	FINDINGS																									
REC	1	2	3	4	5	**6**	7	**8**	**9**	**10**	**11**	12	13	**14**	**15**	16	**17**	**18**	19	**20**	21	22	**23**	**24**	**25**	**26**
						▨		▨		▨	▨				▨								▨			
93-19																										
93-20																										
93-21																	1	1								
93-22														1												
93-23														1												
93-24														1												
93-25																				1						
93-26									1																	
93-27																										
93-28																										
93-29																										
93-30																								1		
93-31																										1
93-32																								1		
93-33																										
93-34																									1	

GPE 861

	FINDINGS																
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
								▨			▨	▨	▨	▨			
93-35									1								
93-36										1							
93-37																	
93-38																1	
93-39																	1

AIA 808

	FINDINGS												
REC	1	2	3	4	5	6	7	8	9	10	11	12	13
			▨	▨			▨	▨	▨		▨	▨	▨
94-105					1								
94-106													
94-107													
94-108													
94-109													
94-110													

NWA 5719

	FINDINGS																	
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
										▨	▨	▨	▨	▨		▨		▨
94-113																		
94-114								1										
94-115																	1	
94-116						1												
94-117						1												

EGL 4184 (1 of 4)

	FINDINGS																								
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
															▨										
94-181																									
94-182																						1	1	1	1
94-183																									
94-184																						1		1	1
94-185																									
95-103																									
95-104																									
95-105																									
95-106																									
96-48																									
96-49							1																		
96-50																									
96-51																									
96-52											1														
96-53												1													
96-54													1												
96-55													1												
96-56														1											
96-57																			1						
96-58																				1					
96-59																		1							
96-60																									
96-61																									
96-62																									
96-63																									
96-64																									
96-65																									

EGL 4184 (ctd - 2 of 4)

	FINDINGS																	
REC	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
	▨	▨						▨				▨	▨					
94-181			1															
94-182																		
94-183																		
94-184																		
94-185																		
95-103																		
95-104																		
95-105																		
95-106																		
96-48																		
96-49																		
96-50																		
96-51																		
96-52																		
96-53																		
96-54																		
96-55																		
96-56																		
96-57																		
96-58																		
96-59																		
96-60																		
96-61																		
96-62			1															
96-63					1													
96-64				1														
96-65											1							

EGL 4184 (ctd - 3 of 4)

	FINDINGS																								
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
															▨										
96-66																									
96-67																									
96-68											1														
96-69																									
96-70												1													
96-71																									
96-72																									
96-73																									

EGL 4184 (ctd - 4 of 4)

	FINDINGS																	
REC	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
	▨	▨						▨				▨	▨					
96-66																		1
96-67																		
96-68																		
96-69																		
96-70																		
96-71																		
96-72											1							
96-73																		

TWA 427

	FINDINGS															
REC	1	2	3	4	5	**6**	7	**8**	**9**	**10**	11	**12**	13	**14**	15	16
										▨		▨				
95-86														1		
95-87															1	
95-88																
95-89								1								
95-90																
95-91																1
95-92																1
95-93																1
95-94						1										
95-95									1							
95-96																
95-97																

ASA 529

	FINDINGS																					
REC	1	2	3	4	**5**	6	7	**8**	9	**10**	**11**	**12**	**13**	14	**15**	**16**	17	**18**	19	20	**21**	**22**
					▨								▨									
96-142								1	1	1	1	1										
96-143																						
96-144															1							
96-145																1						
96-146								1										1				
96-147																					1	
96-148																						1
96-149																						

AAL 1572 (1 of 2)

	FINDINGS																								
REC	1	2	3	4	5	6	7	8	**9**	**10**	11	12	**13**	**14**	15	**16**	17	**18**	**19**	**20**	21	22	**23**	24	**25**
									▨	▨			▨	▨		▨		▨							▨
96-128																	1								
96-129																									
96-130																			1						
96-131																									
96-132																									
96-133																									
96-134																				1					
96-135																							1		
96-136																									
96-137																									
96-138																									
96-139																									
96-140																									

AAL 1572 (ctd - 2 of 2)

REC	26	27	28	29	30	31	32	33
96-128								
96-129								
96-130								
96-131								
96-132								
96-133								
96-134								
96-135								
96-136				1				
96-137					1			
96-138						1		
96-139							1	
96-140								1

VJ 592 (1 of 2)

	FINDINGS																								
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
						▨	▨																		
97-56								1	1																
97-57														1											
97-58															1	1									
97-59																	1								
97-60																	1	1							
97-61																			1						
97-62																				1					
97-63																					1				
97-64																						1			
97-65																							1	1	
97-66																									1
97-67																									
97-68																									
97-69																									
97-70																									
97-71																									
97-72																									
97-73																									
97-74																									
97-75																									
97-76																									
97-77																									
97-78																									
97-79																									
97-80																									
97-81																									
97-82																									

VJ 592 (ctd - 2 of 2)

	FINDINGS																				
REC	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
	▨			▨			▨		▨				▨									
97-56																						
97-57																						
97-58																						
97-59																						
97-60																						
97-61																						
97-62																						
97-63																						
97-64																						
97-65																						
97-66																						
97-67																						
97-68			1																			
97-69						1				1												
97-70								1														
97-71					1																	
97-72										1												
97-73											1	1										
97-74														1	1		1					
97-75																1	1					
97-76																			1			
97-77																					1	1
97-78																				1		
97-79																			1			
97-80																			1			
97-81																			1			
97-82																			1			

UEX 5925

	FINDINGS																				
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
				▨				▨	▨		▨										
97-102										1											
97-103															1	1	1	1			
97-104																	1	1			
97-105																1	1	1			
97-106																			1		
97-107																				1	1
97-108																					1

CMR 3272 (1 of 2)

	FINDINGS																							
REC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
																			▨						
98-88									1																
98-89													1												
98-90																		1							
98-91														1											
98-92															1										
98-93																1									
98-94																				1					
98-95																				1					
98-96																					1				
98-97																								1	
98-98																									1
98-99																									
98-100																									
98-101																	1								
98-102																									
98-103																									
98-104																									
98-105																									
98-106																									
98-107																		1							
98-108															1										

CMR 3272 (ctd – 2 of 2)

	FINDINGS								
REC	26	27	28	29	30	31	32	33	34
98-88									
98-89									
98-90									
98-91									
98-92									
98-93									
98-94									
98-95									
98-96									
98-97									
98-98									
98-99		1		1					
98-100	1	1		1					
98-101									
98-102					1	1			
98-103					1	1			
98-104							1		
98-105								1	
98-106									1
98-107									
98-108									

KAL 801 (1 of 2)

	FINDINGS																								
REC	1	2	**3**	4	**5**	**6**	7	8	**9**	10	**11**	**12**	**13**	14	**15**	**16**	17	**18**	**19**	**20**	21	**22**	**23**	24	**25**
					▨						▨	▨			▨	▨				▨		▨			
00-7			1																						
00-8							1																		
00-9									1																
00-10													1	1											
00-11																	1								
00-12																		1	1						
00-13																									
00-14																									
00-15																									
00-16																									
00-17																									
00-18																									
00-19																							1		1
00-20																							1		1
00-21						1																			

KAL 801 (ctd - 2 of 2)

	FINDINGS										
REC	**26**	27	28	29	**30**	**31**	**32**	**33**	**34**	35	36
							▨	▨			
00-7											
00-8											
00-9											
00-10											
00-11											
00-12											
00-13			1								
00-14			1								
00-15				1							
00-16					1						
00-17						1					
00-18									1		
00-19	1										
00-20	1										
00-21											

APPENDIX 3

Key to Correlation Tables

	F	**R**
PC1	1	1
PC2	0	1
CC1	1	0
CC2	1	1

PC stands for Probable Cause (Sequentially numbered as PC1, PC2 etc)
CC stands for Contributing Cause (Sequentially numbered as CC1, CC2 etc)
F stands for Finding
R stands for Recommendation

A ‘1’ indicates that the Cause is supported by a Finding or is addressed by a Safety Recommendation

A ‘0’ indicates that the Cause is not supported by a Finding or is not addressed by a Safety Recommendation

EAL 111	F	R
PC1	1	1
PC2	1	1
CC1	1	1
CC2	1	1

NWA 299	F	R
PC1	1	1
PC2	1	1
CC1	1	1
CC2	1	1
CC3	1	1
CC4	1	0
CC5	0	0

AAA 1493	F	R
PC1	1	1
PC2	1	1
PC3	1	1
CC1	1	0

ASA 2311	F	R
PC1	1	1
CC1	1	1
CC2	1	1

AAA 405	F	R
PC1	1	1
PC2	0	1
CC1	1	0
CC2	0	0

GPE 861	F	R
PC1	1	1
CC1	1	1
CC2	1	1
CC3	1	1
CC4	1	1

AIA 808	F	R
PC1	1	1
PC2	1	0
PC3	1	0
PC4	1	0
CC1	1	1
CC2	0	0
CC3	0	1
CC4	1	1
CC5	1	1

NWA 5719	F	R
PC1	1	0
PC2	1	1
PC3	1	0
CC1	1	0
CC2	1	0
CC3	1	0

EGL 4184	F	R
PC1	1	0
PC2	1	0
PC3	1	1
CC1	1	1
CC2	1	1

TWA 427	F	R
PC1	1	1
PC2	1	1
CC1	1	1
CC2	1	1

ASA 529	F	R
PC1	1	1
PC2	1	1
CC1	1	1
CC2	1	1
CC3	1	0

AAL 1572	F	R
PC1	1	0
CC1	1	1
CC2	1	0

VJ 592	F	R
PC1	1	1
PC2	1	0
PC3	1	1
CC1	1	1
CC2	1	0
CC3	1	1

UEX 5925	F	R
PC1	1	0
PC2	1	1
CC1	1	0
CC2	1	1
CC3	1	1

CMR 3272	F	R
PC1	1	1
PC2	1	1
PC3	1	1
CC1	1	1
CC2	1	1

KAL 801	F	R
PC1	1	1
PC2	1	1
CC1	1	0
CC2	1	1
CC3	1	0
CC4	1	0

Ramp Accidents and Incidents Involving U.S. Carriers, 1987–2002

By Robert Matthews, Ph.D., Office of Accident Investigation, Federal Aviation Administration, USA

***Robert 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. Dr. Matthews has been with the FAA since 1989, where he has been a safety analyst in the Office of Accident Investigation for the past 8 years. Most recently, he has been heavily involved in CAST, FOQA and other cooperative efforts between the FAA and industry. His previous professional experience includes 9 years in national transportation legislation with the U.S. Department of Transportation (DOT), consulting with the European Union and the Organization of Economic Cooperation and Development in Paris, and several years as an aviation analyst for the Office of the Secretary at the U.S. DOT.*

The views expressed in this paper represent the author's views and may not represent the views of the federal Aviation Administration.

This paper presents an analysis of 144 ramp accidents and 565 identified ramp incidents involving U.S. air carriers from 1987 through 2002. Part I outlines the scale of the issue and the ramp environment. Part II examines the 679 identified events for common factors, typical participants, injuries, and damage to aircraft and other property. Part III examines the cost of these events.

The analysis is based primarily on accident and incident data from the National Transportation Safety Board (NTSB) and the Federal Aviation Administration (FAA), but it also includes events recorded by Airclaims and one ramp accident involving a U.S. carrier in the United Kingdom, as reported in the UK's AAIB database. The paper also cites selected research on the subject of ramp operational safety.

Despite using all these sources, the paper, at best, addresses only a small share of events, because most ramp incidents are not captured by governmental or other central databases. The NTSB database is limited to events involving intended flight. The FAA data are a bit more broadly based, but are limited as well in that the data capture only those events that directly involve aircraft. Even then, many incidents involving aircraft in fact are not captured by the FAA data. Data from Airclaims identified 19 significant events that neither the FAA nor the NTSB identified. Yet, even insurance data is quite limited, as most ramp events are not reported to insurance companies due to high deductible costs. Finally, none of the databases used for this paper capture ramp incidents, regardless of their severity, in which aircraft are not involved. Events involving two or more ground vehicles, or a ground vehicle and some other ramp equipment, are not captured. Occupational safety data increase total fatalities by about half and total serious injuries by nearly 100 percent.

In the end, the data used in this paper represent only about 2.5 percent of all events, or about one in 40, but should include a high percentage of the more serious events that involve aircraft and/or intent of flight. Of the 679 events analyzed here, Airclaims was the source for about 4 percent; the NTSB was the source for just more than 20 percent, and FAA data was the source of reports on 75 percent of the cases. Despite the limitations on the available data, the analysis is able to reach the following findings and conclusions:

- Ramp accidents and incidents constitute a significant safety issue. On average, they cause one fatality per year, as captured in aviation databases, plus an additional fatal accident every other year, as captured in other public databases on occupational safety. Aviation data also report an average of three to four serious injuries and five to six minor injuries per year.
- Ramp accidents and incidents cost U.S. air carriers around $2 billion annually in injury costs, damage to aircraft and other property, cancelled flights, and other indirect costs.
- The principal causes and possible targets for corrective action are procedures, training, and organizational culture. Interventions for these areas typically are inexpensive but very difficult to do well.

Part I: Scale and ramp environment

This paper defines "ramp" as the relatively small area at and around the gate on the airport side of the terminal, plus the immediately adjacent area (the "alley") that handles aircraft access to and egress from the gate. Johnson and McDonald offer a usefully succinct definition of ramp activities to include all operations associated with servicing an aircraft during a normal turnaround between landing and departure. These activities include marshalling, chocking, refueling, cleaning, catering, servicing water and toilets, loading and unloading passengers and baggage, aircraft towing and pushback, and access and egress of large aircraft in confined spaces, etc. [1]

Ramp accidents persistently account for 20 to 30 percent of all air carrier accidents in the United States. Exhibits 1 and 2 show

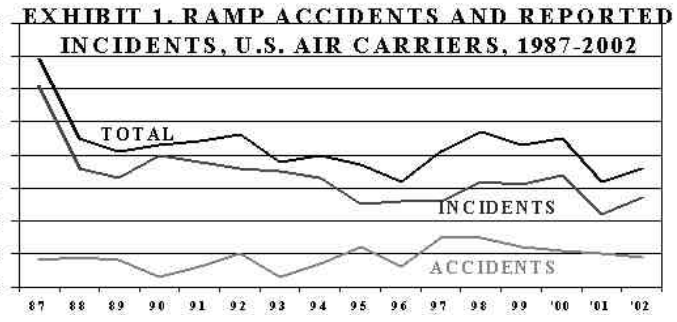
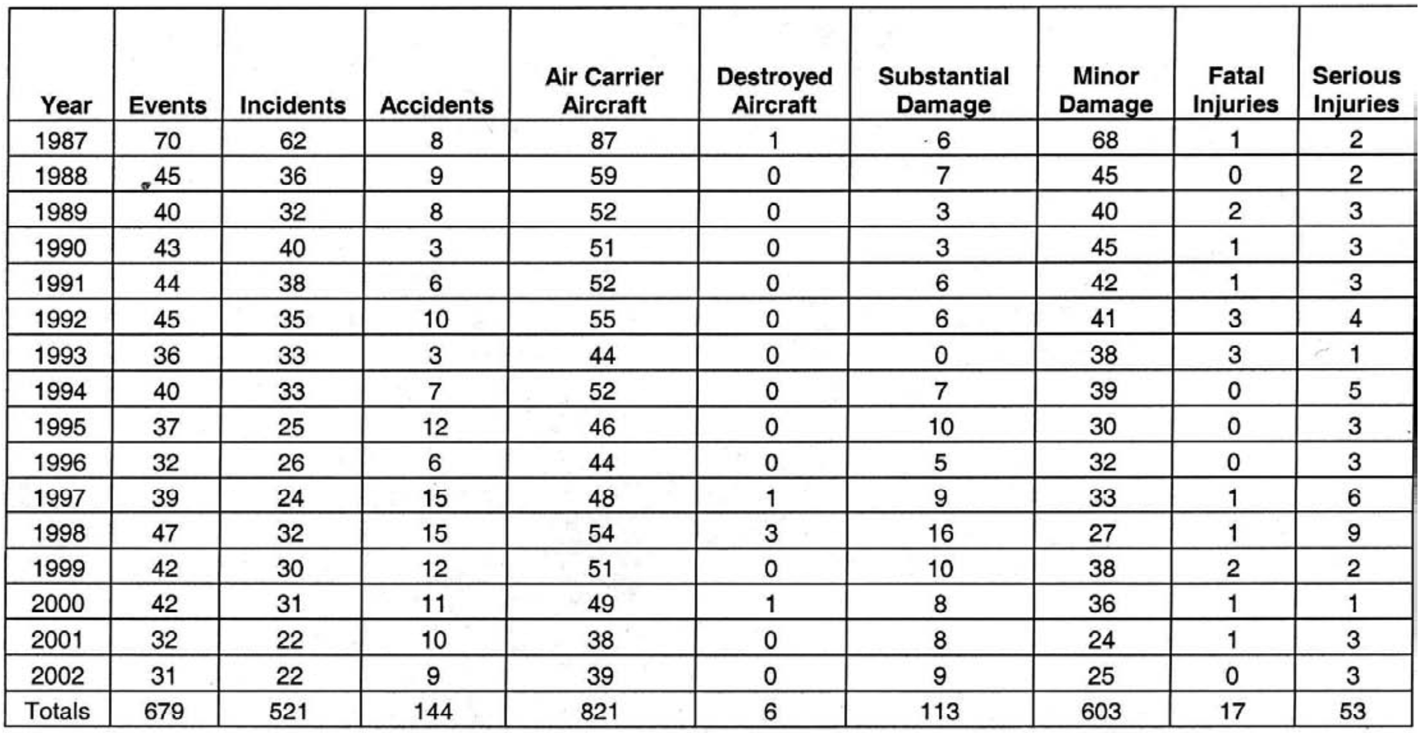


EXHIBIT 1. RAMP ACCIDENTS AND REPORTED INCIDENTS, U.S. AIR CARRIERS, 1987-2002

INJURIES
- 17 Fatalities
- 53 Serious (many Level 5)
- 83 Minor Injuries

AIRCRAFT DAMAGE
- 6 Hull Losses
- 114 Substantial Damage
- 612 Minor Damage

EXHIBIT 2. RAMP EVENTS, AIRCRAFT DAMAGE, AND INJURIES.



Year	Events	Incidents	Accidents	Air Carrier Aircraft	Destroyed Aircraft	Substantial Damage	Minor Damage	Fatal Injuries	Serious Injuries
1987	70	62	8	87	1	6	68	1	2
1988	45	36	9	59	0	7	45	0	2
1989	40	32	8	52	0	3	40	2	3
1990	43	40	3	51	0	3	45	1	3
1991	44	38	6	52	0	6	42	1	3
1992	45	35	10	55	0	6	41	3	4
1993	36	33	3	44	0	0	38	3	1
1994	40	33	7	52	0	7	39	0	5
1995	37	25	12	46	0	10	30	0	3
1996	32	26	6	44	0	5	32	0	3
1997	39	24	15	48	1	9	33	1	6
1998	47	32	15	54	3	16	27	1	9
1999	42	30	12	51	0	10	38	2	2
2000	42	31	11	49	1	8	36	1	1
2001	32	22	10	38	0	8	24	1	3
2002	31	22	9	39	0	9	25	0	3
Totals	679	521	144	821	6	113	603	17	53

that the number of events has been fairly stable since 1988, though the distribution between accidents and incidents varies a bit.

The 679 accidents and incidents included 17 fatal events, all of which involved single fatalities, plus 53 serious injuries and 83 reported minor injuries. The 679 events involved 821 aircraft, of which six were destroyed and 113 incurred substantial damage. Data for a nearly identical 16-year study period from the U.S. Occupational Safety and Health Administration indicate an additional nine fatal injuries and 75 serious injuries.

Even if we limit the data only to aviation databases, ramp accidents and incidents, these numbers show that ramp events are equal to or more serious than some events that attract substantial attention from government and industry, while the risk of a catastrophic event at a gate remains real.

Ramp operations

Generally, larger air carriers have their own ramp departments, which provide baggage handling, marshalling, aircraft towing, and pushback to ensure the overall control and safety of the ramp environment. At stations where a carrier has a limited presence, those services may be conducted under contract by other carriers or by airport service companies. Specialized services, such as fueling, aircraft cleaning, catering, and lavatory service often involve additional contractors.

All these activities put aircraft, surface vehicles, other equipment, and people on the ramp. The ramp area also accommodates airport operations and maintenance staffs, airport police, construction workers, air carrier and airport engineers, planners and others. Finally, FAA airports, fight standards, and security personnel add to the ramp population. All these people conduct their activities as very large aircraft move to, from, and throughout confined spaces. In the end, ramp areas are complex, confined, and busy areas. The activity becomes still more intense during peak periods, with sharp increases in aircraft volume, with more pressure to turn aircraft around and ensure that complex and interdependent schedules are maintained.

Generally, local airport operators are responsible for ramp safety at commercial airports in the United States. FAR Part 139 sets minimal safety requirements for the certification of any airport that serves scheduled or unscheduled air carrier passenger operations in aircraft that seat more than 30 passengers. Yet, FAA Part 139 addresses the ramp environment only indirectly with supplemental guidance on safe fuel programs, safe lighting, etc. That subpart requires an airport self-inspection program in order to maintain certification requirement compliance.

Airport operators typically are special authorities created by the various States, including some authorities created jointly by more than one State (such as the Port Authority of New York and New Jersey). However most airport operators delegate much of the responsibility for ramp safety to individual air carrier tenants through local leasing agreements or other formal mechanisms. An air carrier then may contract with a third party to handle some or all ramp operations at selected stations, particularly where the carrier has a relatively limited presence.

Federal regulatory authority for worker safety in the ramp area is divided between the FAA and the Occupational Safety and Health Administration (OSHA) in the U.S. Department of Labor. The OSHA Act of 1970 established OSHA's basic authority for occupational safety throughout the economy, except in fields where other federal agencies chose to develop and enforce such standards within their respective regulatory domains. In theory, the FAA regulates worker safety on the ramp only when flight is intended, while OSHA, the airport authority, or the States regulate safety for ramp workers when no crewmembers are on board the aircraft or there is no intention for flight.

In addition to the ramp operator, air traffic control (ATC) is responsible for the movement of aircraft and vehicles in the airport movement area. Off the movement area, some air carriers have their own ramp control towers, which control all traffic within the ramp area. Local agreements between ATC and the air carriers define handoff procedures between ATC and ramp control. A hub carrier often provides ramp control for all carriers at an airport. Typically, the air carrier's ramp control operates its own radio frequency and controls pushback, movement within the alleyway, and exit from the alleyway to some defined spot, where control is handed off to ATC on a different radio frequency.

ATC has the authority to designate some or all of the airport ramp area as part of the movement area. Where ATC ground control handles all operations on the airport (including pushback), no formal "non-movement" areas exist. Since airports vary greatly in the number of enplanements and physical layout, the details of decisions on movement areas are left to local authorities and the local ATC facility.

The bottom line is an intensely busy and close environment in which the regulatory relationships are at least as complex as the workplace. In the end, however, under the FARs, pilots remain responsible for the safe operation of their aircraft, and air carriers are responsible for the safe transportation of their passengers.

Part II: Accidents and incidents on the ramp, their characteristics and factors

Part II examines the characteristics of ramp accidents and incidents, or "events." Events involving fatal and serious injuries are examined first, followed by events involving two aircraft, then aircraft-jetways, and aircraft into other equipment and structures.

Events with fatal and serious injuries

Of the 679 accidents and incidents, 17 involved fatalities and 53 involved serious injuries. All 70 of these events involved single aircraft. The 70 cases involving fatal or serious injury differ in several ways from other gate events. First, except for injuries to passengers, they are largely associated with departure. In 1995, NASA had found that most ramp accidents and incidents occur on arrival.[2] This analysis does not confirm that finding. At a minimum, events with fatal and serious injuries have a different profile.

In addition to occurring mostly on departure, fatal injuries disproportionately involve turboprops. Turboprops, which accounted for 30 percent of U.S. air carrier departures in the study period, were involved in nine of the 17 fatalities (53 percent) and 18 of the 53 serious injuries (35 percent). Note, too, that none of the 17 fatal events involved aircraft damage, except for several instances of incidental damage to props. Cases with serious injuries involved more aircraft damage and a more varied collection of scenarios, including two hull losses due to a fire at the gate.

The 17 fatalities included 14 ground workers, two passengers and one flightcrew member. The flightcrew member fell from the cargo door during cargo loading. The two passenger fatalities involved a one-armed passenger who declined assistance from the crew, then fell while exiting a small turboprop. In the other passenger fatality, a blind elderly man was left alone briefly just inside the aircraft during boarding. He continued walking and fell from the catering door. The two passengers and the single flightcrew member illustrate that everyone involved can be exposed to some risk at the gate or on the ramp, but, as Exhibit Three illustrates, the risk of fatal and non-fatal injury rests especially with surface workers.

Of 14 fatally injured ground workers, eight were struck by rotating props, usually at night. In all 14 cases, procedures either were inadequate or, more frequently, were not followed, or training was inadequate (or utterly absent). Prop strikes also accounted for five serious injuries, including a severed hand and a severe head injury. The issue, again, is one of procedure but also involves some visual difficulty in detecting a rapidly rotating prop.

EXHIBIT 3. DISTRIBUTION OF INJURIES, RAMP ACCIDENTS, AND REPORTED INCIDENTS.

INJURED PARTY	Fatalities	Serious Injuries	Minor Injuries
Passengers	2	11	30
Flight Crews	1	1	2
Flight Attendants	0	5	6
Ground Crews	14	36	45
Total	17	53	83

Procedural shortcomings often involved workers trying to do a better job, such as choosing to guide a large jet from the gate without wing walkers, approaching an aircraft unannounced to get last-minute bags on board, off-duty workers helping out while waiting to board flights, etc. Other procedural shortcomings indicated more systemic issues, such as inadequate or no training, manuals and procedures that did not address moving beneath wings or near engines, inadequate staffing, inadequate equipment available to workers (head sets with limited cords, shift management of tools, etc.), failure to halt operations during visible lightning).

Of the 53 serious injuries, ground workers accounted for "only" 36 injuries. Passengers were seriously injured in 11 events, flight attendants in five events, and a flightcrew member in one event. Of the 11 serious injuries to passengers, seven involved turboprops. In most cases, passengers fell from or slipped on airstairs while disembarking or boarding, though one case involved a cabin attendant closing the cabin door prematurely, breaking a passenger's hand.

Failure to follow procedures was a primary factor in most passenger injuries, notwithstanding the passengers' contributions in most cases. Procedural issues included airstairs without proper handrails, improper placement of auxiliary steps beneath the bottom step of the aircraft door, and failure to monitor passengers as they exited. Passenger negligence also played a role, such as passengers disembarking while carrying excessive numbers of bundles or declining assistance that was offered.

The remaining four serious injuries to passengers occurred on jets. In two of the cases, surface vehicles struck aircraft as passengers boarded, causing passengers to fall. In a third case, a van struck an aircraft on taxi out, causing a fire and an ensuing evacuation in which a passenger was injured. The fourth case involved a 4-year-old child who exited via the catering door while three crewmembers helped the boy's mother, who was carrying an infant, a stroller, and several bags. In all four cases, the primary factor was failure to follow procedures (either by drivers or cabin crew).

Of the five cabin attendants seriously injured, four involved failure to follow procedures in opening cabin doors at the gate. Not unlike several fatal injuries to ground workers, two of the five involved flight attendants who were making last-minute attempts to do a good job, such as opening the door to retrieve a stuffed animal dropped by a child upon boarding, only to find that the jetway had already been moved back. Just one of the five serious injuries to flight attendants involved any role by ramp support. In that case, a tow bar became disconnected during pushback and the ground crew signaled to the flight crew for an emergency stop, knocking down a flight attendant who was checking seatbelt compliance.

The lone serious injury to a flightcrew member involved a collision with an employee bus as the aircraft taxied in the alley. The NTSB cited both the bus driver and the flight crew for failure to follow procedure. The bus driver ran a stop sign and failed to yield to an aircraft, while the flight crew taxied while completing paperwork, limiting their visual lookout.

The remaining 36 serious injuries involved ground workers. This number may be surprisingly low, but those injuries generally were more severe than other "serious" injuries. At least four reports cited severed legs or arms, while others cited severe crushing injuries.

Unlike the injuries noted above, a relatively small share of cases (five) involved issues unique to turboprops (prop strikes). Also different from injuries noted above, 16 of the 53 cases involved substantial damage to aircraft and two hull losses. One hull loss occurred on departure and the other involved mechanics operating an aircraft before the day's first flight. In that case, mechanics started the engines at the gate with the throttle in "full thrust" position and brakes not set. The aircraft immediately jumped the chocks and powered into the terminal building. The other hull loss involved a premature engine start by the flight crew. The aircraft ran forward, crushed a ground worker's foot, and struck a ground power unit (GPU) with one prop, which led to a fire beneath the aircraft's engine. In that event, the cabin attendant ordered an evacuation without communicating with the flight crew and three passengers incurred minor injuries. The airport fire service extinguished the fire quickly, but the aircraft was destroyed.

Serious injuries to ground workers almost uniformly involve inadequate ramp procedures or someone's failure to follow procedures. However, the range of causal factors illustrates the variety of procedures and other issues that affect ramp safety and that influenced many other ramp events involving minor injuries and/or damage to aircraft and other property.

Just two of the 36 serious injuries to ground workers failed to involve ramp procedures. Those two cases were exclusively attributable to faulty equipment (a loader with faulty brakes and a collapsed tail strut). Several other cases included inadequate equipment, as marshalers or wing walkers worked with headsets in which short cords restricted workers' movements or caused them routinely to operate too closely to nosewheels.

Four of the 36 cases involved flight crews who failed to follow procedures. In two cases, flight crews failed to follow braking procedures on pushback, while two other flight crews failed to follow engine-start procedures (causing jet blast). These four cases led to severe injuries (loss of limbs or crushing injuries), plus damage to other equipment and a fire at the gate in which an aircraft was destroyed. The four cases also involved two ground crews who failed to follow procedures and one example of inadequate procedures, when a tow bar disconnected and the operator had no procedure for handling the situation. The real point of these four cases is that surface workers are not the sole source of procedural shortcomings.

The remaining 30 cases involved ground operating procedures or failure to follow those procedures. Many cases also involved inadequate training—procedural issues applied to a broad range of ground activities, from marshalers and wing walkers (about half the cases) to operators of tugs, catering trucks, fuel trucks, baggage loaders, buses, maintenance vehicles, and others. The most common issues involved marshalers and wing walkers. Their procedural failures typically involved failure to follow procedures for communicating with each other, failure to observe that other workers had not cleared the area, or simply operating too closely to aircraft. However, in many of these cases, standard operating procedures were found to be inadequate or absent. Other serious injuries involved procedures and training for drivers and operators of catering trucks, buses, fuel trucks, baggage loaders, etc. Drivers often simply failed to yield the right of way to aircraft, drove too fast, or drove outside of designated areas.

The role of organizational culture

The repeated issue of procedures and limited training of ramp workers implies a fundamental cultural issue in the industry. The notion of culture is cited here almost apologetically, because culture too often is glibly suggested as an avenue to a safer system. Conscious efforts to change an organization's culture assume at least the following: (1) we can come to understand and articulate the existing culture, (2) we can identify the direction in which the culture should change and the characteristics that it should adopt (sometimes remarkably arrogant notions), and (3) we can intervene and actually bring the organization to the prescribed set of values and behaviors. Simply put, these are not easy tasks and are not suggested here lightly.

Nevertheless, common and repeated procedural issues imply a certain sense that ramp events and injuries may be one of the inherent costs of doing business. Worse, they might even indicate a willingness to absorb injuries to that segment of the workforce, while simultaneously working hard (and properly so) to reduce injuries to flight crews, cabin crews, and passengers. Injuries to flight attendants, though few in number, also may reflect a cultural value in which we simply fail to treat the ramp area as part of "flight." Clearly, a treatise on organizational culture is beyond the scope of this paper. Yet culture may be the most pervasive issue in the entire dataset.

Summary of fatal and serious injuries

Ramp workers accounted for 14 of the 17 fatalities and 36 of 53 serious injuries. Most worker fatalities occurred on departure or preparation for departure, as was the case with serious injuries to ramp workers (36 of 53 serious injuries recorded). However, most serious injuries to passengers occurred during arrival. The most common fatal scenario involved ramp workers being struck by props (eight of 14). Injuries by props also explained five serious injuries to ramp workers. Fatal injuries seldom include aircraft damage; they typically result from severe falls or being struck by an aircraft, including props. Turboprops were over-represented in fatal accidents (nine of 17) and in serious injuries to passengers.

Events with minor injures and aircraft damage

The large majority of ramp incidents involve only damage to aircraft and other property, and minor injuries. Several classes of events are describe, below.

Aircraft and surface vehicles. The most common scenario, by far, involves a single aircraft and a surface vehicle. Of the 679 events studies, 271 (40 percent) were aircraft-vehicle collisions. Of the 271 events, 15 percent were related to flight crew procedures (failure to follow guides, failure to set brakes, misjudging clearances, inappropriate engine-starts). Again, this makes the point that surface workers are not the only issue.

Another 15 percent involve either ramp conditions, such as ice and snow or clutter, and inappropriate equipment being used. In most cases, the carrier is responsible for the condition of the ramp area. Still another five percent involve inadequate or absent company procedures. As noted above, these figures might imply cultural issues as much as anything else.

Yet, a significant majority (nearly two-thirds) of all cases involved procedural and training issues among surface workers. By far, the most common failures involved marshalers by failing to ensure all-clear behind or beside a moving aircraft, misjudging clearances, failing to follow communications procedures, and failure to follow chocking procedures. However other ground workers were prominent in this group as well, including, in priority ranking, tug operators, fueling operators, baggage cart operators, catering truck operators, operators of other vehicles, loader operators, bus drivers, and, finally, drivers of lavatory service vehicles. This varied list is a good indication of the breadth of issues inherent in ramp safety.

Aircraft-to-aircraft contact. The next most common type of event captured in the aviation data is aircraft-to-aircraft contact in the ramp area. These events typically produce substantial costs but rarely lead to injuries or severe aircraft damage. The 141 such events (282 aircraft) produced no hull losses, but 34 aircraft with substantial damage (qualifying as accidents) and 234 with minor damage.

Again, marshaling procedures accounted for half of all cases, with issues similar to those in aircraft-vehicle collisions, such as marshalers out of position, failing to confirm all-clear, misjudging clearances, communications, etc. Besides marshalers, one-third of these events involved routine procedural failures by flight crews (follow instructions of ground guides, engine-start procedures, failing to set brakes, etc.). The other common factors involved ramp conditions and inadequate company procedures (a combined 25 percent of this group). Issues included using untrained mechanics to marshal aircraft, operating in inadequately designed gate areas, etc. Half of the cases occurred on arrival, 40 percent on departure, and 10 percent during repositioning by mechanics.

Aircraft and jetways. Aircraft striking jetways is the remaining common (and expensive) scenario (54 of the 679 events). Three of every four such events are related to marshalers' being out of position, misjudging clearances, and communication failures. However, 15 percent also involved procedural failure by jetway operators, with 11 percent involving flight crew procedures, and 9 percent involving ramp conditions, especially snow and ice. Company procedures were an issue in several cases, as were other surface workers (such as tug or truck operators striking jetways during boarding or deplanement).

Jet blast. Jet blasts accounted for just 41 of the events. Repositioning by mechanics accounted for 20 percent of the cases, while the remainder were evenly split between arrival and departure. However, 62 percent of this group involved flight crew procedures (not double-counting mechanic operators) due to inappropriate engine-starts, adding thrust in close spaces, not following instructions, confusion upon entering ramp areas, etc. A relatively modest 14 percent of these cases involved the performance of surface workers (marshalling errors and injuries from walking too close to the aircraft). Carrier procedures also explained several of the cases.

Jet blasts, of course, can move all sorts of equipment and debris. As a result, the damage associated with jet blasts is significant. The events identified in this analysis included damage to terminals (glass and structures), damage to 20 other air carrier aircraft, jetways, hangars, vehicles, and other ground equipment.

Aircraft and other property. Similarly, aircraft striking an assortment of other property, including terminal, construction facilities, temporary structures, light poles, etc., was fairly common (91 of the 679 events). Three-quarters of these events involved procedural and/or training issues among surface workers. Marshalers and wing walkers were the most common group, but baggage handlers, tug operators, truck operators, and others also were part of this group. Flight crew procedures were issues in 30 percent of the cases (misjudging clearance, follow guide, set brake, communication, inappropriate engine-start, etc.). Ramp conditions (11 percent), equipment failures (6 percent), and company procedures (6 percent) accounted for the remainder.

Summary of damage accidents and incidents

The large majority of events involving damage to aircraft and property, rather than fatal or serious injury, but they are hardly without risk. Clearly, procedural issues are overwhelmingly dominant, both for ground workers and for flight crews. However, ramp conditions and company procedures are significant issues. Some of the scenarios outlined above shared many characteristics but each category had a slightly different profile from the others.

Part III: Cost of ramp accidents and incidents

In 1994, the United Kingdom's AAIB estimated that the cost of ramp accidents and incidents equaled about $2 billion annually in the early 1990s among the air carriers of Western countries, or about half of the industry's losses during the economic downturn of that era. [3] This paper finds that ramp events now cost about that same amount just among U.S. air carriers.

Direct costs are fairly straightforward. They include the cost of any injuries, damage and repairs to aircraft, structures, vehicles and other property, the cost of staff overtime, the cost of hotels for stranded passengers in the event of cancelled flights, etc. However, these sums are modest when compared to indirect costs, such as network costs associated with cancelled flights, down time for aircraft (often extensive), the cost of leasing replacement aircraft, the cost of replacement staff or other types of staff reallocations, permanently foregone trips by travelers, some loss of customer base, temporary or even extended loss of gates, possible costs to other carriers sharing a terminal, the costs of defending or settling litigation, etc.

Modest estimates put indirect costs at three to five times the scale of direct costs (see Flight Safety Foundation, Borener at U.S. DOT, and others). Qantas has estimated ratios of 7 to 1, while other go very much higher. We can remain on the conservative side with an assumed ratio of just 4 to 1 and still easily make the case that the total cost of ramp accidents and incidents is on the order of $2 billion a year in the United States alone. Assuming a higher ratio could increase the estimated costs proportionately.

Either way, the events identified for this paper averaged direct costs of about $600,000. This is much higher than most estimates of average costs, but it is reasonable if we recognize that NTSB and FAA databases are more likely to capture the more severe outcomes. Note, too, that most databases in the United States and likely elsewhere as well do not capture aircraft-to-aircraft events very well. As a result, the average direct cost of $600,000 in this dataset does not seem out of line. However, in the interests of remaining conservative in the estimated costs, we can also assume a more modest average that the more common estimate of about $250,000 in direct costs for events not captured in this document.

In the end, $2 billion annually to U.S. carriers is a very substantial figure. However, it is very likely on the conservative side.

Conclusions

Ramp areas can be intensely busy, confined spaces, in which a seemingly endless variety of aircraft, vehicles, equipment, and people are moving about. Consequently, ramps pose real safety threats for passengers, crew, and, especially, for surface workers. Accidents and incidents in this environment occur frequently and impose very substantial costs on the industry.

Very nearly all of the 679 ramp accidents and incidents addressed in this paper involved procedural failures of one sort or another, while training and inexperience also were common issues. Procedural failures among surface workers were especially common, but flight crew procedures also were involved in about 25 percent of all cases. Ramp conditions (especially ice and snow) and inadequate company procedures also were common issues. All these issues imply a more fundamental cultural issue within the industry.

The question, though, is what to do about ramp accidents and incidents. Advocating better procedures, better training, and "culture change" often is no more useful than finding that "everyone needs to be careful out there." Yet, action can be taken on these fronts, provided that companies sustain the effort over time. If they do so, they can establish meaningful and clear procedures, they can train to those procedures, and they can begin to transmit the fiscal and safety value of the procedures. The procedural and training issues also need to address the full range of ramp and gate operations, as illustrated by the variety of basic scenarios and their respective characteristics.

However, carriers are far from the only organizations that need to take some action if the ramp is to be made a less risky and less costly place. The paper indicated repeatedly that a wide variety of players are involved, including air carrier employees and management, but also the employees and management of all sorts of service providers, such as toilet services, fueling services, catering services, etc., as well as airport authorities and others.

Finally, government, too, needs to improve its role in the field. At a minimum, the regulatory role between the FAA and OSHA needs to be clarified (the two agencies have been working toward that end for several years). At a minimum, both agencies, particularly the FAA, could copy the effort that the United Kingdom undertook after its 1994 conference. That is, commit to ensuring better reporting of events and the development of a much more reliable database. That would enable better analysis and, presumably, better understanding of the characteristics of these events and their appropriate actions required to reduce the risk and costs associated with them. ◆

Footnotes

[1] Donald, Nick and Fuller, Ray, "The Management of Safety on the Airport Ramp," Aviation Psychology and Practice, page 68.

[2] Aviation Safety Reporting System, NASA; April 1995.

[3] See "Ramp safety" in *Aerospace*, March 1995, page 8.

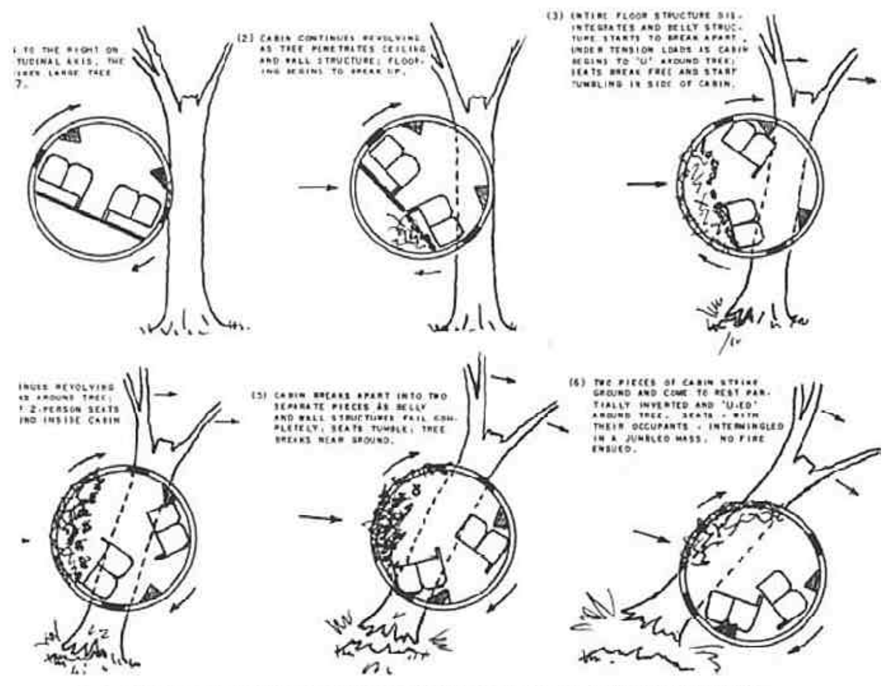


FIG. 7. VIEW (THROUGH SECTION A-A OF FIG. 8) LOOKING FORWARD THROUGH REAR CABIN AREA DURING IMPACT WITH TREE.

SESSION VI

Accident Investigation In Brazil

By Col. Marcus A. Araújo da Costa, Chief Aeronautical Accident Prevention and Investigation Center (CENIPA), Brazil, Keynote Speaker

I. Introduction

Brazil is a country full of contrasts. While having the largest rain forest in the world, Brazil also has one of the top five most populated cities, São Paulo with more than 20 million people.

As to aviation, Guarulhos International Airport, in São Paulo, is the biggest of its kind in Latin America. Countrywide, there were 75 million passengers going through Brazilian airports in 2002. Brazil has the second largest corporate aviation fleet, ranking second only to the United States. Embracing an area of 3,286,170 sq miles (8,511,180 sq km), a little bigger than the continental United States, Brazil poses a challenge for safety investigators to carry out their task, not to mention economic constraints imposed by a developing nation reality.

The Brazilian Aviation Safety System (SIPAER) was designed to help safety investigators cope with local characteristics. In other words, SIPAER paves the way for a cheaper and more dynamic accident investigation. At first, we will cover how SIPAER is structured, showing the safety "links" spread throughout the country. Following that, the main seven areas in which Brazil is divided for safety purpose will be discussed, along with their safety assignments. Here, one will see the advantages of having regional jurisdiction for accident investigation, including who the investigation board members are, who pays for the costs, and so forth. Finally, it will be shown how Brazil is improving safety at airports, where almost 70 percent of the accidents take place.

II. SIPAER (Brazilian Safety System)

SIPAER stands for Aeronautical Accident Prevention and Investigation System, which is in charge of all safety matters in Brazil. The Aeronautical Accident Prevention and Investigation Center (CENIPA) is SIPAER's central office. CENIPA is located in Brasília and is under the Chief of Staff, who reports directly to the Air Force Commander.

As a system, SIPAER has a dynamic and modern structure, allowing an expeditious flow of information without bureaucratic drawbacks. All airlines, commercial, regional, or commuter, as well as aircraft manufacturers, flying schools, Air Force Bases, and so on, are required to have a safety office in their organization structure. All those offices, called "safety links" (SIPAER jargon), report to CENIPA and to one another on a systemic basis.

In summary, CENIPA (hereafter also called the Safety Center) is the top supervisor for every single aircraft accident and incident investigation performed in Brazil, regardless of whether it involves domestic or international flights, civil or military planes.

A lot of accomplishments have been attained at the Safety Center, which is aiming to further improve accident prevention.

III. The investigation process

For civil aviation, SIPAER has seven main Regional Safety Offices—RSOs (located at the Civil Aviation Regional Divisions) and one main supervisor at the Civil Aviation Department (DAC). The RSOs are responsible for investigating any accident in their respective areas, except occurrences involving aircraft operating under RBHA 121 (equivalent to FAR 121) that are in charge of the DAC. Since the RSOs are distributed throughout the country, there is no "Go Team." Even for accidents with RBHA 121 operated aircraft, investigations are initiated by the respective RSO until the DAC takes over the process. All accident reports go through an Accident Investigation Chain (AIC), in which CENIPA is the final step. Should any agency in the AIC be unsatisfied with the investigation, the report can be returned to the investigation board for further analysis.

CENIPA is solely responsible for issuing the final report and for controlling and supervising all safety recommendations, which are compulsory in Brazil. Besides being in charge of investigating the majority of aircraft accidents, the RSOs play an important role in the aviation community. Knowing most of the pilots and mechanics in their region, the RSOs can properly address seminars and speeches to locals. Safety surveys are also conducted in repair stations, operators, flying schools, etc. Furthermore, there is a good and professional relationship with airport managers, who are always at hand in allowing facilities for safety meetings.

As to the investigation team, the board is composed of both civilians and militaries. At this point, it is worth noting that civil and military pilots in Brazil share the same knowledge in accident investigation, since all investigators graduated from CENIPA and take the same course.

The course is a 7-week training program with seven classes a day. There are more than 40 different instructors (airline and air force pilots, engineers, psychologists, airport personnel, etc). The course is free of charge for nationals, and foreigners pay a nominal fee. Students are faced with wreckage investigation techniques in the crash laboratory, which reproduces around 8 actual aircraft accidents. Up to now, CENIPA has graduated more than 5,000 students, with representatives from 18 States, mainly from Central and South America.

The required Accident Investigation Board has a minimum of six members, including pilots, aviation doctors, and psychologists, and follows Annex 13 from ICAO. Costs for accident investigations are paid by the government, heavily using Air Force Command resources. Both CENIPA and the Civil Aviation Department are headed by Air Force officers. Given that most accidents occur close to airports, CENIPA has decided to focus on that area.

IV. Safety in the airport

Sixty-eight percent of accidents involving civil commercial jets occur in the takeoff, initial climb, final approach and landing phases, which means in the vicinity of airports, with ALAs (approach and landing accidents) accounting for 56 percent of accidents and 44 percent of all fatalities.

Accident investigation, as we all know, has the purpose of preventing other occurrences, thus making air transportation safer. A good and thorough investigation requires complete and prompt actions right after the event. Keeping this in mind, CENIPA has developed a safety course for airport personnel, since they work close to where nearly 70 percent of accidents take place. By doing so, the Safety Center ensures that mishaps occurring around or in the airport will be handled accordingly from the beginning.

As to accident prevention, it is important to remember the benefits received from airlines, passengers, and by the airport manager. To illustrate this, most reports that the Safety Center has received related to hazards and incidents, which otherwise would probably have gone unreported, come from airport safety specialists. A healthy safety culture has been implemented in almost all Brazilian airports.

The course, Accident Prevention Course—Airports, is offered once a year. Subjects covered include but are not limited to airport emergency plan, airport safety survey, bird strike, defensive driving, dangerous good handling, apron safety, hazard report management, basic investigation techniques, etc. So far, more than 800 people have attended that course. Today, each of the 65 Brazilian airports handling 97 percent of the total aviation operation has three or more safety staff graduated from CENIPA.

In Brazil, maybe elsewhere, when we talk about airports, the word "bird" pops up in our minds, since most bird strikes occur in the neighborhood of aerodromes. In fact, millions of dollars are spent yearly worldwide as a consequence of bird strikes, not to mention lives lost.

The main domestic problem is related to a one-of-a-kind black bird, "urubu" (Coragyps Atratus). Although other birds have been counted in our statistics, the urubu is the most difficult one to deal with. Its favorite dish is spoiled or deteriorating meat, playing an important role in the ecological system and being a frequent customer at landfills and dumps. It has a 1.5 m average wingspan and weighs about 1.6 kg, flying in thermals and reaching high altitudes.

The urubu has been resistant to all countermeasures used so far. The use of falcons ("falconry") did not work, neither did ground deterrent devices, like gas cannons. A lot has been tried to correct the problem, but nothing worked until 1995, when the National Bird Strike Committee was created. Its major achievement to date was to have a Resolution (similar to a law) enacted by the Ministry of Environment in 1995. That resolution instituted the Airport Safety Area (ASA), making illegal the establishment of any activity that attracts birds in the vicinity of airports, including, landfills, slaughterhouses, tanning industries, etc. ASA varies in size, depending on whether the airport is VFR or IFR certified. For VFR operating airports, the ASA radius is 13 km, and for IFR airports the ASA radius is 20 km.

Having just one hybrid safety system, Brazil has made significant progress in the accident prevention and investigation arena, despite its challenging economic reality. Civil and military aviation have benefited the most from such a unique system. While the Air Force halved its accident rate in the past decade, major airlines sustained a singular fatality to passengers in the last seven years.

SIPAER has proven to be an effective and efficient system, especially for States with limited resources. ◆

Airline Safety Data: Where Are We and Where Are We Going?

By Timothy J. Logan, Director, Flight Operational Safety, Southwest Airlines Company

***Timothy Logan** is currently the Director of Flight Operational Safety for Southwest Airlines. He previously was employed by Northwest Airlines where he held positions of Manager and Director of Flight Safety and Quality Assurance from 1992 until 2001. From 1983 to 1992 he was with the Air Line Pilots Association in the Accident Investigation Department. Prior to 1983, Logan was a Boeing Flight Test Analysis Engineer. Logan holds a bachelor of science in aeronautical and astronautical engineering from Ohio State University and an MBA from George Washington University, with emphasis in the management of science, technology, and innovation. He also holds a private pilot's license. He has participated in numerous industry efforts involving flight data recorder specifications and requirements, flight safety data exchanges, and flight data analysis program development.*

Abstract

Airline safety has evolved to a level where a hull loss accident is now a random event. Airline safety offices do not concentrate on honing accident investigation skills but rather in the investigation of multiple-incident investigations with the intent of preventing or limiting the contributions of system breakdowns in our complex and dynamic operations. Through collaboration with the FAA and employee labor organizations, the airlines have implemented voluntary safety programs based on a voluntary employee self-reporting philosophy. These programs are the aviation safety action program (ASAP) and flight operations quality assurance (FOQA). The initiation of these programs has enabled significant sophistication in the airline safety programs and has brought with it a large increase in information that must be dealt with systematically to be effective.

This paper intends to discuss the development of these important safety programs, their safety contributions to accident prevention, limitations and barriers to effective utilization of the safety data, current industry information sharing efforts, and a look at what the future might hold. The paper will also discuss how the accident investigator may effectively use this information should a carrier involved in an accident have any of these programs.

Introduction

Airline safety offices have evolved from strictly incident investigators of highly visible events to the programs of today that include sophisticated processes involving the analysis of an enormous amount of data on a daily basis. With the advent of these progressive processes, the airline safety programs have been able to move away from employing traditional investigation techniques toward a process involving the identification and implementation of corrective actions to those accident precursors that occur in daily operations.

Along with these new abilities have come new concerns about the handling and the analysis of this data on a regular basis. In addition, the two programs, ASAP and FOQA, have for the most part developed independently of each other, somewhat limiting the ultimate benefits of these two important programs.

This paper will highlight the development and future of FOQA and ASAP programs from an airline safety office perspective. The use of the information from these programs will be discussed from an industry safety perspective in addition to how it relates to NTSB incident and accident scenarios and procedures.

Past airline flight safety office practices

Incident investigations

For the most part, up until approximately 1995, most U.S. airline flight safety offices were, in effect, mini NTSB programs that performed post-occurrence investigations of incidents. Accident prevention was based on the findings of these investigations. This type of process was and is very labor intensive and time consuming and was not conducive to the rapid pace of the growing airline industry that we experienced in the late 1980s and 1990s.

Flight data recorders

Prior to the introduction of FOQA and ASAP, flight data recorder (FDR) analysis was done on individual events, so there was little, if any, information on the actual operation outside what was seen on the FDR and what was stated in the airline *Flight Operations Manual* (FOM). FDR readouts were accomplished to support incident investigations on an as-needed basis. Most airline FDR readout software was not sophisticated and, therefore, did not lend itself to the processing of multiple flights. FDR information contained only minimal parameters that limited its usefulness. In addition, pilot association collective bargaining agreements limited access and use of FDR data that, in some cases, reduced the access to and the effectiveness of this information.

Pilot reporting programs

Most airlines had implemented flight crew reporting programs that served two purposes. The first purpose was to provide a vehicle for reporting of occurrences as required by the FAA and the NTSB. The second purpose was to report safety issues as perceived by the crewmember. While these programs were beneficial if placed in a database with appropriate categorizations, the dual purpose for the reports limited their effectiveness. The FAA's tendency toward enforcement worked against the reporting programs in limiting the quality or detail of the reports as well as limiting the submission, for the most part, to only those required reports.

NASA Aviation Safety Reporting System (ASRS)

ASRS provided crewmembers a place to submit safety issues and to self-report violations by providing the reporting crewmember some administrative relief from FAA enforcement. The ASRS program was and is a huge success and did provide a significant amount of data to be analyzed. It also serves as the base for the development of ASAP and, in a small way, FOQA.

Unfortunately, the carrier safety offices never got to see the ASRS reports from their crewmembers because of the de-identification process involved with the program. In addition, the de-identification involved in the aggregate data available from ASRS limits the usefulness on specific issues associated with the carrier. Also, the submission [1]time frame of NASA ASRS reduces the ability of the airline safety offices from gathering time-critical data that may have been related to an event such as aircraft weight and balance information, weather, and ATC information.

Post-incident crew debriefs

Some airlines developed flightcrew member debrief programs in an attempt to gain more information following incident investigations. In most cases, participation in a post-incident debrief came with relief from company discipline as a motivation for the crewmember to provide the needed details of the incident. These types of program, while effective, still were limited by crewmember concerns of possible FAA enforcement since the FAA was generally not a party to the debrief process but may have had access to debrief results.

ATA Flight Safety Committee

Along with safety information being reported via the ASRS program, airline industry safety information sharing was and still is conducted at the Air Transport Association (ATA) Flight Safety Committee (FSC) quarterly meetings. This process, in place for approximately 20 years, involves the detailed presentation of accident and incident occurrences. This process enables airline safety representatives to share their experiences and to learn about potential problems that might affect their operation. While this process is highly valued by the FSC members, it is very inefficient and the outcome is limited to only those ATA members in attendance.

The programs and processes described above have served the airlines and the traveling public well, but as the accident rate has dropped the need for more sophisticated tools has been recognized. FOQA was well-developed outside of the United States, but significant work on legal and other issues remained to be conquered in the United States to convince the carriers and pilot associations that the risk was worth taking.

The US Airways Altitude Awareness Program and NASA ASRS had provided a road map for the development of ASAP, but there were also significant legal issues to confront. In addition, a huge paradigm shift was needed within the FAA and the carrier's management before ASAP and FOQA could become a reality.

ASAP/FOQA program development

The development of ASAP and FOQA programs has brought a new level of sophistication to airline safety programs. But these new safety tools did not come without a lot of hard work and evolving positions by all parties involved. There is still much work to be done, but significant progress has been made in establishing these programs at most airlines.

Company/pilot association agreements

In most cases, agreements were made under the collective bargaining process that outline the provisions under which ASAP and FOQA programs will be run at each operator. The negotiated agreements highlight the boundaries of the program, what data will be collected, and what process will be used to take corrective action. Possible actions against individual crewmembers are outlined along with confidentiality requirements to ensure individual employees are not specifically identified with events.

ASAP[2]

One specific issue that is pertinent to ASAP is the actions involving sole-source events. Sole-source reports are those reports that provide the only source of information that an event occurred. Since the intent of the program is to encourage reporting, the handling of sole-source reports within the programs is treated differently than those events that are discovered through other means. In most cases, the result is a lessening of the corrective action recommended within the program to the reporting employee(s).

ASAP has been set up as a program based on a three-interested-party system. This involves representatives from the pilot association or employee group, the air carrier, and the FAA. These three stakeholders, normally called the Event Review Team (ERT), participate in the processing of the event information and jointly agree to corrective action that must take place based on the facts of the event. The key factor is that all parties must agree to the recommended corrective action or the program shuts down. This drives the three parties to seek resolution of the event rather than risking the loss of the program. These representatives are also responsible for protecting the confidentiality of the reporting employee to the extent possible and for ensuring follow-up of corrective actions. The employees' accountability stems from the fact that they must comply with the ERT recommendations or risk being removed from the program.

The unique provisions of ASAP foster increased reporting of incidents that, before, would have gone unreported. Most programs report a better-than-90-percent increase in incidents reported that had not been reported before an ASAP was established. In addition, the quality of the reports is improved, providing the safety office increased information on which to formulate corrective actions.

FOQA

One of the key aspects of FOQA programs is the maintaining of confidentiality of flight crews through exhaustive de-identification and data handling provisions. These provisions and other issues pertinent to program data handling are normally outlined in an agreement between the air carrier and the pilot association. In most programs, identification information is limited to a designated "gatekeeper" position normally, a pilot association representative. This position is the only person entrusted with the responsibility of identifying individual flightcrew members. Contact with flightcrew members is not the norm in most programs. The majority of work within the FOQA program is accomplished on aggregate trend information.

Contact with line crews is usually only accomplished when the event cannot be explained through review of the available data and is significant in consequence that further explanation is warranted. As with ASAP, the decision to contact a crewmember is usually a joint decision between the airline and the pilot association members of the FOQA team.

The FAA is not a direct party to the FOQA program within the airline, though regular briefings with the carrier Certificate Management Office (CMO) are conducted.

In many programs, identification information has a shelf life. To ensure confidentiality, the identification information is automatically and permanently erased after a period of time, normally 7-10 days. Thereafter, aggregate trend information can be analyzed, but individual flights cannot be identified.

FAA actions

The FAA has taken considerable action to assist in the promotion of FOQA programs and should be commended on its commitment to these important programs.

FOQA Rule 13.401

On Oct. 25, 2001, the FAA published Federal Aviation Regulation (FAR), 14 CFR 13.401, on flight operational quality assurance programs. This rule outlines the enforcement protections for approved FOQA programs. Except for criminal or deliberate acts, the Administrator will not use an operator's FOQA data or aggregate FOQA data in an enforcement action against the operator or its employees under an approved FOQA program. This is an important step in the development of FOQA programs in the United States and one the carriers and pilot associations supported. This rule has allowed the development of voluntary FOQA programs at all major airlines within the United States. The airlines have invested millions of dollars in equipment, software, and personnel, and well over 1,000 aircraft are now providing data on a continuous basis.

Part 193 FOIA Designation

On June 30, 2003,[3] the FAA designated approved FOQA programs, under the provisions of 14 CFR Part 193, exemption from Freedom of Information Act (FOIA). This designation fosters the sharing of voluntarily provided FOQA information with the FAA. The intent of this designation is to ensure the confidentiality of individual flightcrew members, along with preventing the identification of individual airline FOQA information when information is provided to the FAA.

This designation was another important milestone in the development of FOQA programs sought by both the airlines and the pilot associations. The intent of FOQA programs is to improve flight safety. Without this provision, it would have been very difficult for the airlines to agree to share safety information derived from FOQA programs for fear of the information being used inappropriately. It is hoped ASAP will soon be included as a Part 193 designated program.

Advisory circulars

The FAA has published an advisory circular (A/C) on ASAP. The A/C outlines the provisions of an ASAP, along with procedures on how a program can be developed and established as an FAA partnership. A corresponding A/C for FOQA programs is under development and publishing of the FOQA A/C is slated for late 2003. These documents provide the baseline for the development of these programs within the air carrier industry and also to other large aircraft operators, such as general aviation and even the military.

FAA FOQA Demonstration Project (DEMO Proj)

In the mid 1990s, the FAA established the FOQA Demo Proj to provide seed money to assist the U.S. airlines in establishing FOQA programs. The FAA provided funding to several carriers to enable them to purchase hardware and software to jumpstart their FOQA programs. In addition, the FAA has and continues to sponsor regular forums where air carrier, pilot association, and other industry representatives meet to discuss FOQA program developments, specific program requirements, and lessons learned. Demo Proj has been highly successful as referenced by the number and quality of FOQA programs in existence at both large and regional U.S. carriers. Demo Proj has also helped promote FOQA programs to the U.S. military and also extended carrier FOQA programs to the engineering and maintenance disciplines.

Current status

Airline programs

As of June 1, 2003, there are 12 U.S. operators who have FAA-approved FOQA programs. In addition, the FAA has accepted 40 ASAP programs across 28 operator certificate holder's employee groups including pilots, mechanics, and flight dispatchers. The operators and associated employee unions have responded positively to the FAA actions on enforcement and FOIA relief. The development of either a FOQA or ASAP requires considerable trust among all parties. In light of the recent airline industry environment, the value that has been placed on the programs is very encouraging.

Aviation Rulemaking Committees (ARC)

The Administrator has designated two ARC to assist the FAA in interpreting the FOQA rule and also in fostering ASAP development.

ASAP ARC

The ASAP ARC[4] was crucial in the development and publication of the ASAP A/C. The ARC has also worked within the industry to foster the development of ASAP across airline operational disciplines so that pilots, mechanics, and dispatchers can participate. The Committee was formed to provide advise to the FAA on ASAP policy and has been directly involved in promoting the standardization of ASAP processes and procedures that ensure that the provisions of ASAP are correctly and consistently practiced at all carriers and across operational disciplines. In addition, the ARC provides a source of information for both industry and the FAA on programs that are just beginning. The ASAP ARC has also worked closely with the FOQA ARC on information sharing and data confidentiality issues.

FOQA ARC

The FOQA ARC was chartered as a government/industry forum to provide the FAA with advice on FAA FOQA policy and to prepare recommendations on whether further rulemaking applicable to FOQA is needed. The ARC also functions as a forum between government and industry on FOQA regulations, policy, issues, and concerns.

The FOQA ARC has focused on interpreting the FOQA rule, 14CFR 13.401, specifically the paragraph referring to the form and manner in which aggregate FOQA data will be shared with the FAA. The group has also drafted a FOQA advisory circular that has been presented to the FAA. It is intended for publication in late 2003.

The ARC is now concentrating on establishing a process for the sharing of safety information regarding industry safety issues identified by FOQA. The ARC has two goals. The first is to recommend to the Administrator a method for compliance with the provisions of the FOQA rule requiring the operators to submit aggregate FOQA data to the FAA. The second, and more important, is to establish a process whereby the industry can leverage the additional information provided by FOQA to address industry safety issues in a proactive manner.

Industry data sharing

Collecting safety information is easy. Analysis of this data is always the challenge. The development of FOQA and ASAP has greatly exacerbated the scope of this problem. While there isn't an ASAP or FOQA manager who can't point to major successes from their program, they also, to a person, will tell you they have more data than they are able to definitively analyze on an ongoing basis. Unfortunately, both of these programs have developed, for the most part, independently from each other. For data security reasons, along with simply the specific characteristics of the information sources, collectively using this new-found safety information is a challenge. This problem is magnified significantly when the idea of sharing or combining safety information across airlines is concerned.

The independent development of both ASAP and FOQA has resulted in a lack of industry standards on data collection, issue classification, and issue detection. The lack of standardization works directly against facilitating industry data sharing. One of the key aspects of the development of the ASAP and FOQA programs in the United States is that the airlines have been able to grow these programs to fit their respective cultures. While this assists greatly in fostering an entrepreneur-like flexibility in these programs, it provides an obstacle in implementation of safety information sharing across carriers. These are not insurmountable obstacles, just factors that must be included as the industry discusses how to accomplish the sharing process.

So how do we do it? We first must understand the specifics of each of the two programs. We also must have an idea of what we want to accomplish. The biggest mistake we can make is to create a giant database of FOQA and/or ASAP information without planning how we are going to classify, analyze, identify, implement, and measure safety enhancements. We must always focus on the fact that the purpose of collecting the data is to identify areas where the failure can or may occur. Once these failures are identified, the subject-matter experts in the design, training, and procedural development aspects of our industry must be provided the information to effect implementation. Safety information has to be continually monitored and adjusted to account for the changing environment affecting the industry and also to enable measuring of the effectiveness of the safety enhancements.

Information from FOQA must be integrated with ASAP in a way that the safety personnel not only know what happened but also why it happened. The similarities between the flight data recorder and cockpit voice recorder and FOQA and ASAP should be obvious. The difference is that we may be dealing with terabytes of FOQA information and hundreds of ASAP reports, not a single FDR readout and CVR transcript. In addition, we often lack air traffic control transcripts, current weather, flight releases, or aircraft maintenance records to assist us in the investigation. Safety analysis takes on a whole different dimension with these programs. Let us take a look at the individual program specifics in an attempt to highlight the benefits and limitations of these two important safety programs.

FOQA

FOQA consists of the continual review of flight data downloaded from aircraft at regular intervals during line operations. There are three critical aspects of FOQA programs that must come together for a successful program to function. The first involves data acquisition, the second involves program quality control, and the third involves data analysis and the application of findings to the operational environment.

Data acquisition involves the flight data recording and transportation of the data to the Ground Data Readout and Analysis System (GDRAS). The flight data for most FOQA programs are recorded on quick access recorders (QAR) or as a function of an Aircraft Conditioning and Monitoring System (ACMS). In some cases, the parameters can be selected by the operator; in other cases it is an exact copy of what is being recorded on the FDR.

In most programs transporting, the data from the aircraft to the GDRAS usually involves some time delay. This is primarily due to the nature of airline operations in that the opportunity for download of the data occurs in scheduled overnight maintenance. Since this may occur away from the FOQA office location, transportation of the data may also take a day or two. FOQA data may be 5 to 10 plus days old before it is analyzed so timeliness is an issue regarding practical tactical application to aircraft that have continuously operated during the data transfer process. Moving data from the aircraft to the GDRAS for analysis poses a significant portion of the operating costs of a FOQA program. The data transmission issues and related costs in FOQA programs will eventually be reduced or possibly eliminated as wireless technology evolves, but currently this is still, for the most part, a labor-intensive and costly function resulting in a time delay before FOQA data analysis can take place.

Quality control management of the data in FOQA programs is a continual effort requiring coordination between the FOQA office and the airline engineering group. This is a fertile ground for errors in the FOQA program that must be recognized during any data analysis. Just as important to accident investigation FDR readouts are the maintenance and quality control of the recorded data from the aircraft. The logical frame layout (LFL) or format of the data recorded on the aircraft must be maintained and documented. Also any changes in the LFL must be included in software that may be loaded in the aircraft and also for the GDRAS. Lack of quality control can adversely affect data analysis and credibility of the FOQA program.

The third aspect, data analysis, involves the conversion of the digital flight data and analysis of the data into useable information. Once the data reach the FOQA GDRAS, they must be converted from digital format (zeros and ones) into engineering units (feet and knots, etc.). Once converted, the data can then be analyzed. FOQA analysis has evolved in the last 10 years moving away from just measuring exceedences from specific points or parameter values to a statistical distribution-type analysis. The distribution analysis involves collectively analyzing all of the data in a specific area of interest, let's say takeoff, to identify normal operational patterns and then look for deviations from normalized distributions that can assist in identifying incident causal factors.

This type of analysis is very powerful in that it enables the analyst to continuously monitor normal distributions and how they relate to the carrier policies, procedures, and training program and effect change directly. The GDRAS software today is very powerful, enabling hundreds of data points to be taken throughout the flight. Therefore the benefit of the information is in the large amount of aggregate data, not the individual flights that deviate from the normalized distribution. Significant deviations from the expected performance can be dealt with in most programs, but experience has shown that the more significant benefit is derived through monitoring and management of the entire distribution as opposed to the individual event.

The remaining portion of the analysis aspect involves feeding of the safety information to the subject matter experts (SME) within the organization who can act on the findings and implement corrective action. These SMEs may include flight training, airline engineering maintenance, line employees, airline ATC specialists, and others who are involved in the development of airline policy and procedures. A key part of this aspect is the continual monitoring of the line environment to enable the SME to follow up on corrective actions to judge their effectiveness and, if need be, further modify the actions previously implemented.

These aspects of a FOQA program in a large airline must occur within a system consisting of 100 plus aircraft operating all over the country or all over the world, 365 days a year. The information downloaded and analyzed involves terabytes of data per year. It also requires a significant amount of continual coordination within and across airline departments from flight operations, engineering, information technology, and line maintenance. The program also requires a partnership among the airline management, the FAA, and the pilot association because of the data security issues and potential for misuse of the data.

ASAP

ASAP involves the filing of written reports by line employees involved in possible FAA violations or experiencing events that in their minds compromise safety. The reporting employees are provided a motivation to file the report through reduced enforcement action in the form of administrative action. ASAP reports are subjective and involve the observations of single individuals. ASAP data also do not represent a 100 percent data set of incidents but in most cases a subset of actual events occurring. Estimates are that ASAP reports received may constitute only 10-50 percent of actual events. The actual percentage will never be known, but it must be considered when accomplishing any analysis of ASAP information.

As in FOQA, ASAP information is de-identified to the extent possible to preserve the confidentiality of the information. In fact, most programs involve some aspect of permanent de-identification once an event has been closed out by the ERT. While this helps to maintain the critical relationship between the stakeholders within the program, it does adversely affect data analysis.

ASAP reports in most programs, if not all, are stored in a relational database for record keeping and to perform data analysis. Some sort of classification of each event into the category or causal factor is normally accomplished. Examples of the classification would include *rejected takeoff, go around, and altitude deviations*. Some airlines go further and add causal or contributing factors such as *distractions* or *blocked frequency* to describe the event. The classifications can then be used to accomplish data analysis to identify the most significant issues being reported. The factors can then be applied to the operation and corrective action can be identified and implemented. Some airlines apply formalized risk-assessment practices to prioritize corrective action development and to conserve resources.

A somewhat untapped source of information involves the analysis of the written text provided by the reporting employees in ASAP. Several airlines are experimenting with applying text-mining software, developed within the intelligence field to analyze ASAP reports to identify trends or relationships. While this experimentation is in its preliminary phase, it does provide promise in assisting in the analysis of the hundreds of ASAP reports received on a monthly basis containing large amounts of textual information. Text mining can be used on its own or in combination with existing classification processes to assist in data analysis. It may also be instrumental in assisting in analysis across airline ASAP information because it places less emphasis on classification schemes to identify issues.

The industry has not successfully developed a standard for classification of the ASAP or hazard reporting processes. Therefore the airlines have for the most part developed this aspect of ASAP independently. While it is important that each ASAP fit the culture and resources of each airline operation, the lack of standardization of event classification works against facilitation data aggregation across airline operators at the industry level.

Implementation of industry safety information sharing

As FOQA and ASAP have developed, the industry has realized that there is value in using this information to address industry issues. There are issues identified in these programs that the airlines can't fix through modification to their existing policies, procedures, or training programs. Issues involving ATC procedures, airport issues, or aircraft system design and operation can not readily be changed by the airlines. Collectively, information from multiple carriers identifying a specific issue can be raised to the appropriate SME at the industry level for implementation of corrective action. Already, individual FOQA programs have identified ATC, aircraft, and airfield issues. Collectively, a process that applies the information from multiple carriers on a regular basis can provide a promising source of information that can be used to eliminate or reduce accident precursors.

In theory, the aggregation of industry data for safety purposes sounds like a great idea. In practice, there are significant technical and procedural issues that must be addressed for the program to be successful. Most of the technical issues have been discussed above. While these should not be trivialized, an equally important aspect of industry safety information sharing to be addressed is what track does an issue take once it has been identified and who has accountability to ensure that corrective action is implemented at the industry level? ASAP and FOQA are centered in the FAA Flight Standards branch. How does an issue that involves ATC, airports, or aircraft certification get transferred with accountability and follow up to the other branches of the FAA? Also, how does this safety information get transferred to airframe or engine manufacturers with the same accountability and follow-up? The industry can develop a giant database containing FOQA and/or ASAP information from all of the carriers, but it will be a wasted effort unless we can solve the implementation and accountability aspects of an industry process. As in any safety program, the goal for industry data sharing should not be how much data we can collect but how many safety issues are identified and addressed. This should also be the goal of the industry safety information sharing process.

Currently, through the FOQA ARC, the industry is attempting to create such a process with the emphasis not on creating a database but more importantly creating a forum where the industry safety issues can be addressed. The ARC is attempting to address the technical barriers to the aggregation of safety information across carriers along with developing a process or path that the industry can take to effectively use this information to effect change. Like the initial development of FOQA and ASAP, success in the sharing of safety information is not going to occur overnight. It will take a long-term commitment from government, industry, and labor to successfully implement such a process.

FOQA, ASAP, and the accident investigator

The data confidentiality requirements so crucial to the development of FOQA and ASAP directly affect the usefulness of these programs to the accident investigator. The investigators must realize that they will be unable to use existing FOQA and ASAP information to track the performance of individual flight crews. De-identification process in all of the programs will prevent this. FOQA information can be used to track aspects of an individual airframe, but individual flight and date information will not be available after approximately 7-10 days once the information has been uploaded to the GDRAS.

The accident investigator can do great harm to FOQA or ASAP programs through misuse of the information or through not honoring the confidentiality aspects of the program. It is expected that accident investigators, specifically from the NTSB or another authorized authority, will have access to the FOQA ad ASAP information from a carrier's programs should an airline become involved in an accident. What is important is how the investigator uses the information within the context of the investigation and what information is placed in the public docket.

It is important for the air carriers, labor associations, the FAA and the NTSB to get together on this issue as soon as possible to address proper and responsible accident investigation uses of FOQA and ASAP information. In addition, a parallel effort needs to take place at the ICAO level to develop recommended practices or standards on disclosure of voluntary safety program information under Annex 13 investigations. The intent is not to inhibit the investigation process but to properly use the information in accident prevention and at the same time respecting the fundamental building blocks on confidentiality that has been so important to the development of these important safety programs. ◆

Footnotes

[1] Aviation Safety Action Plan Advisory Circular 120-66B, 11/15/02

[2] *Federal Register*: June 30, 2003 (Volume 68, Number 125)] [Rules and Regulations] [Page 38594-38598] DEPARTMENT OF TRANSPORTATION Federal Aviation Administration 14 CFR Part 193 [Docket No. FAA-2003-15468]

[3] Flight Standard Service Order 1110-129, ASAP, July 2, 2001

Use of Computed Tomography Imaging in Accident Investigation

By Scott A. Warren, Lead Aerospace Engineer, Aircraft Systems Investigator,
National Transportation Safety Board, Washington, D.C.

Scott Warren is the Team Leader for the Aircraft Systems Investigators at the National Transportation Safety Board, where he has worked since 1997. He has been involved in numerous accident investigations including the space shuttle Columbia, *Sen. Paul Wellstone's accident, TWA Flight 800, SilkAir Flight 185, and EgyptAir flight 990 investigations. Warren came to the Safety Board after spending 11 years developing and conducting flight test programs for the U.S. Navy. He has a B.S. degree in aeronautical and astronautical engineering from Purdue University and is a graduate of the U.S. Navy Test Pilot School.*

Abstract

When involved in an aircraft accident investigation where aircraft systems components are recovered, a recurring debate among investigators is whether to test the components first and then disassemble the units, or disassemble them first followed by reassembly and testing. Either choice will irreparably alter the results of the other event. Investigators have long looked for a technological solution to help with this decision.

Investigators for the National Transportation Safety Board have recently started using computed tomography (CT) scanning (formally known as computer-aided tomography or CAT scanning) to provide images of the internal workings of selected components. The use of these images has allowed investigators to better understand the internal condition of the components of interest and make better decisions regarding the "test first" or "tear down first" questions.

In this paper, a brief overview of radiological processes is given, with emphasis on the benefits and drawbacks of CT scanning. The paper also presents the results of specific aircraft systems applications of CT scanning used during NTSB investigations.

Introduction

The use of computed tomography imaging in accident investigation has come about from a need to determine a part's exact condition after it is recovered from an accident scene. The primary goal of the aircraft systems' investigator is to determine if a part was malfunctioning at the time of the accident. Once reasonably intact parts are recovered, systems investigations typically follow one of two paths. The parts can either be tested immediately and then disassembled, or they can be disassembled first, then reassembled and finally tested. Both testing and disassembly are activities that can help the investigation; but regardless of which path is chosen first, the part becomes irrevocably altered for later parts of the sequence. Immediate testing can lead to damaging the part or shifting the positions of internal components away from their accident positions. Immediate disassembly can alter the internal arrangement of the part so that subsequent testing after reassembly is not representative of the part as it was recovered.

Previously, the only technological aid available to an investigator who needed to look inside a part was a simple X-ray, also known as a radiograph[1]. While useful in many cases, radiographs do not allow an investigator to get a complete sense of the internal condition of a part. The use of computed tomography or CT scanning has allowed for a quantum leap in information for the investigator. This is due to the greatly improved resolution inherent in that process and the image enhancements available through digital processing.[2]

Basics of radiology

Radiograph

A standard X-ray image or radiograph is the type of image with which the general public is most familiar. This is the type of image most often used by doctors when they order an X-ray (radiograph) of a broken bone. It is made by illuminating a component using an X-ray source and measuring the attenuation of the X-rays after they emerge from the other side. In general, high-density materials within the component will absorb more X-ray energy than low-density materials. The resulting image shows a two-dimensional projection of the X-ray attenuation (or density) variations within the part. Generally, in industrial radiographs (as opposed to medical radiographs), darker items in a radiograph represent higher X-ray attenuation or high-density material, and the lighter items represent less X-ray attenuation or low-density material. In most components, this density variation type of image can be interpreted to show the internal arrangement of the part. In Figure 1, the internal arrangement of a screw-type actuator (from the Airbus A300 directional control system) can be determined. In the image, items such as the actuating screw, wires for the connector, and the connector pins can be readily distinguished. At the bottom of the image, it is more difficult to distinguish items such as gears and shafts.

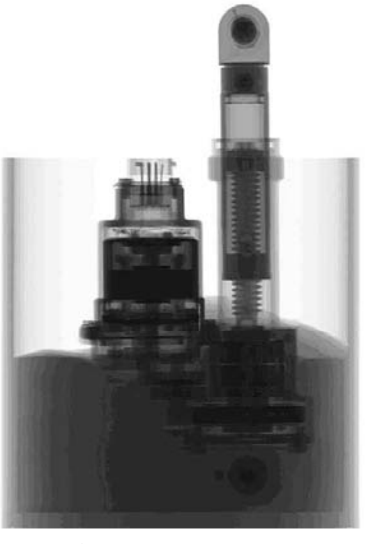


Figure 1

A radiograph may be produced either as a conventional radiograph or a digital radiograph. The difference between the two involves the recording medium used. A digital radiograph uses a photo-detector

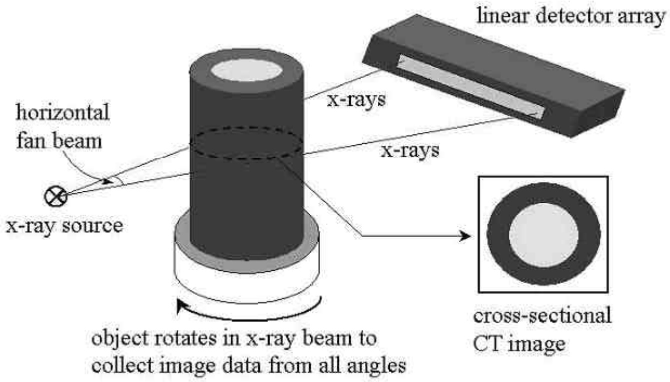


Figure 2: CT image creation.

to record the X-ray intensities while a conventional radiograph is recorded on film. The resulting images are similar in many ways, but a digital radiograph can be processed and enhanced using computer software.

In any case, the limitation of a radiograph is clear—there is no way to determine the complete spatial relationships between the different components from the image. The image presents a two dimensional "shadow projection" of the part with all of the internal components superimposed on each other.

Computed tomography

Computed tomography (CT) scanning is a process where an image is produced by assembling a large number of X-ray projections taken from many different angles around an object. The process of reconstructing an image based on multiple projections has been understood on a theoretical level since the early 1900s. The Austrian mathematician, Radon, provided the mathematical framework for the concept. The first practical application of CT imaging was developed by Dr. Godfrey Hounsfield, and he shared a Nobel prize for this work with physics professor Allan MacLeod in 1979.

A CT image is produced using equipment similar to that used to produce a radiograph. An X-ray source is used to illuminate the object, and then a detector is used to record the resulting X-ray intensity. The X-ray source is designed to produce a very thin beam of X-rays so that only a small slice of the object is illuminated at any one time. After each image is taken, the object is rotated slightly to produce another image from a slightly different direction[3]. Each image is stored in a computer as a single projection. After a complete 360-degree rotation of the object is completed, the computer reassembles the complete CT slice image based on the information contained in each individual projection image. The resulting CT slice image is a thin cross section of the item being scanned (see Figures 2 and 3).

The differences between the radiograph and the CT images can be further explained by referring to Figure 4. In this figure, differences in viewpoints between the two imaging methods are clear. The radiograph produces a shadowgraph containing superimposed images, while the CT image contains an "overhead" view of a single slice of the objects.

In creating the image, the computer assigns a digital gray level value to each image pixel (picture element) based on the X-ray attenuation values. The pixel size is dependant on the field of view of the detector and the number of pixels in the image. Typically, images used by the NTSB have pixel sizes on the order of 0.25 millimeters. Since a CT image represents a slice of finite thickness, each pixel in the image represents a very small volume of the object being scanned. The slice thickness, combined with the pixel area, creates a volume of material represented by the brightness value assigned to each pixel. When discussing CT images, the term "voxel," meaning volume element, is commonly used instead of the term pixel.

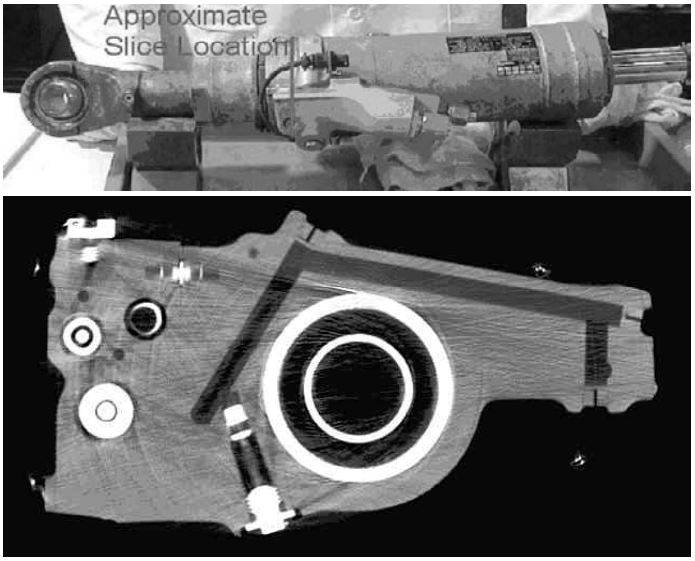


Figure 3: Airbus A300 servoactuator (top), axial slice CT image (bottom).

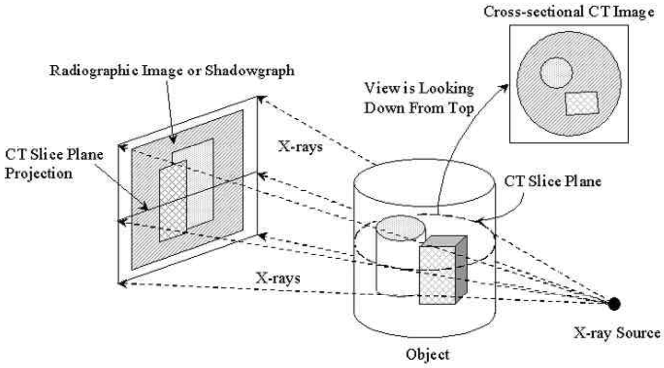
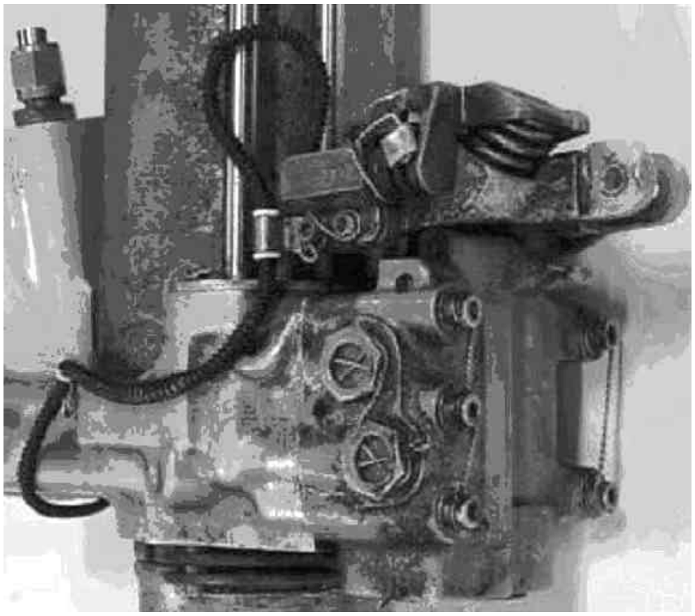


Figure 4: CT and radiograph image creation.

The CT scan equipment can be adjusted to create slices of various thicknesses. A thin slice (on the order of millimeters or even a fraction of a millimeter) is desired since the image properties (gray level value) for each location within the cross sectional image are based on an average of that location's material properties throughout the entire thickness of the slice. Images created using thick slices will have brightness values assigned to a given voxel based on a wide range of densities contained in the slice. Thinner slices have a smaller range of material densities contained within them, so the gray level values assigned to each voxel provide better resolution. Typically, images used by the NTSB have slice thicknesses on the order of 1 mm or less.

By combining many of the slice images together, a three-dimensional image can be created. Since each slice represents a thin volume of the object being scanned, software can be used to reconstruct the full object's volume. The upper image in Figure 5 is an example of a CT image of an Airbus A300 rudder servoactuator



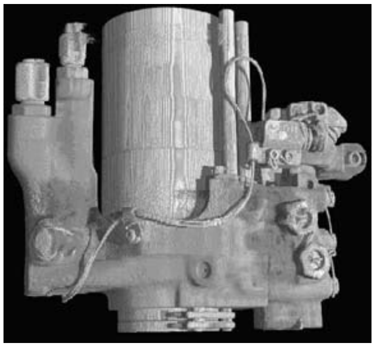


Figure 5: Airbus A300 servoactuator reconstructed from individual slice image (left) and photograph (above).

that was created by combining more than 250 slice images. Each slice in this image was approximately 0.95 millimeters thick. The lower image in Figure 5 is a photograph of the same servoactuator from a slightly different angle.

Digital enhancement of the CT image

The CT image shown in Figure 5 demonstrates the level of resolution and detail that a CT image can provide. Small items such as electrical wires, wire clips, and safety wire can easily be seen. However, a view of the outside of the object is not particularly useful in an investigation. It is the ability to create useful views of the inside of the object that makes CT images so valuable.

Since the CT image is created digitally, software can be used to enhance the investigator's use of the information contained in the scan. Different materials in the scanned object create different X-ray attenuation levels at the detectors, and these differences can be used to classify and select different parts of the image based on their material properties. The aluminum manifold housing and other lower density items create a very different X-ray attenuation value than the steel inner mechanisms in the actuator pictured in Figure 5. If the low-density items are digitally subtracted from the image, the steel inner mechanisms remain. The resulting image is shown in Figure 6.

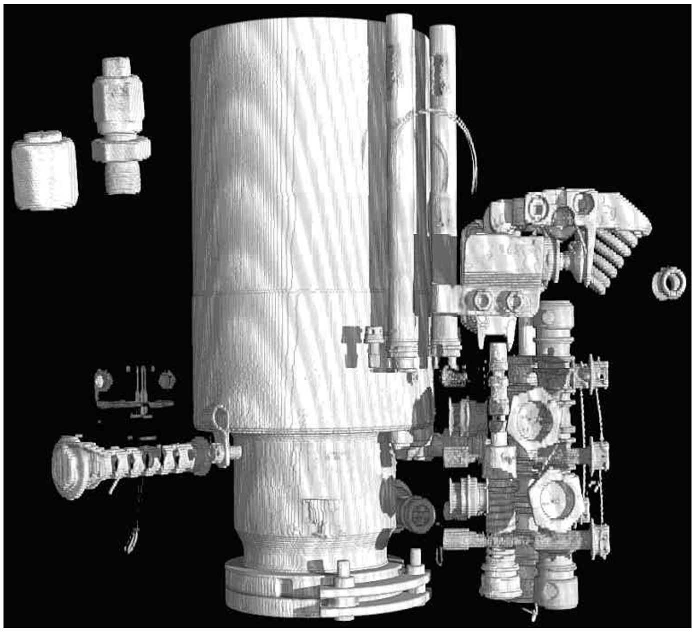


Figure 6: CT image of servoactuator with low-density materials digitally removed.

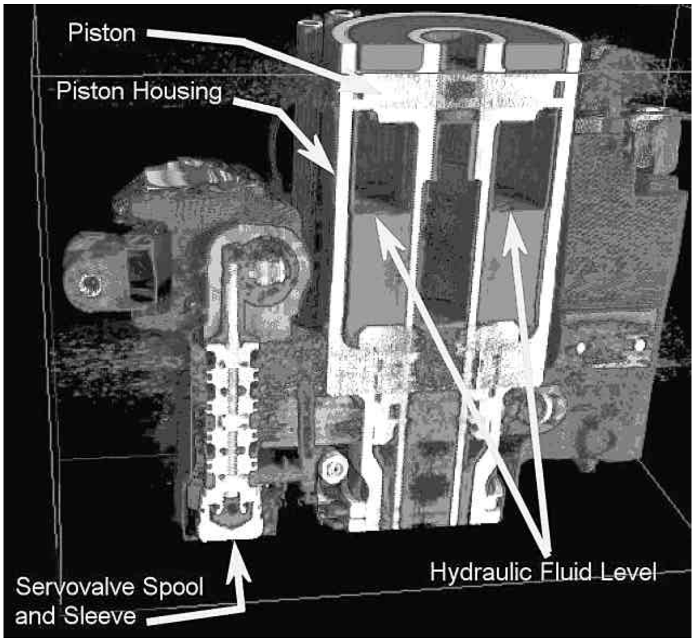


Figure 7: Servoactuator with front portion digitally removed.

The view of the inside of an object can be further enhanced through the use of color and through the use of cut planes, which digitally slice through an object and let the investigator view a cutaway view of an object. In Figure 7, the hydraulic fluid (and other low X-ray attenuation items) in the servoactuator are colored red, and the manifold housing is colored green[4]. The highest density parts (parts with the highest levels of X-ray attenuation) are colored white. The view in Figure 7 shows how the servoactuator appears when the front half of the unit is digitally removed. The piston housing and piston are visible as is the main servovalve spool and sleeve. Looking carefully within the piston housing, the level of hydraulic fluid can be determined[5], [6], [7].

Case studies

Hydraulic fluid passages

The hydraulic fluid passages in a servoactuator can be visualized with CT imaging. Hydraulic fluid is represented on CT images with a specific range of attenuation values. By processing the image based on that range, the complete set of hydraulic fluid passages can be created in an image. This can be of value to an investigator trying to determine either if there are blockages in the hy-

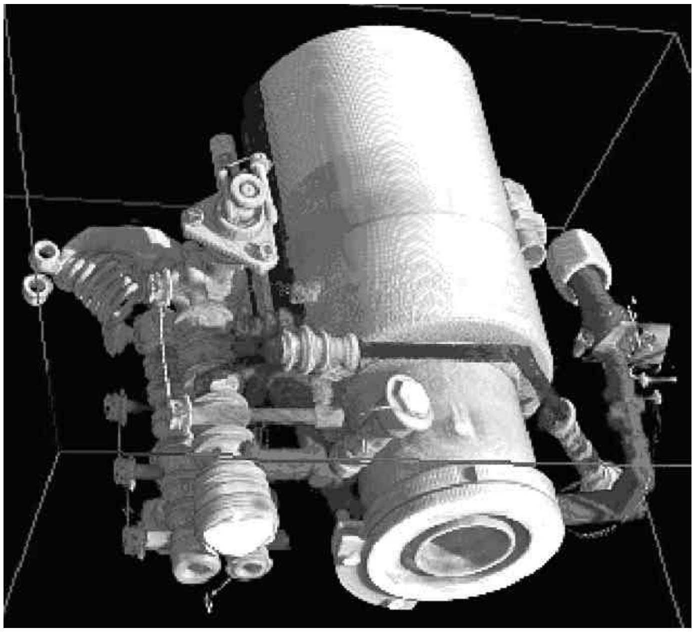


Figure 8: Hydraulic passage in the Airbus A300 rudder servoactuator.

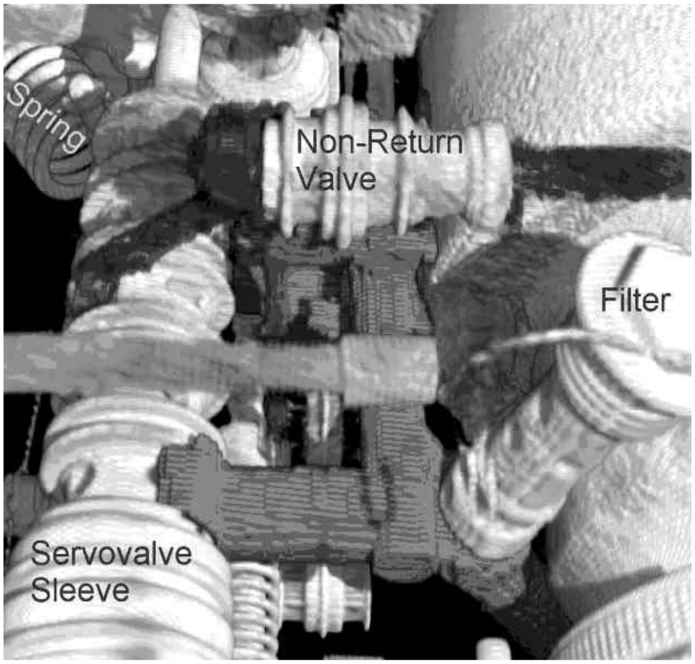


Figure 9: Close-up view.

draulic passages (which may appear in the images as an absence of fluid) or if there are any cracks or leaks in the servoactuator. The visualization of hydraulic fluid passages is shown in Figures 8, 9, and 10.

When trying to look for hydraulic fluid passage blockages, the investigator must be aware of what digital processing is being done. Low-density blockages can be inadvertently removed when noise is digitally subtracted from the image. In addition, the range of values to use for hydraulic fluid should be carefully constructed. Too large a range could lead to inadvertently including the blockage in the image, and too small a range could lead to inadvertently giving the appearance of a blockage. Obviously, the presence of excessive noise in the image will make the job of creating a viable range much more difficult.

Gear train examination

One of the benefits of CT scanning's high resolution is the ability to examine the details of a part's gear train. The alignment of the gears, the absence of teeth in a gear, and the rotational position of a gear set can all be determined in a CT scan.

The NTSB examined a screw-type actuator from the A300 directional control system that was driven by electric motor powered gears[8]. The overall view of the actuator is shown in Figure 11. Once the low density housing is digitally removed, the components of the gear train are visible (see Figure 12). Zooming in on the gear train, the individual teeth of each gear can be examined. As shown in Figures 13, 14, and 15, individual teeth with spacings down to 1 mm can be seen in the images.

An additional benefit of the digital nature of CT scans is that they allow for observations from viewpoints that would be extremely difficult to reach, even if the part was disassembled. The CT image viewing software used by the NTSB contains the capability to use a camera and viewing vector system to allow the investigator to virtually view the component from any angle. In Figure 16, the "camera" (yellow arrow) has been placed inside the screw housing of the actuator, and the field of view (yellow lines spreading out from the yellow arrow) has been pointed at the fastener on top of the screw. This viewpoint allows the investigator to determine if the fastener is present, and to possibly determine if it is fastened properly.

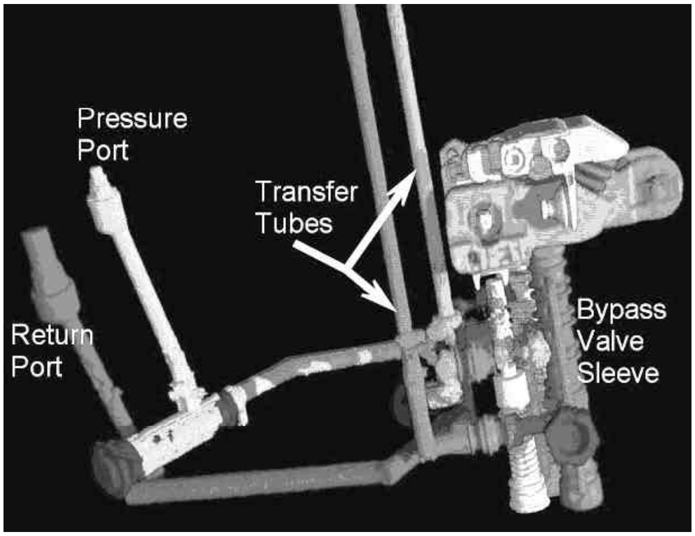


Figure 10: View of a network of hydraulic passages in the Airbus A300 rudder servoactuator.

Drawbacks of CT scans

There are some drawbacks to using CT scans in accident investigation. One of the principal drawbacks is the amount of time required to acquire the scan. Since there are not very many organizations with the capability to perform these scans, the parts must sometimes be transported long distances. The organization doing the scan then has to fit the components into their schedule. Finally, the scans themselves can sometimes take several hours or even one or two days to perform.

Once the scans are complete, the reviewing investigator must continually keep in mind that even though the images are pho-

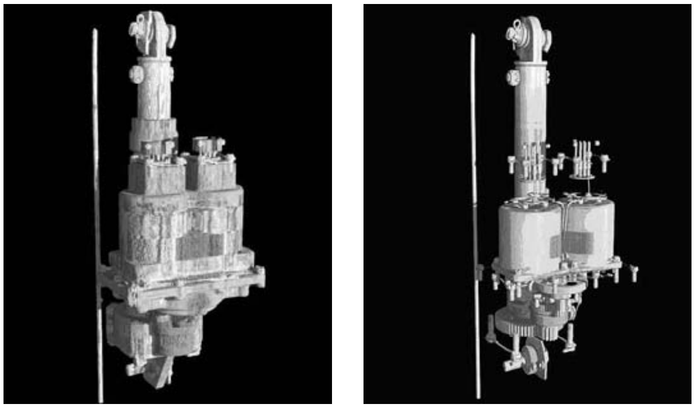


Figure 11, 12: CT image of A300 variable stop actuator, left, and same with low-density housing removed, right.

Figures 13, 14, 15: CT images of gear train showing 3, 2, and 1 M tooth spacing.

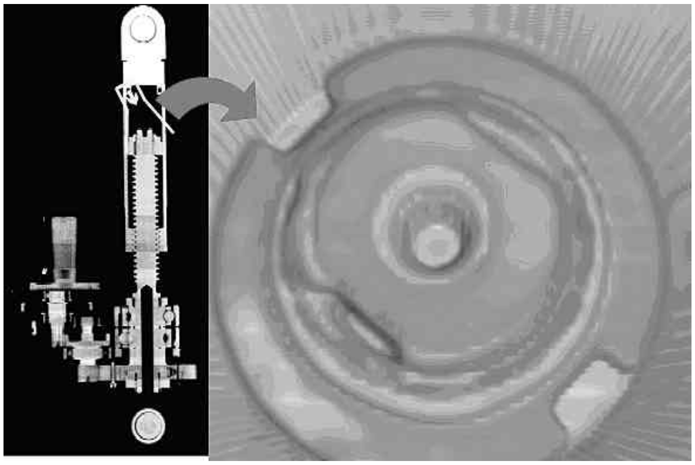


Figure 16: CT image of end fastner assembly from inside the screw housing.

tographic in nature, they are not photographs. Unlike a photograph, the CT images have been digitally enhanced to provide specific views. These enhancements, while making some parts of the image stand out, can also inadvertently filter out important information. It is important that the investigator using CT imaging take the time to understand the process and be aware of the digital manipulations being done to the image.

Summary

The National Transportation Safety Board has developed the capability to use CT imaging in accident investigations. CT imaging provides significant benefits when compared to standard X-rays or radiographs. NTSB investigators have used these capabilities to examine hydraulically driven servoactuators as well as electrically driven screw-type actuators with complicated gear trains. The use of CT imaging has allowed the investigators to gather significantly more information when trying to decide if testing the part first or disassembling the part first is the appropriate course of action. ◆

Footnotes

[1] Radiograph is the term used to describe what the general public refers to as an X-ray. While the term X-ray may be more familiar to the general public, the term radiograph will be used in this paper to avoid confusion between using the term X-ray to refer to an image and using it to refer to the radiation that produces an image.

[2] The NTSB has a memorandum of agreement with the U.S. Army Research Laboratory in Aberdeen, Maryland to generate the CT images using their equipment. The images are then processed by the NTSB using a commercially available software package, VGStudio Max, produced by Volume Graphics, GMBH, in Heidelberg, Germany.

[3] The same effect can be obtained by keeping the object stationary and rotating the X-ray source and detector at the same time. This technique is used in medical CT scanners.

[4] In Figure 7, items in red are intended to denote low-density items, primarily hydraulic fluid. Much of the servoactuator housing is covered in a thin layer of material colored red. This is due to a thin layer of dirt and hydraulic fluid coating the servoactuator.

[5] This actuator was removed from an aircraft accident scene in somewhat damaged condition. The hydraulic fluid does not completely fill the piston housing due to leaks in the actuator.

[6] The CT scan of this actuator focused only on the manifold housing area of the actuator. The remaining portions of the piston housing were not scanned due to time constraints.

[7] Also visible in the middle and upper portions of the picture are some streaks that appear to extend to the left and right of the actuator itself. These streaks represent noise in the CT image, and they are a result of the high material thickness of the bottom of the piston housing and the piston itself.

[8] This is the same A300 variable stop actuator shown in the radiograph presented as Figure 1.

Investigating Survival Factors in Aircraft Accidents: Revisiting the Past To Look to the Future

By Thomas A. Farrier (MO3763)*, Director, Safety Programs,
Air Transport Association of America, Inc.

***Thomas Farrier** has more than 17 years' experience in aviation safety, spanning a broad array of military, commercial, and general aviation safety issues. During his military flying career, he was credited with 17 lives saved as a rescue pilot, including one notable mission over the North Atlantic Ocean for which he was awarded the Air Medal. His final tour of duty was at the Pentagon, where he worked for three consecutive Air Force Chiefs of Safety on flight, ground, weapons, and explosives safety matters. He also served as the U.S. Air Force Delegate to the Accident Prevention Committee (PREVAC) of the System for International Cooperation among the American Air Forces (SICOFAA). Upon his military retirement, he was elected to the U.S. Air Force Safety Hall of Fame. Most recently, he served as National Safety Coordinator for the National Air Traffic Controllers Association, during which time he also was a member of the NASA Aviation Safety Reporting System Advisory Committee. Farrier joined ATA in April 2001. In addition to his participation in the International Society of Air Safety Investigators, Farrier is a member of the American Society of Safety Engineers, serves on the Board of Directors of the International Aviation Fire Protection Association, and is the author of numerous articles and professional papers in the field of aviation safety. His current responsibilities include flight and cabin crew operational and occupational safety, the evolution of the flight operations quality assurance and aviation safety action programs, and government-industry cooperation through the Commercial Aviation Safety Team (CAST) process. Since October 2001, he also has served on the FAA Aviation Rulemaking Advisory Committee's Aircraft Rescue and Fire Fighting Requirements Working Group.*

Introduction

The principal purpose of every aircraft accident and incident investigation is to seek means of preventing the recurrence of similar events in the future. By extension, any contributory investigative activity taking place in the context of a broader investigation must be similarly directed. However, all too often, the tendency of air safety investigators is to focus on the proximate cause of the undesired event, often doing so at the expense of other potentially fruitful lines of inquiry related to the *consequences* of the event. The rationale for making these kinds of judgments in the course of an investigation has changed little throughout the first century of powered flight: if an accident is prevented in the first place, loss of life, injuries, and damage will not have the opportunity to occur.

This reasoning is by no means unjustifiable. Investigative resources frequently are at a premium, and on-scene time in particular seems to be becoming progressively more constrained. Nevertheless, concentrating on cause tends to perpetuate a longstanding pattern of according certain aspects of major investigations distinctly secondary status within the overall investigative process. Further, as major accidents become (thankfully) ever-rarer events, the randomness and complexity of the chain of causality leading up to each of them has tended to make each investigation more resource-intensive. This trend has made the ultimate goal of prevention far more difficult, and also has contributed to the treatment of some investigation-related tasks as ancillary to the main line of inquiry.

Throughout the first century of aviation, there have been a variety of reasons why investigations into the specific causes of casualties resulting from aircraft accidents have rarely received the same degree of focused attention as the accidents themselves. Accident investigations were essential adjuncts to the very earliest efforts at powered flight, and failures had to be assessed as a matter of mastering the basic principles of aviation. By contrast, for more than four decades, there was little in the way of systematic analysis of what happened to crewmembers and passengers during and in the immediate aftermath of a crash. While this disparity may seem surprising, it actually was a natural outgrowth of the trial-and-error process that characterized most pre-World War II aviation operations. It also may be traceable to the fact that commercial air travel was, in its infancy, understood to be a relatively hazardous means of transportation where the risk of misfortune—while significant—usually was outweighed by the advantages that mode of travel provided.

This paper charts the evolution of aircraft accident investigations as they first acknowledged, and then embraced the need to consider not only the prevention of accidents, but the mitigation of the effects of accidents not successfully prevented. It will briefly review the priorities of early aircraft accident investigations; it will explore the reasons why survival factors gained prominence as an area of inquiry within the investigative process, and it will then offer examples of some of the methods used by air safety investigators and other professionals to gain insight into the factors most critical to occupant survival. The paper will conclude with a number of recommendations regarding the goals of future survival factors investigations, information that should be gathered for subsequent study, and possible means of according issues identified through survival factors investigations the primacy they deserve.

Survival factors defined

For the purposes of this paper, the term "survival factors" is broadly defined as embodying three separate areas of concern more commonly treated as stand-alone areas of study. They are

1. Survivability. The U.S. National Transportation Safety Board (NTSB) frequently reiterates its criteria for determining survivability in its final reports on major air carrier accidents. For example, its report on the "Palm 90" accident of 1982 (the Air Florida Boeing 737 that crashed just after takeoff from Washington, D.C.) identifies the three determinants of survivability as (1) decelerative forces not exceeding the known tolerable limits of the human body; (2) integrity of restraint systems (belts, seats, and seat attachments); and (3) protection of the occupiable area (i.e., prevention of ejection and preservation of occupiable volume).[1] These provide a consistent baseline against which to assess each accident and render meaningful recommendations.[2]

However, the problem with such a tightly constrained definition is twofold. First, over time, this model has tended to draw and fix the attention of investigators to the specific parameters listed. Second, by limiting it to the elements above, it treats "survivability" as an end unto itself, instead of the first part of a three-stage process that results in the *actual* survival of people involved in an accident.

2. Evacuation and extrication. The second component of survival factors in aircraft accidents and their subsequent investigation is the ability of occupants to move clear of the potentially hazardous post-crash environment, either under their own power or with assistance. As the survivability of aircraft accidents has increased, there has been a concomitant need to ensure that the interior environment of aircraft subjected to crash forces remains survivable for at least a limited amount of time. Occupants who survive a crash must escape successfully; anything that prevents them from doing so must be documented, evaluated, and corrected.

To these extent that survival factors investigations have explored the issue of evacuations in the context of individual accident reports, they usually have been examined in terms of the *opportunity* to escape based on physical obstructions and elapsed time. However, there is a need to document this aspect of survival factors in a more holistic manner. The specific factors affecting each occupant—both survivors and casualties—in each accident must be marshaled in such a way as to allow correlation of the condition of the aircraft and the deterioration of interior atmospheric and thermal conditions with positive and negative outcomes for the people exposed to them.

3. Post-crash survival. Post-crash survival, especially following planned or unplanned ditchings, was a major preoccupation among aircraft designers, regulators and investigators for a significant period of time in the mid-20th century. This seems to have been the result of two principal concerns: the unreliability of engines and the sparseness of communications coverage. It also was reinforced by a few isolated instances of ditchings of passenger jets in the 1960s, which directly led to most of the current requirements for personal flotation devices to augment dedicated rafts and combination evacuation slide/raft provisions.

The present-day codification of the concern for post-crash survival in the context of investigations usually revolves around the availability and effectiveness of emergency responders. The reliability of engines and communications, as well as the availability of rafts and other flotation aids "in the unlikely event of a water landing" seem to have rendered most of the historical concerns in this area moot; accordingly, this aspect of survival factors investigation will not be expanded upon in this paper. However, investigators must remain alert to the possibility that post-crash survival issues could arise in the context of virtually any off-airport accident and should be prepared to address them as necessary.

The objectives of survival factors investigation

Throughout this paper, readers should bear in mind that the principal threats to occupant survival in an aircraft accident are *impact and decelerative forces, inhalation hazards,* and *fire*. Over time, these conditions have been addressed individually and in combination by a range of design and retrofit changes aimed at

- reducing potential sources of fuel and fire sustainment;
- improving physical containment of inflight fires;
- attenuating crash forces;
- improving seat retention;
- preserving a "survivable volume" within occupied portions of aircraft;
- slowing flame-front movement through onboard components and furnishings;
- reducing sources of toxic by-products of combustion; and
- reducing radiant heat emissivity of furnishings.

While all of these improvements have contributed greatly to the overall survival experience following aircraft accidents, their cumulative effect has been to shift when loss of life is most preventable from the moment of impact to the post-crash period. Once death was no longer an instantaneous and likely consequence of a crash, concern necessarily turned to the preservation of a survivable environment within the aircraft following each crash.

A 1993 "background paper" on the subject of evacuation testing prepared by the Office of Technology Assessment of the United States Congress summarized the desired end state to be attained for occupant safety as follows: "Passenger safety may be better improved by extending the period of survivability than by attempting to reduce the time required for evacuation."[3] Moreover, successful evacuations, both precautionary and post-crash, are essential elements of public confidence in air transportation. In a 2001 report, the NTSB took note of the public perception that aircraft accidents are uniformly fatal;[4] it is incumbent upon investigators to continue to work to dispel such misconceptions.

The foregoing discussion shows that each survival factors investigation must accomplish multiple objectives. The current thinking as to these objectives, as evidenced by the content of reports and published guidance on the conduct of major investigations, seems to distill down to a few broad goals:

- Document what happened to the aircraft and its occupants throughout the accident sequence; tabulate fatalities and injuries by severity and whether the persons involved were crewmembers or passengers.
- Identify failures of aircraft equipment and structures, crew and passenger performance, and emergency response that contributed to casualties.
- Determine which of the above have been observed in other accidents and/or addressed in prior recommendations.
- Make new recommendations specific to the circumstances observed in the accident under investigation; alternately, reiterate previously expressed recommendations with reference to the increased urgency the new accident suggests they warrant.

Experience suggests, however, that concentrating on these areas alone results in reduced attention, or no attention at all, to a host of equally important considerations. In part, this is because "survivability," as defined by the NTSB, is an assessment that relies upon specific criteria applied to an environment with an extraordinary number of variables. For every accident, there are four possible outcomes with respect to survivability and the fate of the aircraft's occupants:

- a survivable accident in which all occupants survived;
- a survivable accident in which one or more occupants were killed;
- a nonsurvivable accident in which one or more occupants survived; and
- a nonsurvivable accident in which all occupants were killed.

All four of the above scenarios offer opportunities to gain insight into survival factors, that is, what worked and what didn't in trying to preserve the lives of an aircraft's occupants. Too often, the inclination of investigators is to document the negatives—seats that failed to be properly retained, exits that failed to operate properly, and so forth. The record frequently is quite thin when it comes to objective data regarding the success stories: lives saved by designed-in protections, emergency equipment, or furnishings that performed as desired with respect to limiting blunt force or thermal injuries.

The evolution of survival factors as a consideration in investigations

Almost from the moment that heavier-than-air flight became a reality, while there was ongoing concern for the hazards to human life associated with aircraft accidents, the prevailing sense throughout the aviation community was that fatalities were natural by-products of aircraft accidents. This somewhat fatalistic attitude has been remarked upon by various commentators over time, but it also had a practical aspect to it as well: it served to focus the attention of pioneering aviators on the need to master their craft as quickly as possible.

In 1909, the Royal Aero Club of the United Kingdom began publishing *Flight*, billed as the "first aero weekly in the world." The Jan. 11, 1913, issue of this magazine, which was dedicated to "the prevention of accidents," contained the following editorial comment on page B-2: "It is self-evident that there is no branch of the science of greater importance than this question of safety. Accidents continue to happen, and of late many of the accidents have resulted in death…. It is evident that it is the accident that must be avoided, since there can be no satisfactory remedy to the evil consequences thereof." In other words, less than 10 years into the first century of flight, the focus of structured aviation safety thought in one of the world's great forums for such matters already was beginning to settle almost exclusively on accident prevention, with little thought given to *mitigation* of the forces and consequences of accidents.

However, later in this same essay, Royal Aero Club founder/editor Stanley Spooner made a more interesting and specific observation on the nature of accidents themselves: "In general, accidents seem attributable to two causes, one of which is the failure of materials and the other failure of control." While his use of the term "control" referred to the operation of flight control surfaces—a subject not well understood in his day—Spooner's pronouncement does demonstrate the clear understanding of the aviation community of the day that better construction techniques and more effective control of aerodynamic forces were essential to consistently safe operations. In other words, safety was seen as achievable through the successful resolution of these two key concerns; fix them, and all other undesirable outcomes (like occupant fatalities) would be solved.

This is not to say that the "passenger" dimension of aviation safety received much in the way of conscious consideration in the early years of aviation. In fact, although Zeppelins began serving paying passengers in the summer of 1910[5], prior to World War I little thought was given to the use of heavier-than-air aircraft in passenger service. The world's first scheduled heavier-than-air passenger service is generally thought to be the St. Petersburg-Tampa Airboat Line, which operated briefly in 1914. It was only after the Armistice that both governments and private concerns began to consider the possibility that airplanes might be useful in regularly scheduled passenger service.[6] Of course, as a recent Transport Canada publication on aviation history aptly describes it, "In the early aviation days, passengers in airplanes were just another kind of cargo. Passenger service was an offshoot of the freight and mail delivery done by bush pilots, taking people beyond their usual rail and road connections. For several years, passengers were part of the payload in cramped, noisy and cold cabins."[7]

The Air Mail Act of 1925 gave a much-needed boost to commercial aviation in the United States, but it wasn't until the following year that the Air Commerce Act of 1926 was signed into law, taking official note of the growth of commercial air passenger service by assigning a number of duties to the Commerce Department with respect to the conduct of commercial air carrier operations. In particular, it authorized the Secretary of Commerce to designate air routes, to develop air navigation systems, to license pilots and aircraft, and to investigate accidents.[8] This was the first legislation to assign an aviation regulatory body the sometimes conflicting tasks of "promoting air commerce" and "promoting air safety."

From 1928 through 1937, the "miles flown per accident" in air carrier service grew steadily, from just over 100,000 in 1928 to more than 1.5 million in 1937. Still, even during the best years, more than one in 10 of those accidents were fatal. While commercial air transport was undeniably getting safer and passenger miles flown grew steadily every year during this same period, of the 400 to 600 aircraft in commercial service, more than a half-dozen were involved in fatal accidents every year.[9] Notwithstanding the periodic serious accidents that made headlines, the 1930s were a period of significant growth in air carrier service, which in turn provided the economic impetus for a whole range of safety improvements.[10]

According to the Air Transport Association's *Airline Handbook*, "There were so many improvements to aircraft in the 1930s that many believe it was the most innovative period in aviation history. Air-cooled engines replaced water-cooled engines, reducing weight and making larger and faster planes possible. Cockpit instruments also improved, with better altimeters, airspeed indicators, rate-of-climb indicators, compasses, and the introduction of artificial horizon, which showed pilots the attitude of the aircraft relative to the ground—important for flying in reduced visibility."[11]

In 1938, during a speech to the students and faculty of Norwich [Vermont] University, Dr. Edward Pearson Warner observed, "The typical air transport of 1920, if one may use the word typical of anything that was in so tentative a state, was a biplane with a cat's-cradle of external bracing. It usually had one engine, but occasionally two. The cabin contained from four to 10 wicker chairs. The cruising speed was 90 miles an hour…. The aggregate of 19 years of development has created a cantilever monoplane, its landing gear retracted in flight, its two or four engines well set into the wing's thickness. Its 10 to 40 seats appear as rugged as those of the Pullman car, and by popular appraisal they are substantially more comfortable."[12]

Dr. Warner made no mention of survival factors concerns during his remarks, preferring to cite five major advances in the technical development of aircraft in the twenty years following the end of World War I:

- understanding and increasing wing loading;
- the advent of multiengine aircraft, with their attendant increase in reliability and safety;
- the development of "total enclosure" cowls for air-cooled engines, with their attendant reduction in drag and improvement in performance;
- the improvement of aviation fuel; and
- the elimination of the need for external bracing for fuselages.

In passing, however, Dr. Warner makes a revealing observation regarding the role of interior aircraft furnishings as marketing features rather than safety-related design elements: "Less interesting to the aeronautical engineer than the changes in external form and structure, but even more obvious and beguiling to the uninstructed passenger, were the improvements in interior arrangement [since 1920]. Chairs that had no other virtue than that of lightness gave way to solid-looking pieces of furniture with back and seat angles separately adjustable."[13] Many of those solid, comfortable pieces of furniture undoubtedly were equally solid as they flew unrestrained through cabins during crashes, or as they implacably transmitted crash energies directly to their occupants!

In 1939, Jerome Lederer, who at the time was working in the private sector, spoke to the same audience at Norwich University. Even Lederer, who gave the world its most clear-eyed visions of future aviation safety requirements throughout his illustrious career, was far more preoccupied with the necessities of improved engine reliability and instrumentation to recommend devoting much in the way of resources toward survival factor concerns. This is not to say he was unaware of the potential hazards; he simply recognized that there were far more pressing needs against which investments in safety should be made.

During his Norwich address, Lederer made the following observations regarding passenger safety: "Besides seeing that passengers are transported in a safe vehicle, the airlines also do their utmost to see that passengers are not injured in other ways. Safety belts are provided to keep passengers in their seats in bumpy weather and during landing or takeoff. Airplane furniture is designed so passengers will not inadvertently knock themselves against sharp corners. Ramps leading from the door to the ground are substantially built and covered with slip-proof tread. The infirm are carefully assisted to and from their seats. Medical supplies are available when needed. In these and hundreds of other little ways, the airlines try to round out their desire to see passengers go from place to place in safety."[14]

Despite what amounts to 40 years of benign neglect resulting from a host of more urgent safety priorities, the challenges of passenger crash protection began to gain attention on a variety of fronts almost as soon as World War II was over. A 1945 Army Air Forces report to the Chamber of Commerce of the United States, referring to "the design problem ahead," noted that, in military aircraft, "Considerations of safety have necessarily been limited in most cases to such basic requirements as safe wing loading, structural strength, adequate power, protection from fire, protective armor, escape hatches, safety belts, and the like…. [In civilian flying, however,] [f]or the future, it is inconceivable that any important progress toward flying safety can be made until safety is first of all built into the airplane to the maximum degree possible." [15]

The immediate postwar era also brought to the fore the pioneering work of Harvard University's Dr. Ross A. McFarland, who since the late 20s had been interested in some of the physiological effects of aviation on humans. Over the next 20 years, he identified two key disconnects in aviation safety thinking: a lack of integration between aircraft operators and manufacturers, and the inaccessibility of concrete data on the capacities and limitations of human beings. His seminal 1946 work, *Human Factors in Air Transport Design*, helped chart the scientific course that has been followed by researchers and investigators alike in examining survival factors to the present day.

Dr. McFarland identified three distinct classifications of accident analysis: post-accident studies, "near accidents," and "advance analysis." The latter, which he felt should be given primacy, embodied two simultaneous considerations: mistakes that air crews may make and "every possible fault of the design of the aircraft itself."[16] McFarland saw five issues as being uniquely suited to advance analysis with respect to occupant survival factors:

- the location of the wings and strengthening of the fuselage for ditching;
- the stressing of chairs [sic], safety belts and harnesses for withstanding high decelerations;
- the means of escape in emergency landings;
- fire-prevention measures; and
- the reliability of the hydraulic and electrical systems.[17]

Dr. McFarland also gave due regard to the work of Cornell's "Crash Injury Research" program (of which more presently) in discussing the pressing problem of improving survival rates during crashes: "Both the maximum forces and their optimum distribution must be determined if the survival rates in crashes are to be substantially increased. An excellent example of desirable collaboration toward this end is afforded by the studies of Hugh DeHaven, an engineer working with medical scientists, on the way in which design features influence the magnitude and distribution of decelerative forces in relation to injuries."[18]

Working on a parallel but complementary path, in 1946 the National Fire Protection Association (NFPA) "Committee on Aviation and Airport Fire Protection" began publishing a long-running series of bulletins that included several devoted to this specific concern. In June of 1950, it gave wide dissemination to a series of recommendations developed by the Civil Aeronautics Board's Bureau of Safety Investigation, intended for consideration by the CAB's Bureau of Safety Regulation, with respect to future transport category aircraft design requirements.[19] This and similar documents clearly show the rapid emergence of a deliberate, scientifically based approach to occupant protection that drew upon accident experience as a principal source of support.

The International Civil Aviation Organization (ICAO) entered the investigation arena in 1949, with the release of the first edition of Document 6920-AN/855, the *Manual of Aircraft Accident Investigation*. This initial effort followed the general pattern of focusing on investigating for the causes of accidents as a whole, but took the novel additional step of allowing for the possibility of materiel failure, or even a failure of "safety equipment," to be considered causal in its own right. It also set the stage for a highly effective information collection effort with respect to survival factors: "Details relating to injuries sustained by persons involved in aircraft accidents are of great value in providing data for the extensive research in progress to eliminate injuries or death resulting from faulty cockpit or cabin design and personal restraining devices, etc."[20]

The second edition of this document, published in 1951, represented a significant improvement in its treatment of survival factors issues. It included the first version of the "Aircraft Crash Injury Report Forms" developed by Cornell University's "Crash Injury Research" group, and expanded significantly on how the causes of passenger death and injuries, as well as post-crash survival issues, should be recorded.[21] By 1959, the third edition provided even more elaborate forms for documenting injury sources and causes, and also offered the first discussion of what have come to be recognized as "aviation pathology" protocols for post mortem injury analysis.[22]

Also in the 1950s, serious professional attention began to be given to the challenges of emergency evacuation following an accident. For example, in May of 1954, the NFPA published two noteworthy papers presented at its "Third Annual Aviation Seminar" that same month. The first of these, entitled "Human Survival in Aircraft Crash Fires," was the first clear articulation of the limiting factors faced by occupants of crashed aircraft, including:

- skin burning;
- respiratory system damage;
- exposure to carbon monoxide combined with oxygen depletion; and
- accumulation of carbon dioxide.[23]

The second valuable contribution to the professional literature of the day in this area was a monograph by Barry G. King of the Civil Aeronautics Administration's Office of Aviation Safety, on the subject of evacuation under fire conditions.[24] This essay includes a detailed analysis of the relative effectiveness of window versus door exits, as well as different configurations of slides, and their respective impact on evacuation time. Given that challenges regarding escape slide availability continue to crop up in present-day accidents and incidents[25], this kind of thinking was as forward-looking as it was useful in the context within which it was developed.

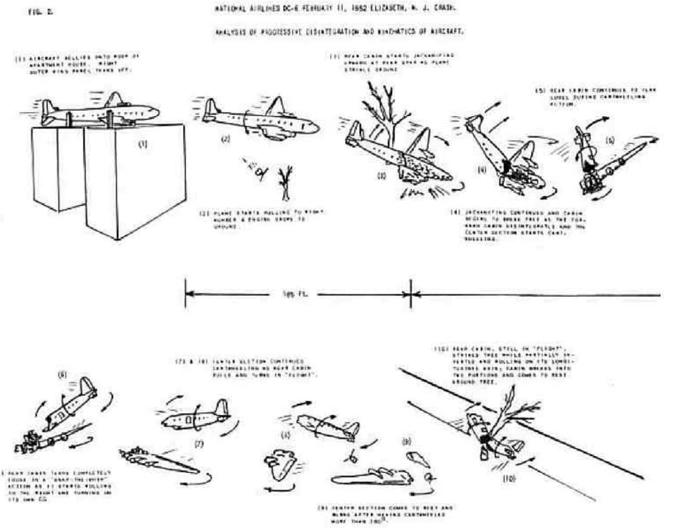
Survival factors concerns became more prominent in government research studies throughout the 1960s and 1970s. There were two reasons behind this increased interest: the steadily shifting fleet mix from propeller to jet aircraft in commercial air carrier service, and increased public sensitivity to "preventable" hazards. The latter may be discerned in the popular media, through such offerings as Arthur Hailey's novel *Airport* and its spin-off into a virtual movie franchise. However, it also is evident in the public and political response to consumer advocate Ralph Nader's 1965 book *Unsafe at Any Speed*, which fueled significant interest in the regulation and oversight of all modes of transportation.

Notwithstanding the apparent clear understanding of the issues needing to be addressed in the area of occupant safety, a whole series of studies conducted in the most recent 20 to 30 years seem to have been written in an effort to further refine and focus regulatory efforts. For example, in 1976 a report by the FAA's Office of Aviation Safety identified "recurring persistent cabin safety problems:"

- cabin fire, smoke and toxic gases
- cabin interiors
- emergency equipment locations
- flight attendant seating
- emergency equipment availability (axes, overwater rafts, life vests)
- crew training (especially the separation between flight and cabin crews in emergency procedures training)
- galley equipment
- communications (especially cabin-to-flight deck and vice versa)
- handicapped passengers
- crew duty day
- carry-on baggage
- alcoholic beverage service
- timing of passenger service[26]

When looking at this plethora of apparently repetitive studies, one can either make a case for the glass being half-empty or half-full. The author opts for the latter; after 40 years of inattention, survival factors asserted themselves as both critically important and worthy of concerted study in the 30 years that followed. Detailed research requirements and better support for technological solutions to many of these problems were documented and defended, and in the process, a legacy of creative thinking and imaginative approaches to issue identification and description was created that has survived to the present day. It is that resource that is explored in the balance of this paper.

Figure 1. Crash kinematics of National Airlines DC-6 crash, Feb. 11, 1952.



Model documentation and data visualization efforts

Investigations of accidents throughout the 50s, 60s, and 70s routinely reinforced all of the reports and studies cited above. However, it was only in rare cases that individual accident investigation reports seemed to capture all of the data necessary to make inroads into the known problems. More often, it was the special studies conducted by government agencies and private concerns that seemed to assemble the most useful and accessible nuggets of knowledge from the investigation reports, often by reinvestigating after the fact or working in parallel with ongoing accident investigations.

Figure 2. Injuries correlated to structural damage.

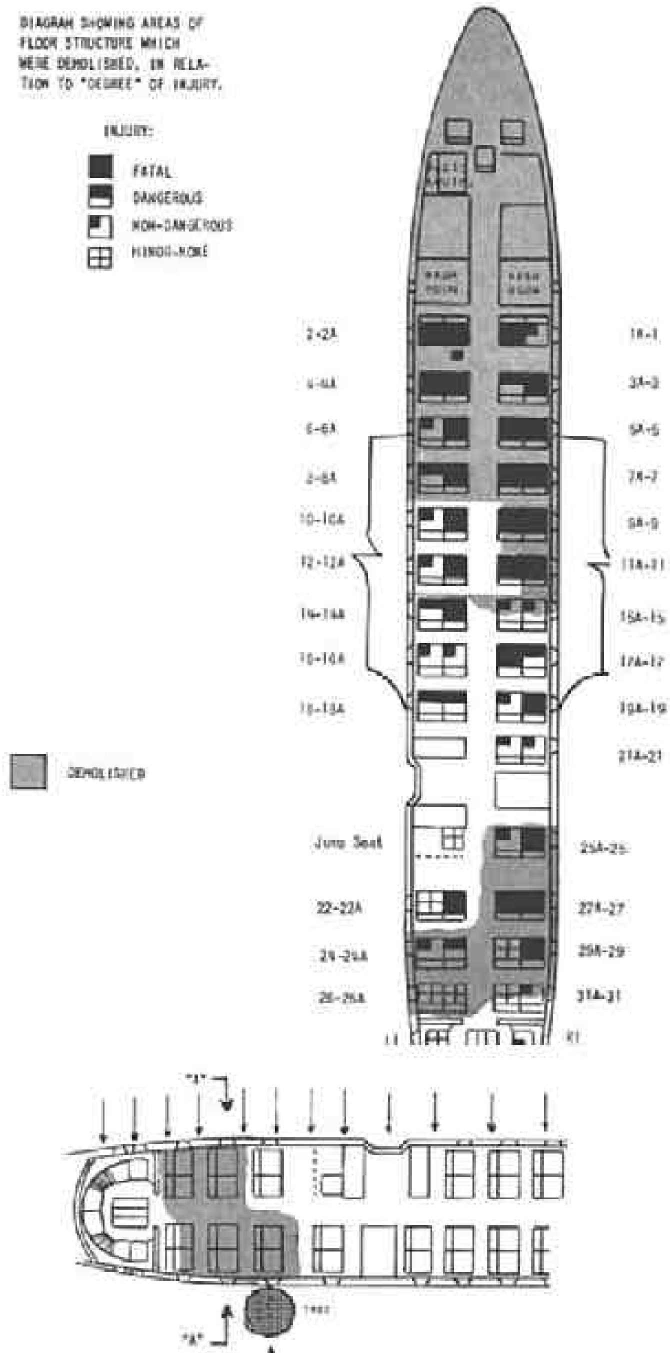


FIG. 6. VIEW SHOWING (1) POINT AND DIRECTION OF CONTACT OF REAR CABIN WITH TREE, AND (2) FLOOR AREA WHICH DISINTEGRATED AS CABIN BROKE IN TWO.

It is easy to assemble a huge, virtually indigestible body of information regarding survival factors in the course of an aviation accident investigation. Some investigation authorities, such as the National Transportation Safety Board, try to organize this wealth of data by placing as much purely factual data as possible into the "public docket." Unfortunately, the reams of information available on the public record rarely has more than a rudimentary structure to it, and many consolidated or indexed compilations of that information undoubtedly have been found to be works of "analysis" and thus exempt from public disclosure.

Given the need for hard data in making increasingly difficult arguments for specific safety initiatives, this is a pattern of information management that needs reform. The question is, how should such reform be pursued, and what good examples should be used as benchmarks? Ultimately, the challenge to investigators and researchers who may wish to build upon the work done during survival factors inquiries remains one of retrieval and interpretation. To this end, the following examples of historical studies are offered as a means of inspiring readers to consider alternate means of arraying complex data sets for ready interpretation, and to use in approaches to their respective investigative authorities.

"Informative Accident Release #15"

In the winter of 1952, a National Airlines DC-6 crashed shortly after takeoff from Newark, N.J., crashing with the loss of more than half of its occupants. This was ably investigated by the Civil Aeronautics Board's Bureau of Safety Investigation. However, as is sometimes the case with aircraft accidents, politics led to this particular accident being treated as something far more than a routine nighttime crash.[27] In response to the political pressure, as well as in the interests of advancing the state of the investigative art, a parallel investigation was conducted under the auspices of Cornell University Medical College's "Aviation Crash Injury Research" (AvCIR) initiative. This effort resulted in a study of survival factors that was, without question, both groundbreaking and well ahead of its time.

The report in question is the *Crash Survival Study: National Airlines DC-6 Accident at Elizabeth, N.J., on Feb. 11, 1952.* It was prepared by A. Howard Hasbrook (for whom a present-day award presented by the Aerospace Medical Association is named), under the supervision of the Crash Injury Research program's equally eminent director, the late Hugh DeHaven. It is copiously but not elaborately illustrated, using a variety of techniques to diagrammatically present a number of complex concepts in an extremely accessible form.

Several of the illustrations from this superb report are provided on the following pages:

- Figure 1 illustrates the crash "kinematics" of the Elizabeth accident, that is, the various stages during which the airframe and its occupants encountered objects that changed their energy state from flight to being fully at rest.
- Figure 2 relates the severity of injuries experienced by aircraft occupants to structural damage; the smaller of the two diagrams on this page shows the effects of the aircraft's broadside collision with a tree during the crash sequence.
- Figure 3 shows how the aircraft cabin was compromised by mid-crash contact with a tree, which in turn dislodged a number of passenger seats.
- Figure 4 brings together essentially all of the information provided in the preceding three diagrams, showing depictions of the actual damage suffered by each seat (with the seats placed in their pre-crash position), the extent of injuries sustained by that seat's occupants, the areas of cabin floor destruction, and the external forces applied to the fuselage during the crash sequence.[28]

The most remarkable contribution the *Crash Survival Study* makes to the body of literature surrounding survival factors is its forthright, astonishingly prescient set of recommendations regarding aircraft design requirements for occupant survivability.

Figure 3. Dynamics of aircraft impact with tree.

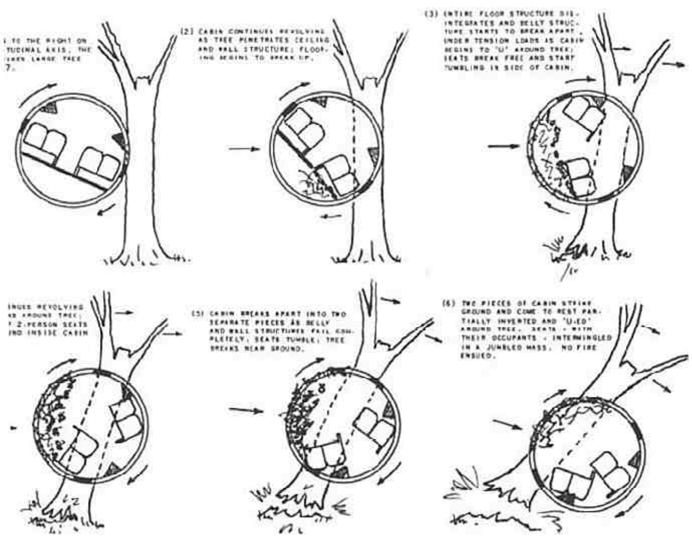


FIG. 7. VIEW (THROUGH SECTION A-A OF FIG. 8) LOOKING FORWARD THROUGH REAR CABIN AREA DURING IMPACT WITH TREE.

Figure 4. "Compilation" diagram blending injuries, actual appearance of seats, and impact force vectors.

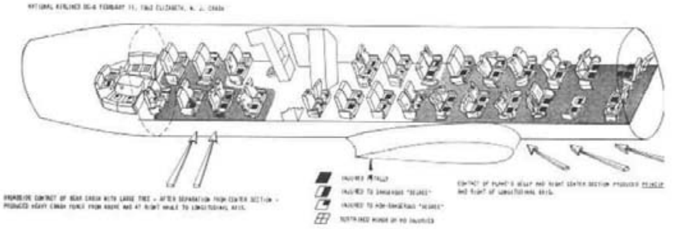


Figure 5. Depiction of wind influence on smoke, flame front propagation, and exit availability.

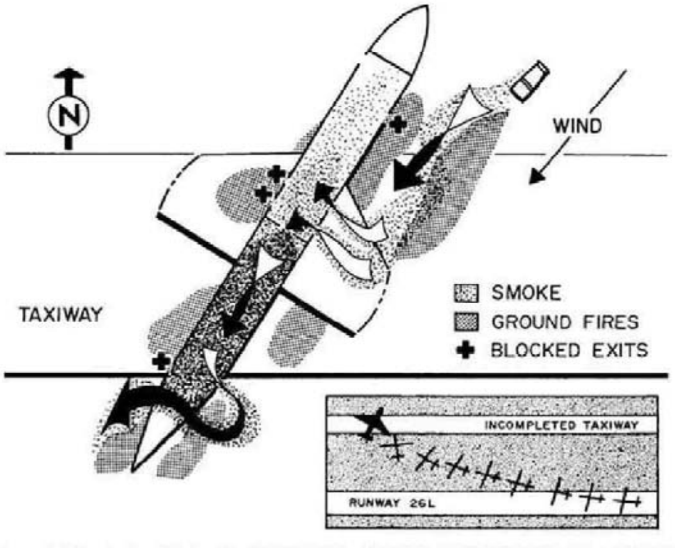


FIGURE 1. Path (inset) and final position of Denver DC-8. Smoke from ground fuel fires forward of right wing entered cabin through opened right window exits. Concentration of smoke was particularly intense in 2nd-class (aft) passenger compartment due to draft produced by open right rear galley exit.

Figure 6. Flame propagation versus elapsed time.

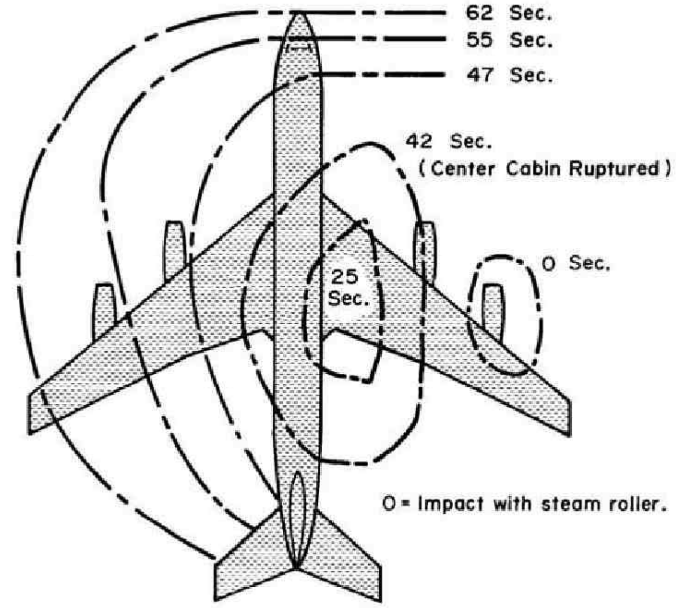


FIGURE 26. Pattern of fire propagation of the Rome 707 accident as reconstructed from survivor reports, ground witnesses, and physical evidence.

Figure 7. Two examples relating egress routes to other conditions (smoke and flame propagation on the left, injured occupants and blocked exits on the right).

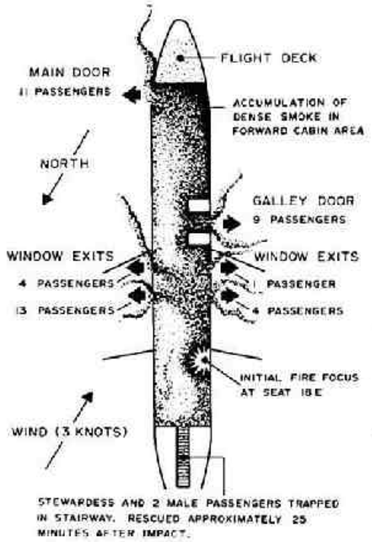


FIGURE 19. Interior diagram of Salt Lake City 727 showing initial fire focus and smoke dispersion in relation to exits.

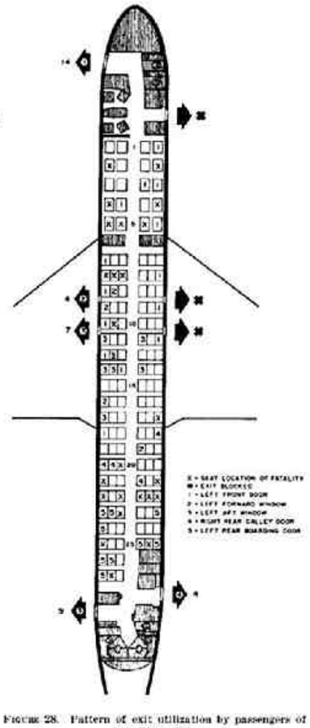


FIGURE 28. Pattern of exit utilization by passengers of the Rome 707.

They cite the need to ensure proper integration of the fuselage and floor to maximize energy absorption, to design seats for retention and energy absorption, and to perform a variety of specific tests to verify proper seat performance under crash conditions… and the recommendations are graphically supported by the diagrams that accompany them.[29] Beyond that, the *Study* establishes the baseline against which all subsequent—and future—survival factors investigation reports should be measured.

Assessing successful and unsuccessful evacuations

A successful evacuation generally may be considered a function of occupant mobility, the availability of usable exits, the delay of fire and smoke propagation, and the minimization of toxic byproducts of combustion within the cabin environment. As with the crash survival studies described earlier in this paper, much of the most valuable analytical work on successful and unsuccessful evacuations has been accomplished by stand-alone studies instead of being a part of the main investigation reports on accidents where evacuation issues came into play.

In May of 1962, the U.S. Federal Aviation Administration (FAA) completed an in-depth review of the post-crash evacuation of a United Airlines DC-8 at Denver, Colorado's Stapleton International Airport following an emergency landing and runway departure the previous summer.[30] The accident subjected to this analysis was ideal for the purpose, being completely "survivable" by standard definitions of that term, yet resulting in the deaths of 16 occupants. This report was the first to offer significant insights into the "whys" of evacuation successes and failures, offering recommendations regarding before-landing instructions to passengers, exit placarding requirements, post-crash fire control, and the need to reevaluate aisle width, number and location of emergency exits, passenger capacity, and cabin compartmentation.

The themes above were expanded upon in 1974, when the NTSB issued a comprehensive study[31] identifying 12 factors with a bearing on the success or failure of an emergency evacuation.

- Weather)
- External illumination)
- Terrain) **"Environmental" Factors**
- Aircraft attitude)
- Presence of fire and/or smoke)

- Condition/availability of slides)
- Emergency lighting) **"Machine" (Aircraft) Factors**
- Emergency communications)
- Obstructions to egress)

- Passenger preparedness)
- Crew training) **"Man" (Human Performance) Factors**
- Crew procedures)

However, these were somewhat at variance with an FAA study[32] conducted 4 years earlier, which offered a substantially broader menu of considerations:

- Seating density)
- Aisle width)
- Size, number, and location of exits) **Configurational Factors**
- Condition/availability of slides)
- Physical exit cues)

- Crew training) **Procedural Factors**
- Crew experience)

- Presence of heat)
- Presence of toxic by-products)
- Secondary explosion(s)) **Environmental Factors**
- External illumination)
- Weather)

- Gender)
- Age) **Biobehavioral Factors**
- Physical condition)
- Passenger experience)

Figure 8. Body locations within the cabin, correlated with occupant demographics: gender (■…for females, ♂…for males), age, and assigned seat.

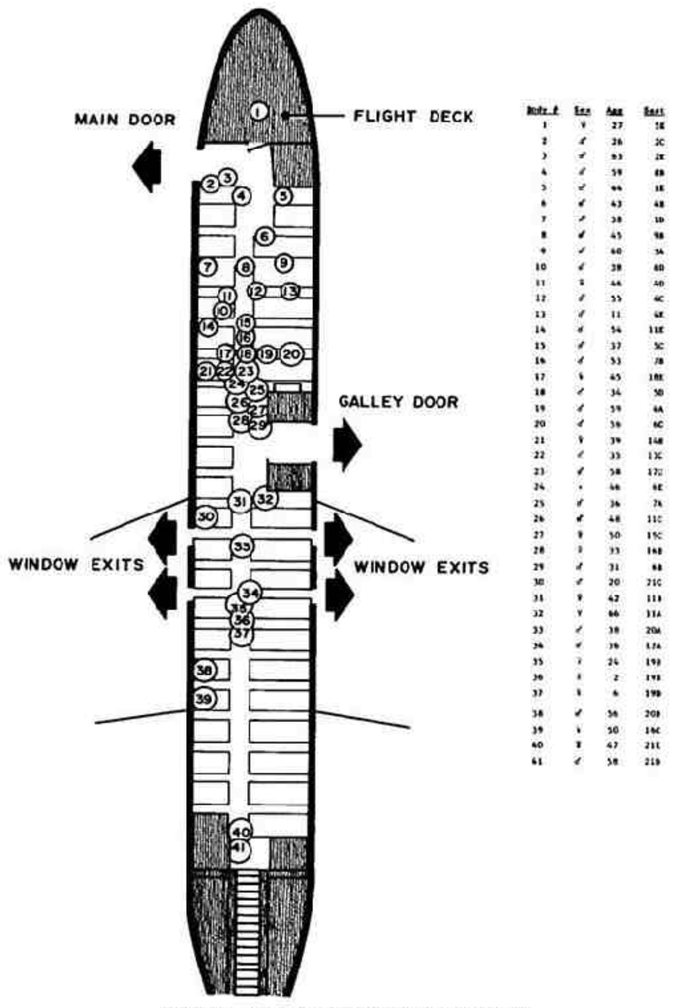


FIGURE 24. Distribution of bodies in Salt Lake City 727.

What do the foregoing lists tell us?

1. Different groups of experts looking at evacuations over time have assigned different priorities to the various factors encountered.
2. Each group of experts seems to have worked at least somewhat in isolation, relying upon its own preferred models and organizational schema.
3. While a number of issues show up in more than one of these lists, that repetition is not necessarily an indication of particular prominence.[33]

As in the case of the 1952 AvCIR report, the 1970 FAA study cited above also serves as a rich source of ideas regarding the depiction of useful configuration, orientation, and mortality information to supplement narrative descriptions of injuries, egress routes, and other relevant survival factors data. Figures 5 through 10 on page 152 and the following pages show examples of how such information can be assembled in a meaningful manner for later study:

- Figure 5 shows how the prevailing wind and the orientation of the aircraft affected the occupants' ability to evacuate from the Denver DC-8 crash of July 1961.
- Figure 6 shows how fuel from a ruptured tank spread and ig-

Figure 9. Alternate means of depicting starting and ending positions for unsuccessful evacuations.

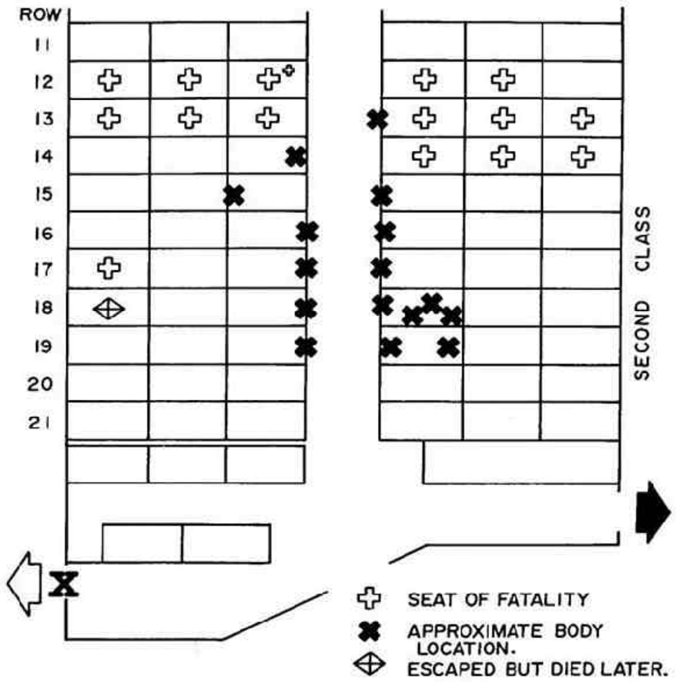


FIGURE 15. Diagram of aft cabin showing approximate body locations of 16 fatalities and their original seat locations.

nited by depicting the extent to which the flames had spread at various time intervals from the initial breach.

- Figure 7 offers examples from the Salt Lake City Boeing 727 crash of November 1965 and the Rome Boeing 707 accident of November 1964 showing how information about the condition of aircraft occupants can be correlated with other aspects of the post-crash environment.
- Figure 8 is an example of an aircraft layout diagram showing the locations of fatalities, with an accompanying key providing demographic information about each casualty.
- Figure 9 shows an alternate means of showing occupant movement from assigned seat to body position within the aircraft.
- Figure 10 shows a timeline created by the Aerospace Industries Association charting the amount of time elapsed between discrete events in a test replicating a post-crash evacuation sequence and successful evacuations by exit.

The bottom line is that *all* of the factors cited by the different studies cited above have merit, *all* should be accounted for in the course of every survival factors investigation, and all have a great deal to remind modern-day investigators about the value of visual presentation of the results of analysis.

A great deal of useful research has been conducted in the areas of both survivability and evacuation considerations since these reports were originally issued; some of the best are listed in the bibliography at the end of this paper. The appeal of the examples selected for presentation above lies in their innovativeness, their accessibility, and the means by which their respective approaches to marshaling information could be lent to modern-day presentation and database management efforts.

Conclusions and recommendations

The art and science of aircraft accident investigation has advanced by leaps and bounds throughout the first century of powered flight, especially in the area of survival factors. Some of the oldest diagrammatic investigative techniques still hold up well, and deserve both codification and modification to permanently enshrine them in survival factors assessment toolkits for use in the 21st century investigative environment. However, it is equally important to confront the central concern: justifying investments in survival factors investigation, research, and equipage. The requirement to support such activities is not well enough documented in a publicly available form, and much of the documentation that *is* available is too insubstantial or inadequately defended to permit meaningful action to be based on it.

Throughout this paper, there have been general observations regarding the practicality and ingenuity of many of the techniques discussed. In many cases, the labor-intensive nature of certain products limited their use to cases where the prohibitive costs of creating them was clearly justified on the basis of the insights they were expected to provide. However, modern information technology is more than up to the tasks of creating engineering drawings, correlating occupant data contained in "flat file" tables, and preparing graphical depictions of accident conditions and outcomes that would be of far greater use to future investigators than the more customary, text-heavy narratives used in typical investigation reports today.

Four specific recommendations are offered with respect to survival factors investigation goals and objectives for the next "century of flight." Those tempted to suggest that these recommendations would be unduly burdensome to implement should reflect on two facts of life in today's aviation environment:

1. As far as survivability and aircraft design criteria are concerned, much of what needs to be done, has been done. The contemporary safety and economic climate is far different from that of 50 years ago, when even the most rudimentary protective provisions were considered novel, but had immediate and powerful effects on the overall safety record. Justification of the need for major investments in either survival or evacuation capabilities will need to be as thoroughly and unequivocally documented as possible, should safety professionals deem such proposals essential at some point in the future.
2. While it is true that far fewer people are dying in present-day aircraft accidents, the ratio of survivable to nonsurvivable accidents seems to be undergoing a subtle but definite shift in the direction of nonsurvivability. That trend, if it matures and persists, will have two results: it will pull attention away from survival factors, just the way the need for prevention did in the first half-century of flight, and it will reduce the number of accidents from which real learning can be drawn in the area of survival factors. In other words, every opportunity for concentrated attention to the issues of survivability and evacuation will need to be taken advantage of for the foreseeable future.

Recommendation 1. Make survival factors a more prominent part of every major investigation, even if doing so requires outsourcing to ensure completeness.

In any survivable accident, as well as any "nonsurvivable" accident in which there are nonetheless survivors, it is essential to document what preventive and protective measures failed or were not present. However, it is equally important to identify what *did* work as designed or expected. NTSB records are replete with

Figure 10. Evacuation timeline analysis (availability of exits based on exterior conditions).

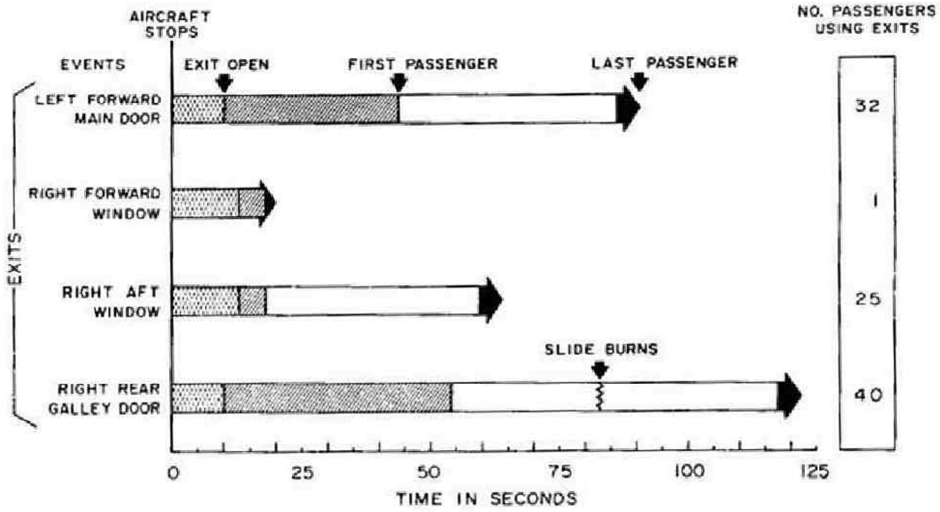


FIGURE 13. Estimated minimal evacuation times for exits used in Denver DC-8 crash. Time estimates are derived from AIA evacuation analysis of DC-8 test evacuation except at aft door where a 10 sec. delay is added for slide deployment and a rate of 2 sec./passenger assumed after the slide burned.

recommendations, both open and closed, regarding various configurational and procedural changes identified as necessary in previous investigations. The effectiveness and usefulness of prior recommendations cannot fairly be assessed without consciously and directly addressing them in subsequent investigations.

For example, the NTSB is on record as recommending specific requirements for passenger seat energy absorption. This means the following questions should be asked and answered in each final report:

1. What forces were the seats and occupants subjected to during the accident sequence?
2. Did the seats conform to the recommended level of protection?
3. Did the seats perform as expected in terms of dissipating loads and restraining their occupants?
4. Did that performance result in the expected protection of seat occupants?

Note that these issues should be explored regardless of the answer to #4 alone. If passengers are not injured as a result of seat function, that means that the existing provisions were adequate for the conditions encountered during the impact sequence. That fact is germane to the investigation at hand, and also needs to be available to future investigators of other accidents involving similar seat installations.

Some recommendations that remain in "Open—Unacceptable Action" status may warrant reconsideration if subsequent accidents fail to demonstrate the degree of unsatisfactory performance that led to the recommendation having been made in the first place. By the same token, "closed" recommendations that were not acted upon may be worth a second look if subsequent investigations effectively document conditions similar to those which prompted the original call for action. In both cases, though, a clear and convincing body of investigative evidence is essential to both the success *and* the credibility of any such retrospective efforts.

This recommendation cannot be fully realized without significant improvements in the accessibility of as much correlated, relevant survival factors data as can be collected in the course of each investigation. The rigidity of the NTSB report format—which itself is at least partly dictated by the perceived need to distinguish "factual" information from conclusions based on analysis—requires users to cull the various data points relevant to occupant survival from several different parts of the same document. (For example, the factual section devoted to "wreckage and impact information" is always separate from the "survival factors" section.)

Each NTSB final report is, inescapably, the product of analysis. Vast amounts of relevant factual information contained in the public docket for each major investigation never find their way into the formal report. Therefore, the reports themselves should become exclusively analytical in nature, tying together all relevant pieces of fact (even at the risk of repeating some facts in different sections of the report). Further, the analytical report could and should be greatly strengthened by direct reference to the relevant portions of the public docket relied upon by the members and staff in developing each section's conclusions. Printed documents should accomplish this by footnote; electronic versions should provide direct links.

Recommendation 2. Establish a standard set of products related to survival factors, to be prepared for every major accident in which there is even a single survivor or a single fatality.

One of the principal defects of many current accident reports is in the lack of correlation among various pieces of factual information they include—in different sections—with respect to occupant survival. For example, it is common to have to compare wreckage and impact information with narrative descriptions of post-crash survivor actions and movements to gain insight into the "why" of an evacuation sequence… a cumbersome and often imprecise process. Government investigators often cite such depictions as being analytical in nature, and for that reason decline to create them on that basis in the interest of objectivity. However, it is hardly a matter of "analysis" to show the destruction of a portion of the aircraft from impact forces or post-crash fire, and then to note who lived and died within that area.

Virtually the only time wreckage diagrams and descriptions are illuminating with respect to survival factors are when they are expressly designed to do one of two things: document an inflight event involving loss of components or structural integrity or document post-impact events with a bearing on the survival of the aircraft's occupants. Nevertheless, seating arrangement and wreckage orientation diagrams are a part of virtually every accident report, regardless of the degree of illumination they contribute to the understanding of the event.

The author's contention is that, if reports must be constructed along formulaic, standardized designs, their content must be exhaustively inclusive instead of expressly exclusive. The final report on an aircraft accident rendered by an investigative body is the only comprehensive compilation of relevant data regarding that accident, assembled by those with the most complete knowledge of the event and subsequent investigative activities.

The following is a bare-bones list intended to serve as a baseline for establishment of a standard portfolio of survival factors documentation, to be used for every accident in which a fatality, serious injury, or evacuation-related injury takes place. It is based on the historical record, early ICAO and AvCIR forms, and the current state of computer generation and animation. The ideal outcome would be for every accident investigation final report to have a "survival factors annex" that would build upon this basic content, but the creation of the standard portfolio, in both hard copy and electronic formats, would be a good start:

1. Cabin configuration chart: seat/aisle/galley/exit diagram, showing the layout of the accident aircraft prior to impact and specifically listing seat pitch in each separate cabin – this is to be used as a template for Chart #2).
2. Census chart: where each occupant was at the start of the impact sequence, including full demographic data (gender, age, preexisting disability, weight[34], etc.)
3. Kinematics chart: a depiction of how the crash sequence unfolded, including impact with ground structures, airframe compromise, and other energy-inducing and diffusing events taking place from initial impact until all movement has stopped.
4. Cabin compromise charts: Chart #1, redrawn to show:
   a. The location of fuselage separation(s) and intrusions, and the specific seats affected.
   b. The position of separated aircraft sections relative to each other, the prevailing wind, and the location of exterior fire.
   c. Areas where seats were not retained and the specific seats affected.
   d. Areas where occupiable volume was not retained and the specific seats affected.
5. Fatality/injury chart: mortality information, including severity of injuries as defined by ICAO, effect of injuries on mobility, and whether death occurred during or subsequent to impact (key to Chart #2).
6. Egress route chart: color-code to match seat vacated with exit used. Include availability of each exit and wind direction (key to Chart #3(b)).
7. Casualty location chart: location of fatally injured occupants found within or adjacent to each fuselage section, by seat number (key to Chart #3(b) and/or (c) as appropriate).
8. Fire propagation chart: point(s) of origin, direction of spread, elapsed time (key to Chart #3(b)).
9. Timeline: initial impact through final stop, opening of first exit, exit of first occupant, exit of last occupant.
10. Relational database "flat file," listing each seat by number and populating the following fields as a minimum:
    a. Gender
    b. Age
    c. Height
    d. Weight
    e. Disabled at time of accident (Y/N)
    f. Occupant status (fatal, serious, minor, none)
    g. Nature of injuries (multiple selections possible, including compression fracture(s), thermal, carbon monoxide, flail, aortic tearout, etc.)
    h. Source of injuries (multiple selections possible, including impact with furnishings, impact with other occupants, impact with intruding material, etc.)
    i. Survived impact (Y/N)
    j. Seat retained during impact (Y/N)
    k. Occupant protected from impact forces (Y/N)
    l. Occupant restraint in use (Y/N)
    m. Occupant restrained as intended throughout the sequence (Y/N)
    n. Seat within survivable volume
    o. Seat ejected from aircraft
    p. Occupant self-evacuated
    q. Distance between seat and nearest exit
    r. Distance between seat and nearest usable exit
    s. Exit used (number/location)
    t. Type of exit (e.g., Type II, Type III, etc.)
    u. Distance between seat and exit used

The more comprehensive a database of this type, the better; the use of statistical tools such as scatter plots to show comparative factors (e.g., age versus injury severity) is greatly facilitated by as complete a data set as possible.

Recommendation 3. Ensure that as much objective and subjective information regarding evacuation successes and failures, including both survivor statements and post-mortem information, is collected and retained for use by other investigators and researchers.

This is a sensitive issue, involving a variety of privacy concerns, but one which must be specifically addressed. There is an undeniable need for a reliable body of data on this subject to augment research and development efforts, both in the establishment of requirements and in the execution of the studies themselves. A 1995 CAMI report made the point that, "Continuing fundamental research in smoke toxicity, fire safety, and fire hazards assessment in aircraft accidents is clearly warranted. As fire science changes from a descriptive discipline to a mechanistic one, multidisciplinary skills will be required to develop practical applications from existing and projected research."[35] Such multidisciplinary efforts cannot succeed if they lack data upon which to build their common core of understanding, and as the CAMI report observes, when it comes to toxicity effects, "there is no standard fire."[36]

Recommendation 4. Where the failure of aircraft structural components and furnishings contributes to occupant fatalities, survival factors investigators should ensure as much objective data as possible is collected by structures investigators to support ongoing research. Such data must be correlated with occupant injury and fatality information to ensure the appropriate targeting of that research.

One of the inherent limitations associated with the early stages of a major investigation is the need to divide investigative efforts and tasks along functional lines for ease of management. This "chimneying" of expertise frequently persists throughout the fact-gathering phase of the investigation as all parties work to meet various deadlines; interaction among the various groups often is deferred until the analytical phase, through dialogue among investigative authority group chairs. However, interdisciplinary activities can and must occur during the information-gathering phase as well to ensure cross-functional information needs are fully met before the evidence or data winds up in the hands of a single specialized team.

A variety of ongoing research and development efforts are continuously in need of substantive data with which to work. For example, the European Community's "Crashworthiness" Project involves separate subtasks for establishment and distribution of background data, establishment, verification and comparison of analysis methodologies, studies of major airframe structure, and studies of occupant and local structure.[37] Activities of this scope and broad view warrant all possible support from the investigative community. ◆

Appendix

Recommendations from A. Howard Hasbrook, *Crash Survival Study: National Airlines DC-6 Accident at Elizabeth, N.J. on February 11, 1952* (NY: Crash Injury Research,

Cornell University Medical College, October 1953), pp. 44-45

1. The floor structure should preferably be the strongest part of the entire fuselage in order to provide a platform to which the seats will remain attached—up to the point of disintegration of major portions of the aircraft.
2. The floor structure should also be sufficiently ductile to provide failure by progressive buckling and collapse rather than by shattering or "explosive types" of failure.
3. The passenger "tie down" (safety belt, anchorage, portions of the seat which carry the safety belt loads, seat anchorages and the basic floor structure) should have a strength, fore and aft (see item #5, below) equal to the load capacity of the safety belt. If the basic floor structure has a greater strength, the passenger seats and seat anchorages should not be designed to fail completely under loads less than those required to cause extensive failure of basic cabin structures.
4. Seat structure should be ductile, as well as strong, to permit deformation without complete failure of major portions of the seat, and resultant failure of passenger tie-down.
5. Seats should be designed to resist fore and aft longitudinal loads imposed from any point within 30° of the longitudinal axis of the aircraft.
6. Seat-floor anchorage units should deform without complete failure, up to the point of disintegration of the floor structure.
7. If the seats are attached to both the wall and floor structure, the seats and their attachments should be designed so that *flexion* of the wall and floor will not break the seats loose. [emphasis in original]
8. Seats and seat anchorages should be tested dynamically—as well as statically—on typical portions of floor and/or wall structure. "Weaving" and deformation of the floor and wall structures should accompany the application of dynamic impact loads—particularly if the seats are of rigid design.
9. If practical, seat-backs should be high enough to provide some protection for the tops of the passengers' heads.
10. Buffet units should be attached to primary fuselage structure in such a way as to prevent large scale displacement up to the point of fuselage disintegration.
11. If practical, buffets should be used to partition off the cabin in a number of sections.
12. Overhead hatrack structure should be of delethalized design and construction.
13. Fire extinguishers and other "lethal" objects should be secured according to load factors not less than those used for the passenger tie-down.
14. Brittle plastic partitions should not be used in the passenger cabin.
15. The stewardess should be in the most aft section of the cabin.
16. The stewardess and other crewmembers should wear shoulder harness, as well as safety belts, during takeoffs and landings—regardless of the direction they are seated, i.e., aft, forward, or side-facing.
17. End attachment fittings of the safety belts should be mounted on swiveling anchorages to prevent fracture failures due to bending.

Bibliography

Advisory Group for Aeronautical Research and Development. *Aircraft Accident Investigation_Manual for Air Surgeons / Manuel d'Enquête sur les Accidents Aériens à l'usage des Médecins de l'Aviation*. NY: Pergamon Press, 1961.

Allward, Maurice. *Safety in the Air*. London: Abelard-Schuman, Ltd., 1967.

Aviation Safety Council, Republic of China. *Aircraft Accident Report: Crashed on a Partially Closed Runway during Takeoff, Singapore Airlines Flight 006, Boeing 747-400, 9V-SPK, CKS Airport, Taoyuan, Taiwan, October 31, 2000*, Report Number ASC-AAR-02-04-001. Taipei, ROC: Aviation Safety Council, 2002.

Biederman, Paul. *The U.S. Airline Industry: End of An Era*. NY: Praeger Publishers, 1982.

Caves, Richard E. *Air Transport and Its Regulators: An Industry Study*. Cambridge, MA: Harvard University Press, 1962.

Chaturvedi, Arvind K. and Saunder, Donald C. Saunders. *Aircraft Fires, Smoke, Toxicity, and Survival: An Overview,* Report Number DOT/FAA/AM-95/8. Oklahoma City, OK: Civil Aeromedical Institute, February 1995.

Department of the Air Force. *Air Force Manual 62-5, Aircraft Accident Prevention—Investigation—Reporting*. Washington, D.C.: Department of the Air Force, 1 February 1956.

Federal Aviation Administration. *Survival in Emergency Escape from Passenger Aircraft,* Report Number FAA/AM 70-16. Washington, DC: Department of Transportation, October 1970.

Hasbrook, A. Howard et al. Evacuation Pattern Analysis of a Survivable Commercial Aircraft Accident. Oklahoma City, OK: Civil Aeromedical Research Institute, May 1962.

International Civil Aviation Organization. *Manual of Aircraft Accident Investigation*. ICAO Doc. 6920-AN/855. Montreal: International Civil Aviation Organization, 1949.

International Civil Aviation Organization. *Manual of Aircraft Accident Investigation, Second Edition*. ICAO Doc. 6920-AN/855. Montreal: International Civil Aviation Organization, 1951.

International Civil Aviation Organization. *Manual of Aircraft Accident Investigation, Third Edition.* ICAO Doc. 6920-AN/855. Montreal: International Civil Aviation Organization, 1957.

King, Barry G. "Aircraft Evacuation Under Fire Conditions," in *Aviation Bulletin No. 107*. Boston, MA: National Fire Protection Association, May 1954.

Lederer, Jerome, M.E. *Safety in the Operation of Air Transportation: A James Jackson Cabot Professorship Lecture*. Northfield, VT: Norwich University, April 20, 1939.

Lederer, Jerome. *Perspectives in Air Safety: Daniel Guggenheim Medal Award Lecture to the ASME Aviation & Space Conference*. NY: Flight Safety Foundation, Inc., 1962.

Lederer, Jerome. *Aviation Safety Perspectives: Hindsight, Insight, Foresight—The Nineteenth Wings Club "Sight" Lecture. NY: The Wings Club, April 21, 1982.*

Ministry of Transport and Civil Aviation. *Civil Aircraft Accident: Report of the Court of Inquiry into the Accidents to Comet G-AYLP on 10th January, 1954 and Comet G-ALYY on 8th April, 1954*. London: Her Majesty's Stationery Office, 1955.

McFarland, Ross A., PhD. *Human Factors in Air Transport Design* (NY: McGraw-Hill Book Company, Inc., 1946.

Moscow, Alvin. *Tiger on a Leash*. NY: G.P. Putnam's Sons, 1961.

National Transportation Safety Board. *Aircraft Accident Report: Loftleider Icelandic Airlines, Inc., Douglas DC-8-61, John F._Kennedy International Airport, Jamaica, New York, June 23, 1973 (Report Number NTSB-AAR-73-20)*. Washington, D.C.: National Transportation Safety Board, December 5, 1973)

National Transportation Safety Board. *Aircraft Accident Report: Air Florida, Inc., Boeing 737-222, N67AF, Collision with 14th Street Bridge, Near Washington National Airport, Washington, D.C., January 13, 1982* (Report Number NTSB-AAR-82-8). Washington, D.C.: National Transportation Safety Board, August 10, 1982.

National Transportation Safety Board. *Special Study: Safety Aspects of Emergency Evacuations from Air Carrier Aircraft,* Report Number NTSB-AAS-74-3. Washington, D.C.: National Transportation Safety Board, November 1974.

National Transportation Safety Board. *Survivability of Accidents Involving Part 121 U.S. Air Carrier Operations, 1983 through 2000*, Safety Report Number NTSB/SR-01/01. Washington, D.C.: National Transportation Safety Board, March 2001.

Office of Aviation Safety. *A Survey of Air Carrier Cabin Safety*. Washington, D.C.: Federal Aviation Administration, December 1976.

Office of Flying Safety, HQ USAAF. *Safety as a Factor in the Future of Aviation.* Washington, D.C.: Headquarters, Army Air Forces, 1945.

Office of Technology Assessment. *Aircraft Evacuation Testing: Research and Technology Issues,* Report Number OTA-BP-SET-121. Washington, D.C.: Congress of the United States, September 1993

Pesman, Gerard J. "Human Survival in Aircraft Crash Fires," in *Aviation Bulletin No. 106.* Boston, MA: National Fire Protection Association, May 1954.

Reals, William J., M.D., ed. *Medical Investigation of Aviation Accidents*. Chicago, IL: College of American Pathologists, 1968.

Sadeghi, M.M. and Hashemi, S.M.R. *An Overview of the Aircraft Crashworthiness Study Project: A European Programme*. Cranfield, Bedfordshire, UK: Cranfield Impact Centre, 1997.

Smith, C.R. *Safety in Air Transportation Over the Years—The Eighth Wings Club "Sight" Lecture*. NY: The Wings Club, May 19, 1971.

Tufte, Edward R. *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press, LLC., 1983.

U.S. Army Transportation Research Command. *Crash Injury Investigation: U.S. Army G-91 Reconnaissance Jet Fighter Accident, Fort Rucker, Alabama, 1 February 1961*. (Prepared by, New York, New York—Contract DA-44-177-TC-707, TREC Technical Report 61-91, AvCIR 61-2). Phoenix, AZ: Aviation Crash Injury Research (a Division of Flight Safety Foundation, Inc.), July 1961.

U.S. Civil Aeronautics Authority. *Aircraft Accidents and Casualties: Civil Aeronautics Bulletin No. 3, September 1, 1938.* Washington, D.C.: Government Printing Office, 1938.

Warner, Edward Pearson, Sc.D. *Technical Development and its Effect on Air Transportation: A James Jackson Cabot Professorship Lecture*. Northfield, VT: Norwich University, February 23, 1938.

Footnotes

[*] The views expressed in this paper are the author's and do not reflect official positions of the Air Transport Association of America, Inc., or its member airlines.

[1] National Transportation Safety Board, *Aircraft Accident Report: Air Florida, Inc., Boeing 737-222, N67AF, Collision with 14th Street Bridge, Near Washington National Airport, Washington, D.C., January 13, 1982,* NTSB-AAR-82-8 (Washington, D.C.: National Transportation Safety Board, August 10, 1982), p. 22.

[2] Investigators also may wish to differentiate between "contact injuries" and "decelerative injuries" encountered during the sudden stoppages associated with crash sequences. This useful distinction was made by the Royal Australian Air Force's Directorate of Flying Safety in a 1997 article reprinted by the U.S. Air Force Safety Center the following year. See http://www-afsc-saia.af.mil/magazine/htdocs/febmag98/crshsurv.htm.

[3] Office of Technology Assessment, *Aircraft Evacuation Testing: Research and Technology Issues,* OTA-BP-SET-121 (Washington, D.C.: Congress of the United States, September 1993), p. 3.

[4] National Transportation Safety Board, *Survivability of Accidents Involving Part 121 U.S. Air Carrier Operations, 1983 through 2000,* Safety Report NTSB/SR-01/01 (Washington, D.C.: National Transportation Safety Board, March 2001), p. 7.

[5] The Zeppelin LZ7 operated by DELAG (Deutche Luftshiffahrt Aktien Gesellschaft, began service between Frankfurt and Dusseldorf on June 22, 1910. See http://www.adamsaviation.co.uk/new_page_3.htm for an interesting chronology of this and other ground-breaking events in aviation history.

[6] One example of this new perspective may be seen in British aviation history; in a 2002 letter to the Greater London Industrial Archaeology Society, Mr. Bill Firth noted that, in the beginning of May 1919, Hounslow Heath was converted from Royal Air Force to civil aviation operations as "London Terminal Aerodrome," and that commercial passenger operations serving London were moved to Croydon the following year. See http://www.glias.org.uk/news/198news.html.

[7] "Altitude is Everything: Canadians in the Sky," May 2003, Ottawa, Transport Canada, p. 13. Available at http://www.altitudeis.com/YOUTH%20ACTIVITY%20BOOK%20English%20WEB%20Version.pdf.

[8] See the Air Transport Association (ATA) on-line version of its *Airline Handbook* (http://www.airlines.org/public/publications/display1.asp?nid=961) for an expanded discussion of the legislative history underlying early U.S. commercial air operations.

[9] U.S. Civil Aeronautics *Authority, Aircraft Accidents and Casualties: Civil Aeronautics Bulletin No. 3, September 1, 1938* (Washington, D.C.: Government Printing Office, 1938), p. 10 (Table A).

[10] Paul Biederman, *The U.S. Airline Industry: End of An Era* (NY: Praeger Publishers, 1982), p. xiii.

[11] *ATA,* op. cit.

[12] Edward Pearson Warner, D.Sc., *Technical Development and its Effect on Air Transportation: A James Jackson Cabot Professorship Lecture* (Northfield, VT: Norwich University, February 23, 1938), p. 5.

[13] *Ibid.,* p. 32.

[14] Jerome Lederer, M.E., *Safety in the Operation of Air Transportation: A James Jackson Cabot Professorship Lecture* (Northfield, VT: Norwich University, April 20, 1939), p. 15. Readers should also note that innovation in cabin furnishings in early airliners was to some extent bound up in air carrier competition. Prior to the jet era, airlines and manufacturers had more or less exclusive agreements that tied aircraft development to the purchasers. In the postwar economy, however, research and development enabled manufacturers to grow independent of airline agreements, so furnishings that were better (and safer) began forming part of the "market" drive for better, safer aircraft. See generally Richard E. Caves, *Air Transport and Its Regulators: An Industry Study* (Cambridge, MA: Harvard University Press, 1962), pp. 100-102 passim.

[15] Headquarters, U.S. Army Air Forces, Office of Flying Safety, *Safety as a Factor in the Future of Aviation* (Washington, D.C.: Government Printing Office, 1945), p. 10.

[16] Ross A. McFarland, Ph.D., *Human Factors in Air Transport Design* (NY: McGraw-Hill Book Company, Inc., 1946), pp. 566-569 passim.

[17] *Ibid.,* p. 571.

[18] *Ibid.,* p. 637.

[19] *CAB Bureau of Safety Investigation's Recommendations for Increasing the Passenger Safety Level in Transport Category Aircraft, Bulletin No. 57* (Boston, MA: National Fire Protection Association, June 30, 1950).

[20] ICAO Doc. 6920-AN/855, *Manual of Aircraft Accident Investigation* (Montreal: International Civil Aviation Organization, 1949), p. 42.

[21] ICAO Doc. 6920-AN/855, *Manual of Aircraft Accident Investigation, Second Edition* (Montreal: International Civil Aviation Organization, 1951), pp. 30-31.

[22] These same forms and protocols were in large part adopted by the Advisory Group for Aeronautical Research and Development (AGARD) in 1961, thus bringing together once more civil and military perspectives on survival factors and their investigation. AGARD was a particularly strong advocate of comprehensive documentation of injuries incurred during crashes: "[Data collection] is a basic prerequisite of prevention. Before preventive measures can be exercised, the accident potential conditions must be observed, recorded, and proven by analysis. Such conditions may be demonstrated in accidents or incidents, but it is not necessary for an accident to occur to prove the accident potential of a condition… The process is unending, since data must continue to be assembled to assess the effectiveness of the preventive measures as well as to detect the accident forces arising out of the advances in aviation equipment and techniques." See *Advisory Group for Aeronautical Research and Development, Aircraft Accident Investigation Manual for Air Surgeons / Manuel d'Enquête sur les Accidents Aériens à l'usage des Médecins de l'Aviation* (NY: Pergamon Press, 1961), pp. 67 – 69.

[23] Gerard J. Pesman, *Human Survival in Aircraft Crash Fires, Aviation Bulletin No. 106* (Boston, MA: National Fire Protection Association, May 1954). Mr. Pesman's graphical depictions of the relationships between elapsed time and temperature increase, and between elapsed time and toxic gas circulation, are dated but otherwise excellent conceptual models that would easily lend themselves to contemporary investigative applications. Bulletins in this series are available on microfilm at the Morgan Technical Library at NFPA's headquarters in Quincy, Massachusetts.

[24] Barry G. King, *Aircraft Evacuation Under Fire Conditions, Aviation Bulletin No. 107* (Boston, MA: National Fire Protection Association, May 1954).

[25] For example, the effects of wind on escape slides, as well as uncommanded inflations, continue to plague evacuation efforts, as was seen in the accident involving a Singapore Airlines Boeing 747-400 at Taipei, Taiwan on October 31, 2000; see Aviation Safety Council, *Aircraft Accident Report: Crashed on a Partially Closed Runway during Takeoff, Singapore Airlines Flight 006, Boeing 747-400, 9V-SPK, CKS Airport, Taoyuan, Taiwan, October 31, 2000, ASC-AAR-02-04-001* (Taipei, ROC: Aviation Safety Council, 2002), p. 224

[26] Office of Aviation Safety, *A Survey of Air Carrier Cabin Safety* (Washington, D.C.: Federal Aviation Administration, December 1976), pp. 14-26 passim. An Appendix to this report, prepared by Richard Ostlund of the Aerospace Industries Association on "The Designer's View of Cabin Safety" suggests why this knowledge was so slow to be translated into action: "Special interest groups seem to consistently advocate change without proper consideration of the economic impact versus degree of improvement." Id. at p. V-1. This pessimistic but realistic appraisal has been to some extent belied by the success that has been seen in addressing so many of the aforementioned issues since airline deregulation.

[27] Six people on the ground, as well as a former Secretary of War aboard the aircraft, died in this accident. New Jersey Senators Smith and Hendrickson had already been reacting to constituent complaints about operations at Newark; within days of the crash, they offered Senate Resolution 268, which drove a separate congressional investigation into the accident conducted by the Committee on Interstate and Foreign Commerce. That Committee's report, published as 82nd Congress, 2nd Session, Report No. 1140 (just nine days after the accident!) made a few graceful observations regarding the need to "continue to study ways and means of improving aircraft safety and reducing the danger and annoyance to persons in their homes and on the ground," but concluded by leaving investigating to the professionals: "The problem of aviation safety presents the greatest challenge to the aeronautical industry and requires the intent and constant attention of all concerned."

[28] The value of illustrations along the lines of the examples provided is self-evident, and also makes their content and importance extremely accessible to both experts in aviation and laymen alike. Readers interested in developing more ideas regarding the visual presentation of information are encouraged to consult the work of Edward R. Tufte, a true innovator in the field who has done exceptional work regarding the application of computer graphics to that use. A good initial work to start with would be *The Visual Display of Quantitative Information* (Cheshire, CT: Graphics Press, LLC., 1983), available from a variety of on-line book sources or directly from the author at http://www.edwardtufte.com/tufte/.

[29] Readers are encouraged to review the full list in the Appendix to this paper—drawn verbatim from the report—and reflect on the fact that (a) it was prepared a full half-century ago, and (b) it was created purely on the basis of work done by this small group of researchers since the early 1940s, after virtually no organized attention had been paid to any of the issues it raises in the preceding 40 years.

[30] A. Howard Hasbrook, et al., *Evacuation Pattern Analysis of a Survivable Com-*

mercial Aircraft Accident (Oklahoma City, OK: Civil Aeromedical Research Institute, May 1962).

[31] NTSB-AAS-74-3, *Special Study: Safety Aspects of Emergency Evacuations from Air Carrier Aircraft* (Washington, D.C.: National Transportation Safety Board, November 1974).

[32] FAA/AM 70-16, *Survival in Emergency Escape from Passenger Aircraft* (Washington, DC: Department of Transportation, October 1970). This report, which was an in-depth review of three accidents from the 1960s, also contained a useful analysis of passenger evacuation times and numbers by the exits used, as well as detailed epidemiological analyses of all occupants that went so far as to document parental status (p. 46) as a possible delaying factor that might have had a bearing on the higher female mortality rates observed in all three accidents.

[33] In 1999, in identifying the various domains across which emergency evacuation problems must be addressed, the French Direction Général de l'Aviation Civile (F-DGAC) offered a list similar to the above. The four areas of consideration proposed in this study were fires, smoke and toxic gases; technical specifics of evacuation systems, e.g. opening of emergency exits, use of slides [and] communication systems; human factors, including communications problems; and preparing passengers to evacuate (from providing information to cabin preparation). Although not differentiated by types of factors as seen in the other two, the overlaps are striking, but the omissions are equally noteworthy. See F-DGAC, *Interim Report: Bibliography Review—Research study on emergency evacuation, Revision nº 2, March 10th, 1999, p. 4.* (English version available at http://www.dgac.fr/html/actu_gd/sfatsecu/dedale1A.pdf.)

[34] There is little evidence that passenger weight ever was taken into consideration as a factor in seat failure during a crash sequence until it was specifically included as part of an analysis performed in the mid-1990s by the Civil Aerospace Medical Institute's "Aircraft Accident Research Team." Once addressed, however, the importance of this variable became obvious. An abstract of a presentation on this issue, A.L. Pennybacker and S.J.H. Veronneau, *Description of Failures of Passenger Seats in a High Vertical Acceleration Accident,* is available at http://www.cami.jccbi.gov/AAM-600/AccientResearch/600Air-Pre-Bec.html.

[35] Arvind K. Chaturvedi and Donald C. Saunders, *Aircraft Fires, Smoke, Toxicity, and Survival: An Overview,* DOT/FAA/AM-95/8 (Oklahoma City, OK: Civil Aeromedical Institute, February 1995), p. 4.

[36] *Ibid.,* p.3.

[37] M.M. Sadeghi and S.M.R. Hashemi, *An Overview of the Aircraft Crashworthiness Study Project: A European Programme* (Cranfield, Beds, UK: Cranfield Impact Centre, 1997), p. 2.

The Accident Database of the Cabin Safety Research Technical Group

By Ray Cherry, R.G.W. Cherry & Associates Limited, UK

***Ray Cherry** is a Chartered Engineer, a Fellow of the Royal Aeronautical Society, and a member of the Institution of Mechanical Engineers. He joined the aircraft industry in 1968 and has been a member of the Airbus, BAe 146, and BAe 125/Hawker design teams. He has held many positions during his career with Hawker Siddeley Aviation, British Aerospace, and Raytheon, including Head of Development & Reliability, Chief Safety & Certification Engineer with BAe, and Head of Product Integrity and Airworthiness with Raytheon Corporate Jets. He is now part of a team offering a consultancy and contractual service to the industry.*

1. History of the database

The accident database of the Cabin Safety Research Technical Group (CSRTG) was developed out of a European Union research project carried out by R.G.W. Cherry & Associates Limited.

The database was subsequently adopted and its development funded by the CSRTG. The CSRTG is a group whose members consist of the aviation authorities of North America, Europe, Japan, Australia, Brazil, and Russia, and whose purpose is to "enhance the effectiveness and timeliness of cabin safety research by establishing an international framework."[1]

The database has proved to be an extremely useful analytical tool in studying trends and quantifying improvements in aircraft safety and has been used many times in benefit analyses carried out for the airworthiness authorities.

Its prime attributes are

i) Its word search capability allows rapid retrieval of accidents with similar features.

ii) Its compatibility with Microsoft software means that all of the features of Excel and Word may be used for data analysis and documentation.

2. Population of the database

The database consists of accidents involving occupant injuries for passenger and cargo operations over the period 1967 to 2001.

All data have been derived from reliable sources, primarily from accident investigating authorities. Records are stored for transport-category passenger aircraft (with 19 or more passenger seats) and cargo aircraft certificated under Part 25 requirements or equivalent. The database contains photographs and diagrams as well as textual and numerical data.

At Issue 21, the database currently contains information on 2,819 accidents, and of these, textual information is available on 742.

The database may be downloaded from the following websites:

www.fire.tc.faa.gov/cabwg.stm
www.rgwcherry.co.uk

3. Content of the database

The database access menu is as follows:

Screen 1
Screen 2
Screen 3
Photographs
Injury Locations
Exit Usage
Aircraft Data
Occupant Data
Fire Factors
Water Factors
Impact Factors
Environment
Orientation
Exit and Assist Means
Custom List (No data present)

Screens 2 and 3 are textual fields providing text extracted from reports generated by accident investigating authorities.

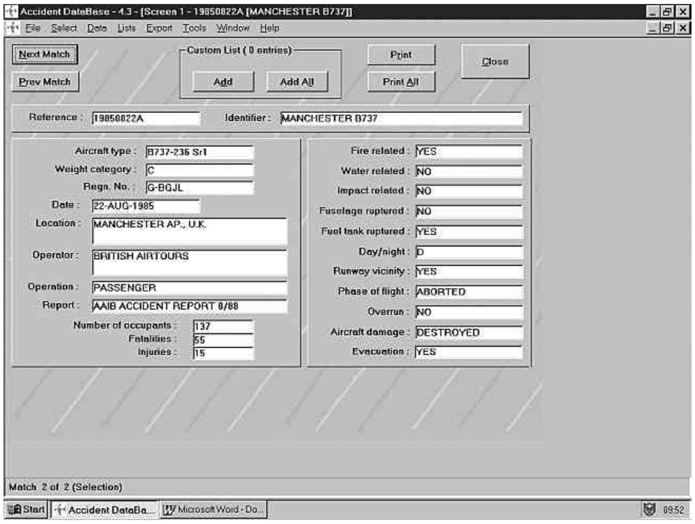
General fields

Reference

Each accident has a unique reference number based on the date of occurrence of the accident. Hence an accident occurring on the July 25, 1991, would have the following code: 19910725A. The alphanumeric code has been used to differentiate between accidents, should more than one occur on the same date. In this event, subsequent accidents will be annotated "B," "C," etc.

Identifier

This field is used where an accident is commonly known by an identifier or name, e.g., "Sioux City" and "Kegworth."



Accident DataBase - 4.3 - [Screen 1 - 19850822A [MANCHESTER B737]]

Reference : 19850822A
Identifier : MANCHESTER B737
Aircraft type : B737-236 Sr1
Weight category : C
Regn. No. : G-BGJL
Date : 22-AUG-1985
Location : MANCHESTER AP., U.K.
Operator : BRITISH AIRTOURS
Operation : PASSENGER
Report : AAIB ACCIDENT REPORT 8/88
Number of occupants : 137
Fatalities : 55
Injuries : 15
Fire related : YES
Water related : NO
Impact related : NO
Fuselage ruptured : NO
Fuel tank ruptured : YES
Day/night : D
Runway vicinity : YES
Phase of flight : ABORTED
Overrun : NO
Aircraft damage : DESTROYED
Evacuation : YES

Match 2 of 2 (Selection)

Figure 1. Example of a Screen 1 entry in the accident database.

Screen 1

All accidents on the database have a Screen 1 entry.

An example of Screen 1 is shown in Figure 1.

Screen 1 contains the basic data regarding the accident, the aircraft, and the injuries to occupants.

Screen 1 contains the following fields:

Aircraft Type

This field defines the aircraft type and series, e.g., B-737-236

Weight Category

This field defines the weight category of the aircraft. The following categories of maximum takeoff weight (MTOW) have been used:

A = less than 12,500 lbs
B = 12,500-100,000 lbs
C = 100,000 lb-250,000 lbs
D = 250,000 lb-400,000 lbs
E = greater than 400,000 lbs

Registration Number

Date of Accident

Location of Accident

Aircraft Operator

Accident Report Reference

This field contains the reference number of the official accident report.

Number of Occupants

Number of Fatalities

Number of Injuries

Fire Related

This field contains YES or NO depending on whether the accident involved a fire.

Water Related

This field contains YES or NO depending on whether the accident involved alighting on water.

Impact Related

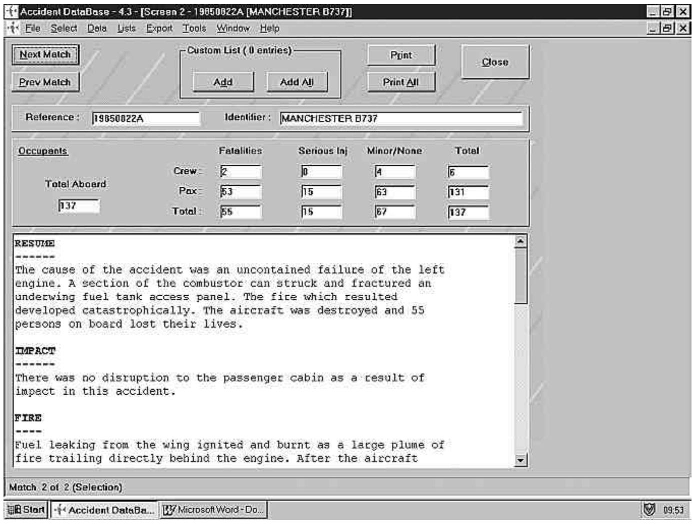
This field contains YES or NO depending on whether the accident involved an impact with the ground or water.

Fuselage Ruptured

This field defines whether the fuselage was ruptured as a result of impact.

Fuel Tank Ruptured

This field defines whether the fuel tank was ruptured as a result of impact.



Reference : 19850822A

Identifier : MANCHESTER B737

Occupants	Fatalities	Serious Inj	Minor/None	Total
Crew :	2	0	4	6
Pax :	53	15	63	131
Total :	55	15	67	137

Total Aboard: 137

```
RESUME
------
The cause of the accident was an uncontained failure of the left
engine. A section of the combustor can struck and fractured an
underwing fuel tank access panel. The fire which resulted
developed catastrophically. The aircraft was destroyed and 55
persons on board lost their lives.

IMPACT
------
There was no disruption to the passenger cabin as a result of
impact in this accident.

FIRE
----
Fuel leaking from the wing ignited and burnt as a large plume of
fire trailing directly behind the engine. After the aircraft
```

Match 2 of 2 (Selection)

Figure 2. Example of a Screen 2 entry in the accident database.

Day/Night

This field defines whether the accident occurred during the day or during the night.

Runway Vicinity

This field defines whether the accident took place within the vicinity of the airfield.

Phase of Flight

This field defines the phase of flight in which the accident occurred.

Overrun

This field defines whether the accident was caused as a result of the aircraft overrunning the runway.

Aircraft Damage

This field defines the extent of aircraft damage as a result of the accident. The aircraft damage has been classified into the following categories:

Destroyed
Substantial
Minor
None

Occupant Injuries

Occupant Fatalities

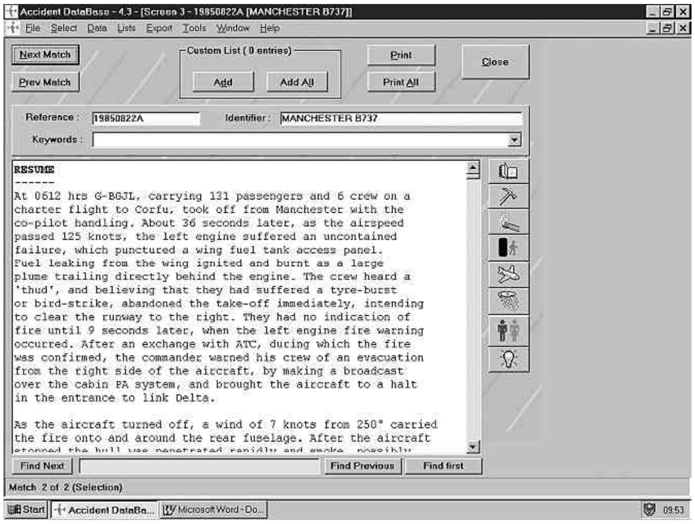
Evacuation

This field defines whether the accident involved an emergency evacuation.

Screen 2

Screen 2 contains additional fields to Screen 1 and provides a textual summary of the accident. See Figure 2 for an example of a typical Screen 2 entry.

The Screen 2 fields are as follows:



Reference : 19850822A

Identifier : MANCHESTER B737

Keywords :

```
RESUME
------
At 0612 hrs G-BGJL, carrying 131 passengers and 6 crew on a
charter flight to Corfu, took off from Manchester with the
co-pilot handling. About 36 seconds later, as the airspeed
passed 125 knots, the left engine suffered an uncontained
failure, which punctured a wing fuel tank access panel.
Fuel leaking from the wing ignited and burnt as a large
plume trailing directly behind the engine. The crew heard a
'thud', and believing that they had suffered a tyre-burst
or bird-strike, abandoned the take-off immediately, intending
to clear the runway to the right. They had no indication of
fire until 9 seconds later, when the left engine fire warning
occurred. After an exchange with ATC, during which the fire
was confirmed, the commander warned his crew of an evacuation
from the right side of the aircraft, by making a broadcast
over the cabin PA system, and brought the aircraft to a halt
in the entrance to link Delta.

As the aircraft turned off, a wind of 7 knots from 250° carried
the fire onto and around the rear fuselage. After the aircraft
```

Match 2 of 2 (Selection)

Figure 3. Example of a Screen 3 entry in the accident database.

Total Aboard

This field contains the total number of occupants on board encompassing flight crew, cabin crew, and passengers.

Number of Fatalities and Injuries

The database has a group of fields containing the number of fatalities, number of non-fatal serious injuries, and number of minor/no injuries for the crew, passengers and total.

Screen 2 Text

The Screen 2 text field contains a high-level summary of the accident under the following headings:
Résumé
Impact
Fire
Evacuation
Aircraft Factors
Environmental Conditions
Injuries to Occupants
Conclusions

Screen 3

The Screen 3 text field contains an expanded version of the Screen 2 text field and uses the same headings. The text is taken directly from accident reports although it will have been reordered to appear under each of the headings. An example of a Screen 3 entry is shown in Figure 3.

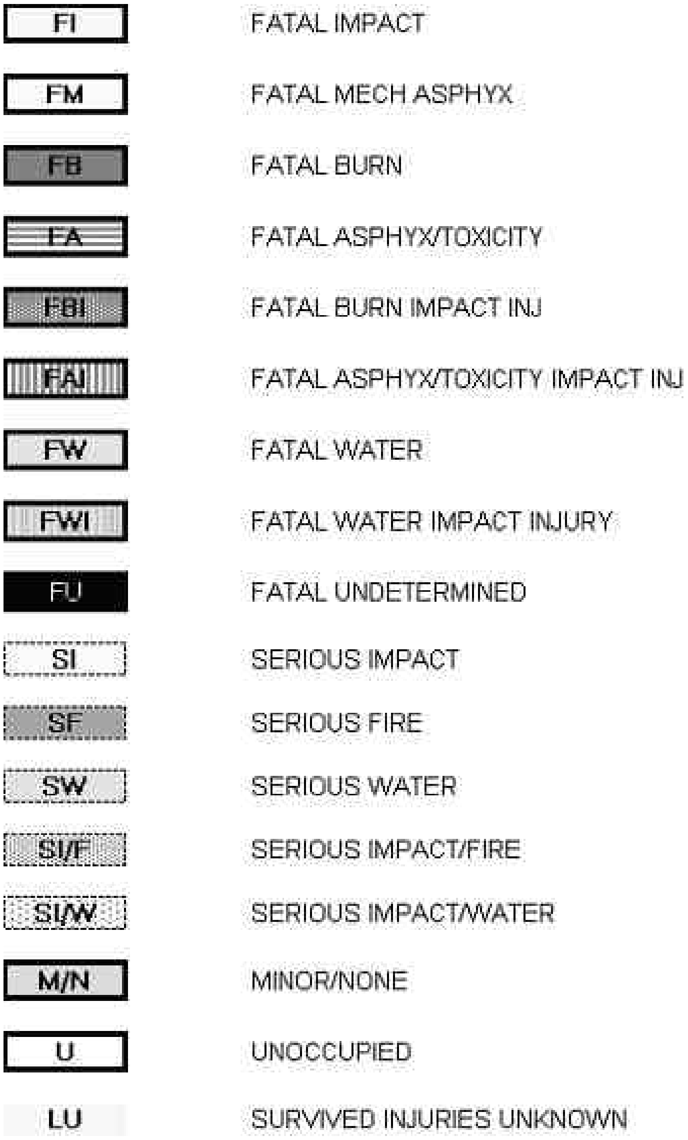
Photographs

This section of the database contains a selection of available photographs and drawings pertinent to the accident for on-screen display.

Injury locations

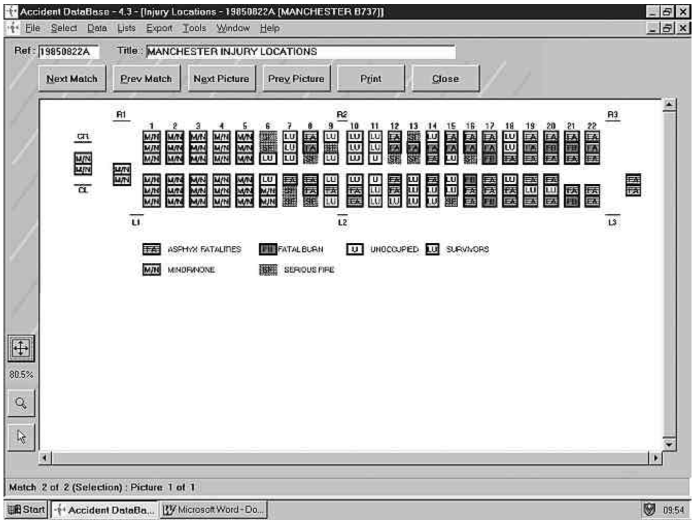
This section of the database contains a diagram of the injuries sustained by each occupant by assigned seat position.

The codes used to indicate causes and extent of injury are shown in Figure 4.



FI	FATAL IMPACT
FM	FATAL MECH ASPHYX
FB	FATAL BURN
FA	FATAL ASPHYX/TOXICITY
FBI	FATAL BURN IMPACT INJ
FAI	FATAL ASPHYX/TOXICITY IMPACT INJ
FW	FATAL WATER
FWI	FATAL WATER IMPACT INJURY
FU	FATAL UNDETERMINED
SI	SERIOUS IMPACT
SF	SERIOUS FIRE
SW	SERIOUS WATER
SI/F	SERIOUS IMPACT/FIRE
SI/W	SERIOUS IMPACT/WATER
M/N	MINOR/NONE
U	UNOCCUPIED
LU	SURVIVED INJURIES UNKNOWN

Figure 4. Codes used for injury locations in the accident database.

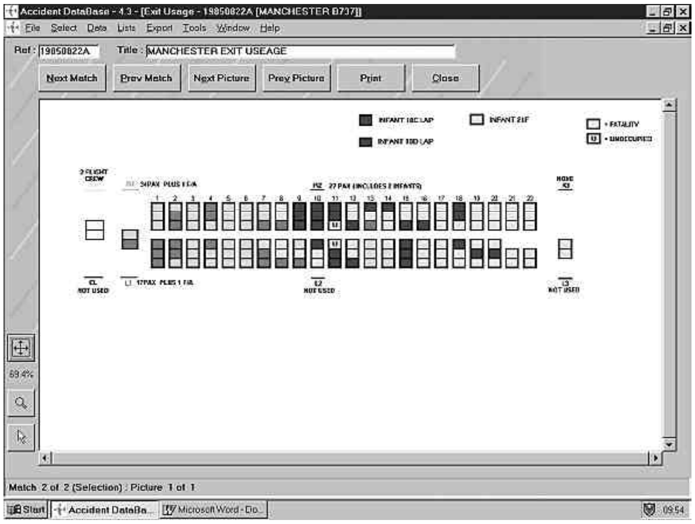


Ref : 19850822A

Title : MANCHESTER INJURY LOCATIONS

Match 2 of 2 (Selection) : Picture 1 of 1

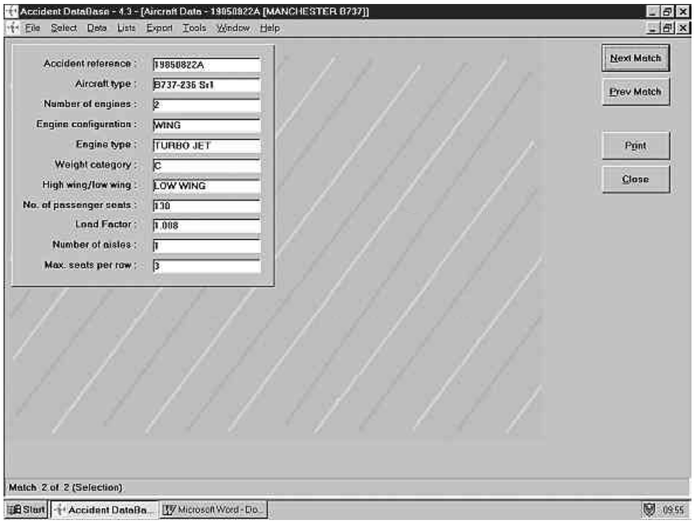
Figure 5. Typical example of injury location diagram in the accident database.



Ref : 19850822A
Title : MANCHESTER EXIT USEAGE

Match 2 of 2 (Selection) : Picture 1 of 1

Figure 6. Example of exit usage diagram in the accident database.



Accident reference : 19850822A
Aircraft type : B737-236 Sr1
Number of engines : 2
Engine configuration : WING
Engine type : TURBO JET
Weight category : C
High wing/low wing : LOW WING
No. of passenger seats : 130
Load Factor : 1.008
Number of aisles : 1
Max. seats per row : 3

Match 2 of 2 (Selection)

Figure 7. Aircraft data fields as they appear on the database.

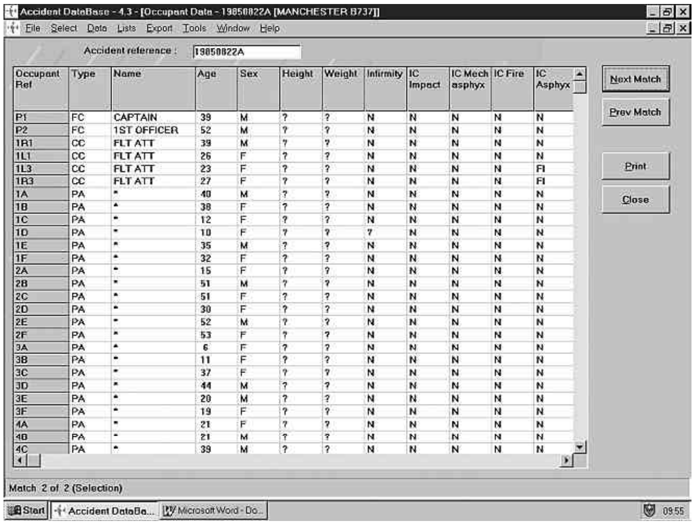
A typical example of an injury location diagram is shown in Figure 5.

Exit usage

This section of the database contains a diagram of the exit used by each occupant by seat position. A typical example of an exit usage diagram is shown in Figure 6.

Aircraft data

This section of the database contains basic information pertinent to the aircraft. Figure 7 shows the aircraft data fields as they appear on the database. The fields are as follows:
Aircraft
Number of Engines
Engine Configuration
Engine Type
Weight Category
High Wing/Low Wing
Number of Passenger Seats



Accident reference : 19850822A

Occupant Ref	Type	Name	Age	Sex	Height	Weight	Infirmity	IC Impact	IC Mech asphyx	IC Fire	IC Asphyx
P1	FC	CAPTAIN	39	M	?	?	N	N	N	N	N
P2	FC	1ST OFFICER	52	M	?	?	N	N	N	N	N
1R1	CC	FLT ATT	39	M	?	?	N	N	N	N	N
1L1	CC	FLT ATT	26	F	?	?	N	N	N	N	N
1L3	CC	FLT ATT	23	F	?	?	N	N	N	N	FI
1R3	CC	FLT ATT	27	F	?	?	N	N	N	N	FI
1A	PA	*	40	M	?	?	N	N	N	N	N
1B	PA	*	38	F	?	?	N	N	N	N	N
1C	PA	*	12	F	?	?	N	N	N	N	N
1D	PA	*	10	F	?	?	?	N	N	N	N
1E	PA	*	35	M	?	?	N	N	N	N	N
1F	PA	*	32	F	?	?	N	N	N	N	N
2A	PA	*	15	F	?	?	N	N	N	N	N
2B	PA	*	51	M	?	?	N	N	N	N	N
2C	PA	*	51	F	?	?	N	N	N	N	N
2D	PA	*	30	F	?	?	N	N	N	N	N
2E	PA	*	52	M	?	?	N	N	N	N	N
2F	PA	*	53	F	?	?	N	N	N	N	N
3A	PA	*	6	F	?	?	N	N	N	N	N
3B	PA	*	11	F	?	?	N	N	N	N	N
3C	PA	*	37	F	?	?	N	N	N	N	N
3D	PA	*	44	M	?	?	N	N	N	N	N
3E	PA	*	20	M	?	?	N	N	N	N	N
3F	PA	*	19	F	?	?	N	N	N	N	N
4A	PA	*	21	F	?	?	N	N	N	N	N
4B	PA	*	21	M	?	?	N	N	N	N	N
4C	PA	*	39	M	?	?	N	N	N	N	N

Match 2 of 2 (Selection)

Figure 8. Occupant data fields as they appear on the database.

Load Factor [This field is not stored but derived from dividing the number of passengers aboard by the number of passenger seats. If the number of passenger seats is estimated (indicated by being surrounded by square brackets) or unavailable, the field contains a question mark "?".]
Number of Aisles
Maximum Seats per Row

Occupant data

This section of the database contains basic information pertinent to the occupants—passengers, cabin crew, and flight crew. Figure 8 shows the occupant data fields as they appear on the database.

The fields contained in this section are as follows:
Occupant reference
The flight crew, cabin crew, and passengers each have unique occupant references.

Type
The occupants are classified into flight crew, cabin crew, and passengers.

Name
The occupant names are not included in the database. This field is utilised solely as part of the data preparation process and passenger names are replaced with an asterisk for data presentation purposes.

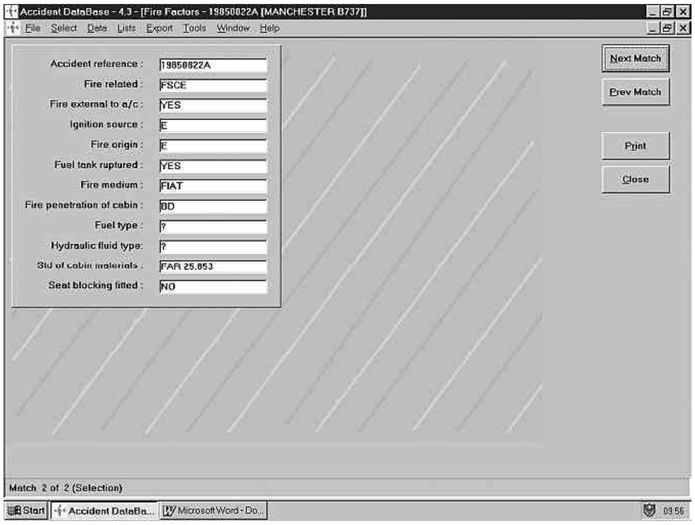
Age

Sex

Height

Weight

Infirmity
Passengers having any form of infirmity that may impair their evacuation capability are annotated with a "Y." All other occupants are annotated as "N" in this field.



Accident reference : 19850822A
Fire related : FSCE
Fire external to a/c : YES
Ignition source : E
Fire origin : E
Fuel tank ruptured : YES
Fire medium : FIAT
Fire penetration of cabin : BD
Fuel type : ?
Hydraulic fluid type: ?
Std of cabin materials : FAR 25.853
Seat blocking fitted : NO

Match 2 of 2 (Selection)

Figure 9. Fire factors fields as they appear on the database.

Injury Code (Occupant Data)
Occupant Injuries are indicated by seven 2-digit codes indicating cause of injury and whether the injuries were sustained internally or externally to the aircraft.

ISS Level
Occupant Injuries may be indicated by Baker's Injury Severity Score (ISS). The ISS is the sum of the squares of the highest AIS score in three different body regions[2]. ISS scores range from 1 to 75. The greater the number the higher the injury severity.

AIS Level
There are nine fields available for indicating the Abbreviated Injury (AIS) Score for nine areas of the body. The higher the injury severity the higher the AIS level.

Exit Used
This indicates the exit used by the occupant.

Seat Backs
This indicates whether the occupant used the seat backs as an exit route.

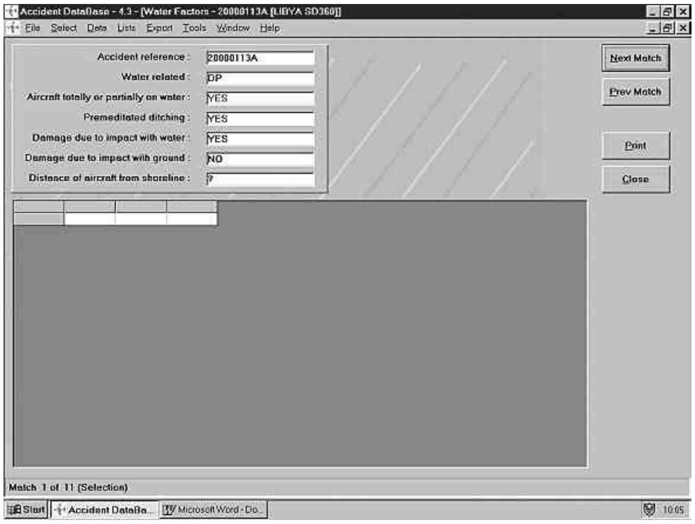
Seat Allocated
This field indicates the seat that the occupant was originally allocated.

Seat Belt
This field indicates whether the occupant had their seat belt fastened at the time of the accident.

Seat Impact Damage
This field indicates whether the occupants seat was damaged as a result of the accident.

Seat Standard/Class
This field indicates the standard of requirement that the seat was approved to and the class of seat.

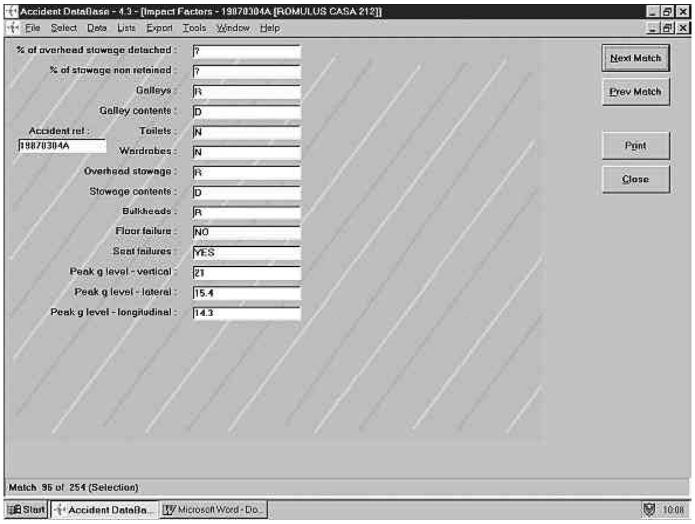
Seat Pitch
This field indicates the seat pitch between the occupants seat and the seat in front, or a bulkhead, in inches.



Accident reference : 20000113A
Water related : DP
Aircraft totally or partially on water : YES
Premeditated ditching : YES
Damage due to impact with water : YES
Damage due to impact with ground : NO
Distance of aircraft from shoreline : ?

Match 1 of 11 (Selection)

Figure 10. Water factors fields as they appear in the database.



% of overhead stowage detached : ?
% of stowage non retained : ?
Galleys : R
Galley contents : D
Accident ref : 19870304A
Toilets : N
Wardrobes : N
Overhead stowage : R
Stowage contents : D
Bulkheads : R
Floor failure : NO
Seat failures : YES
Peak g level - vertical : 21
Peak g level - lateral : 15.4
Peak g level - longitudinal : 14.3

Match 95 of 254 (Selection)

Figure 11. Impact factors fields as they appear in the database.

Number of Seats to Nearest Aisle
This field indicates the number of seats from the occupants location to the nearest aisle.

Aisle Width
This field indicates the minimum aisle width in inches from the occupants seat row to the nearest exit.

Floor Failure
This field indicates whether there was any disruption to the floor in the immediate vicinity of the occupants seat. Floor disruption is annotated with "Y"; no floor failure is annotated "N."

Life Vest
This field indicates whether the occupant utilised a life vest.

Life Raft
This field indicates whether the occupant utilised a life raft.

Fire factors

This section of the database contains basic information pertinent to the fire for cabin fire-related accidents. Figure 9 shows the Fire Factors fields as they appear on the database. The fields contained in this section are as follows:

Fire Related

This field defines whether the accident was fire or smoke related and defines the extent of the fire.

Fire/Smoke External to the Aircraft

This field indicates whether there was a fire external to the aircraft.

Ignition Source

This field gives details of the ignition source of the fire in a fire-related accident.

Fire Origin

This field gives details of fire origin in a fire-related accident.

Fuel Tank Ruptured

This field gives details of whether the fuel tank was ruptured by the impact.

Fire Medium

This field gives details of the media involved in the fire.

Fire Penetration of Cabin

This field gives details of the mechanism for fire penetration of the cabin.

Fuel Type

Hydraulic Fluid Type

Standard of Cabin Materials

This field specifies the requirement standard applicable to the cabin materials

Seat Blocking fitted

This field specifies whether seat-blocking layers were fitted to the aircraft involved in the accident.

Water factors

This section of the database contains basic information pertinent to the fire for water-related accidents. Figure 10 shows the water factors fields as they appear on the database.

The fields contained in this section are as follows:

Water Related

This field defines whether the accident was water-related and defines the nature of the event.

Aircraft Totally or Partially on Water

Premeditated Ditching

Damage Due to Impact with Water

This field specifies whether the aircraft pressure hull was penetrated as a result of impact with water.

Damage Due to Impact with Ground

This field specifies whether the aircraft pressure hull was penetrated as a result of impact with ground prior to alighting on water.

Distance of Aircraft from Shoreline

Flotation Time

This field specifies the estimated flotation time of the aircraft in minutes. If the occupiable area of the aircraft broke into sections, as a result of the impact (ground or water), the flotation time is given for each section of the aircraft.

Section Supported by Water

Impact factors

Figure 11 shows the impact factors fields as they appear on the database.

The fields contained in this Section are as follows:

Percentage of Overhead Stowage Detached

Percentage of Stowage Non-Retained

Galleys

This field specifies whether galley disruption occurred as a result of the impact.

Galley Contents

This field specifies whether the galley contents were uncontained as a result of the impact.

Toilets

This field specifies whether toilet disruption occurred as a result of the impact.

Wardrobes

This field specifies whether wardrobe disruption occurred as a result of the impact.

Overhead Stowage

This field specifies whether overhead stowage disruption occurred as a result of the impact.

Stowage Contents

This field specifies whether the stowage contents were uncontained as a result of the impact.

Bulkheads

This field specifies whether bulkhead disruption occurred as a result of the impact.

Floor Failure

This field specifies whether floor disruption occurred as a result of the impact.

Seat Failure
This field specifies whether seat disruption (includes distortion or structural failure) occurred as a result of the impact.

Peak "g" Levels
These fields indicate the peak "g" levels encountered during the impact, as reported in the accident report, in the vertical, lateral, and longitudinal axes.

Environment

Figure 12 shows the environment fields as they appear on the database.

The fields contained in this section are as follows:
External to the Aircraft
This field indicates whether injuries were sustained by the occupants external to the aircraft.

Impediment to Rescuers by Meteorological Conditions
This field indicates whether rescuers were impeded by meteorological conditions.

Impediment to Rescuers by Water or Fire
This field indicates whether rescuers were impeded by water or fire.

Main Weather Conditions
This field summarises the prevailing weather conditions at the time of the accident.

Visibility
This field indicates the visibility at the scene of the accident.

Precipitation
This field indicates the precipitation at the scene of the accident.

Wind
This field indicates the wind conditions at the scene of the accident.

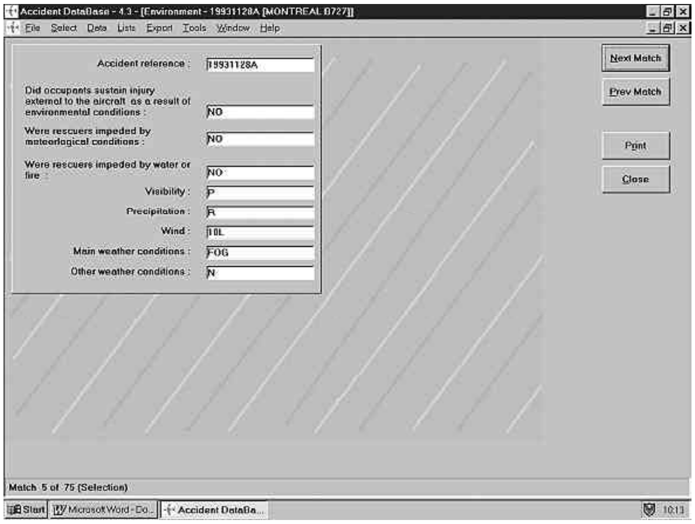
Other Weather Conditions
This field indicates the other weather conditions at the scene of the accident.

Orientation

Figure 13 shows the orientation fields as they appear on the database.

The fields contained in this section are as follows:
Section Reference
This field assigns a reference number to each of the sections of the aircraft bounded by major ruptures of the fuselage caused by impact.

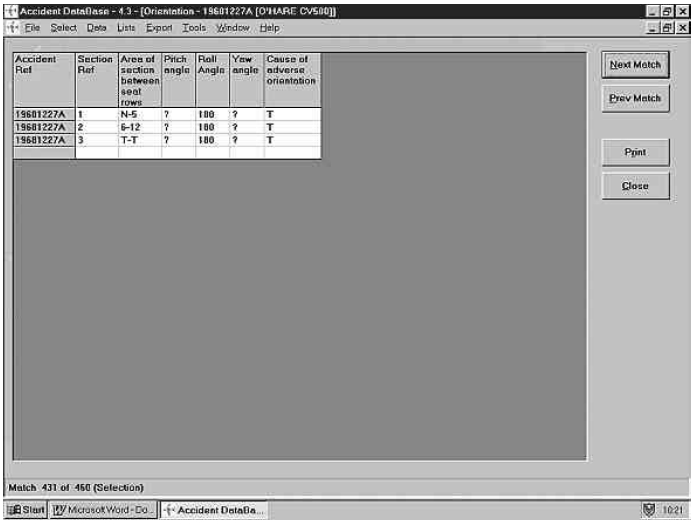
Area Between Seat Rows
This field indicates the size and location of each section of the aircraft, bounded by major ruptures of the fuselage, by providing the first and last seat row in each section.



Accident reference : 19931128A
Did occupants sustain injury external to the aircraft as a result of environmental conditions : NO
Were rescuers impeded by meteorological conditions : NO
Were rescuers impeded by water or fire : NO
Visibility : P
Precipitation : R
Wind : 10L
Main weather conditions : FOG
Other weather conditions : N

Match 5 of 75 (Selection)

Figure 12. Environment fields as they appear on the database injury.



Accident Ref	Section Ref	Area of section between seat rows	Pitch angle	Roll Angle	Yaw angle	Cause of adverse orientation
19601227A	1	N-5	?	180	?	T
19601227A	2	6-12	?	180	?	T
19601227A	3	T-T	?	180	?	T

Match 431 of 460 (Selection)

Figure 13. Orientation fields as they appear on the database.

Pitch, Roll, and Yaw Angle
This field indicates the pitch, roll, and yaw angle for each referenced section of the aircraft, in degrees.

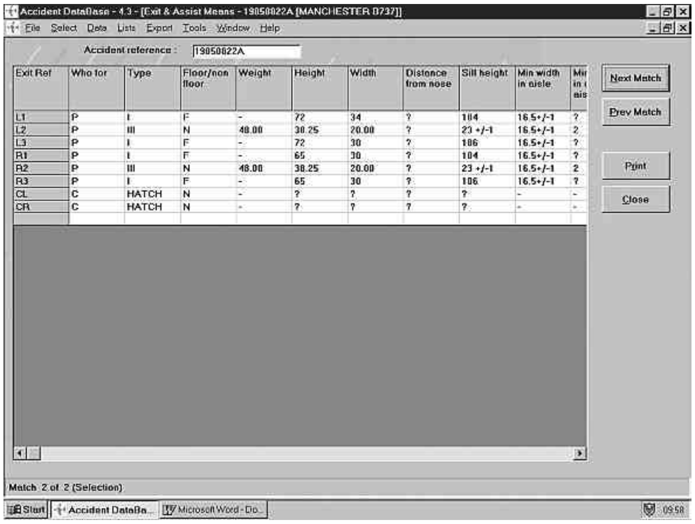
Cause of Adverse Orientation
This field indicates the cause of the adverse orientation for each section of the aircraft.

Exit and assist means

An example of the exit and assist means fields as they appear on the database is shown in Figure 14.

The fields contained in this section of the database are as follows:
Exit Reference
This field references each of the exits

Who For
This field indicates for whom the exit is intended.



Accident reference : 19850822A

Exit Ref	Who for	Type	Floor/non floor	Weight	Height	Width	Distance from nose	Sill height	Min width in aisle	Mi in ais
L1	P	I	F	-	72	34	?	104	16.5+/-1	?
L2	P	III	N	48.00	38.25	20.00	?	23 +/-1	16.5+/-1	2
L3	P	I	F	-	72	30	?	106	16.5+/-1	?
R1	P	I	F	-	65	30	?	104	16.5+/-1	?
R2	P	III	N	48.00	38.25	20.00	?	23 +/-1	16.5+/-1	2
R3	P	I	F	-	65	30	?	106	16.5+/-1	?
CL	C	HATCH	N	-	?	?	?	?	-	-
CR	C	HATCH	N	-	?	?	?	?	-	-

Match 2 of 2 (Selection)

Figure 14. Exit and assist means fields as they appear on the database.

Type
This field indicates the type of exit as defined in JAR/FAR 25.807.

Floor/ Non-Floor
This field indicates whether the exit is a floor level exit or a non-floor exit.

Weight
For exits that require lifting to open by the occupants the weight of the exit is given in pounds.

Height
This field indicates the height of the exit in inches as defined in JAR/FAR 25.807.

Width
This field indicates the width of the exit in inches as defined in JAR/FAR 25.807.

Distance from Nose
This field indicates the relative disposition of the exits.

Sill Height
This field indicates the distance from the door sill to the ground with the aircraft supported by the undercarriage for floor level exits, or the step down height for non- floor level exits.

Minimum Width in Aisle
This field indicates the minimum aisle width, in inches, from the referenced exit to the next nearest exit.

Minimum Width in Cross Aisle
This field indicates the minimum aisle width, in inches, for non-floor level exits.

Width Between Seats
This field indicates the width between seats, in inches, for non-floor level exits.

Open Attempted
This field indicates whether an attempt was made by occupants to open the referenced exit.

Opened
This field indicates whether the referenced exit was opened by occupants.

Failed
This field indicates whether the referenced exit failed to open although an attempt was made to open it.

Obstructed (Exit)
This field is applicable to exits that were opened or attempted to be opened and indicates whether the referenced exit was obstructed.

Number of Occupants Using Exit

Assist Means Fitted

Deploy Attempted

Deployed
This field indicates whether the assist means at the referenced exit was successfully deployed.

Failed
This field indicates whether the assist means at the referenced exit failed, and if so, the mode of failure.

Obstructed (Assist Means)
This field indicates whether the referenced assist means was obstructed. ◆

Footnotes

[1] United States Federal Aviation Administration, www.fire.tc.faa.gov/cabwg.stm

[2] The Abbreviated Injury Scale" 1990 Revision - Association for the Advancement of Automotive Medicine

Search & Recovery: The Art and Science

By Steven Saint Amour, Commercial Operations Manager, Phoenix International, Inc.

PHOTO NOT AVAILABLE

***Steven Saint Amour** is the Commercial Operations Manager for Phoenix International, where he is responsible for Phoenix's ROV Build Program. During the last 4 years, he has been directly involved in one civil aviation disaster, three rocket recoveries, four military aircraft recoveries, and five vessel search and inspections. He began work in the diving industry in 1983 and was with Eastport International, an ROV operations company, from 1989 until 1998 when he joined Phoenix. [This paper served as an alternate selection for the seminar but was not orally presented.—Editor]*

Introduction

A commercial 747 with 230 passengers has been lost 100 kilometers offshore in over 2,000 meters of seawater. As an air safety investigator, you need to analyze all the data, as well as pieces of the aircraft, in order to determine the cause of the crash.

Your problem is: How are you going to find the aircraft?

How are you going to recover the pieces you need for your investigation?

My name is Steven Saint Amour, and I am the Commercial Operations Manager for Phoenix International, Inc. (Phoenix), the search and recovery specialist for the U.S. Navy.

Phoenix holds the U.S. Navy's 5-year undersea operations contract. Under this contract over the past two years, we have performed search-and-recovery operations on 10 military aviation accident investigations in the last 2 years. Over the past 28 years, while working for other companies that held the Navy contract, our current operations personnel have located and recovered more than 110 military aircraft, 16 commercial civil aviation aircraft, and 10 space-related craft from the depths of the ocean.

While considering the subject of this paper, I was confronted by the sheer magnitude of the subject matter. Then, I remembered the many conversations on the back-deck of ships during search-and-recovery operations with air crash investigators.

I've often been asked about the equipment, capabilities, and the techniques that we apply to the location and recovery of military and civilian aircraft. In many instances, the investigators were surprised by the capabilities of the equipment. Overwater aviation accident investigations present unique challenges and difficulties. So, rather than tell you how to do your aspect of the job, I will tell you how we do ours.

Background

Side scan sonar and remotely operated vehicles (ROVs) have played a pivotal role in search-and-recovery operations. Initial development of these systems took place in the 1960s in both the government and commercial sectors to meet various requirements. When the U.S. Navy CURV (cable controlled underwater recovery vehicle) system recovered an atomic bomb lost off Palomares, Spain, in an aircraft accident in 1966, it became an indisputable fact that remote technology could be used for search-and-recovery missions.

In recognition of the applicability of commercial underwater expertise to government underwater search-and-recovery needs, the U.S. Navy established a search-and-recovery contract to allow the U.S. Navy to rapidly access this expertise in cases where external assistance was required. Remarkably, the "tools of the trade" used in the 1960s and 70s are similar to those still used today—side scan sonar, ROVs, and manned submersibles. The new generation systems are more complex yet more reliable, and driven by recent rapid advances in technology, are far more capable than their earlier counterparts.

Phoenix was competitively awarded the contract, now called the undersea operations contract, in 2001. Many of our employees have been involved with the performance of search-and-recovery operations under this contract for many years. The professionals who carried out these difficult missions, from the president of Phoenix to our senior technicians, average 16 years of experience in this field, with some of our personnel having been in the business for more than 30 years.

Through the undersea operations contract, Phoenix personnel operate a mixture of company- and government-owned assets during at-sea search and recoveries for the U.S. Navy and other U.S. government agencies. The U.S. Navy also makes this expertise available to foreign governments and investigatory agencies in times of emergency.

For example, the FAA and the NTSB have utilized the U.S. Navy contract and assets for such investigations as TWA Flight 800, Swissair Flight 111, Alaska Airlines Flight 261, and EgyptAir Flight 990. We have also conducted underwater search and recovery operations to assist investigators during national tragedies such as the space shuttle *Columbia* and *Challenger* disasters.

Tools of the trade

Before we delve into the operational aspects of search-and-recovery missions, I would like to present a brief description of the equipment that is referred to throughout this paper so you will have a better understanding of what is in our toolbox.

Pinger locators: In 1976, the U.S. Navy tasked its search-and-recovery contractor, Seaward, Inc., to design and build a prototype system to assist in rapidly locating aircraft lost over water. Mike Kutzleb, currently president of Phoenix, worked for Seaward at the time and was part of that team. The concept took advantage of the presence of acoustic beacons (pingers) carried on all commercial and many military aircraft. The pingers emit signals for an extended period of time immediately upon their immersion in water. A handheld pinger locator system was commercially available for locating pingers in shallow water, but the Navy needed a system to detect pingers in deep water.

The resulting prototype system was named the Towed Pinger Locator (TPL) system. Field tests of TPL showed that it could reliably detect an acoustic pinger at ranges of up to 2,000 meters. The system was designed to fit into two suitcases, enabling the search team to respond quickly in an emergency. The current versions of the TPL can be used in water depths to 6,000 meters. There are two different systems—one has an omni-directional hydrophone and the other has a directional hydrophone to enable searchers to quickly pinpoint the location. With its extended detection range, TPL has evolved into a reliable and cost-effective search tool.

Side Scan Sonar: The U.S. development of side scan sonar systems began in the 1960s as a result of underwater acoustic experiments conducted by Dr. Harold Edgerton. Subsequent design refinements have led to present-day acoustic imaging devices capable of searching large areas of the sea floor to water depths of 6,000 meters with a high degree of resolution.

A typical side scan sonar system consists of a towfish, tow cable, and topside sonar control/data processing system. The towfish contains two or more transducers mounted on its port and starboard sides and is pulled through the water using the tow cable. The depth of the towfish is determined by the length of cable deployed and the speed of the tow ship.

Side scan sonars can be considered analogous to radars in that they emit a discrete pulse of energy (sound) that radiates out into the medium (water column). Upon striking the ocean floor or other objects (natural or man-made), a portion of the energy is reflected back to the sonar system where the return signal or echo is received, processed, and displayed in a fashion that allows interpretation by a skilled side scan sonar operator.

The operational frequency of the transducers determines the range and resolution of the sonar system. The lower the frequency, the greater the range of the sonar, but the resolution is degraded. Using a higher frequency results in extremely good resolution but much shorter ranges. By operating with two simultaneous frequencies, one low and the other high, the optimum sonar performance is achieved. The lower frequencies (30-100 kHz) are used to detect large objects at great range while the higher frequencies (200 kHz or more) provide very high resolution imagery at the short ranges. Digital technology can allow the production of near-photographic quality acoustic images of the sea floor.

Tow speeds for side scan sonar search operations range from four knots in relatively shallow water to about 2 knots in 6,000 meters of water. Some new designs can operate up to 10 knots in very shallow water. Given the tow speed and area coverage of side scan sonar, it is the system of choice when searching for a lost aircraft or mapping an underwater debris field.

Remotely Operated Vehicle (ROV): Remotely operated vehicles are tele-presence robotics. The ROV has thrusters for maneuvering, cameras for seeing and sonar for detecting objects outside visual range. They also have arms-manipulators for handling objects. The ROV is controlled from the surface and is attached to the work platform by an umbilical that carries copper conductors and fibers for power and computer telemetry between the ROV computer and the surface control computer. ROVs come in all shapes, sizes and capabilities. I will limit my explanation to the two primary types—search/inspection and work-class vehicles.

Search and Inspection ROVs: These ROVs are typically small, easily transported, and quickly set up. The depth capability is generally no more than 300 meters but more commonly 150 meters. Its mission is to locate and inspect. The ROV might have the capability to pick up small items—10 pounds or less—but this would not be considered part of its mission. An example of the application is TWA Flight 800, where the Navy's minirovers were used to scout areas for debris and stand by while divers were sent down.

Work-Class ROVs: As their name indicates, these vehicles are capable of conducting sophisticated operations by use of manipulators or robotic arms. They range in size from relatively small (2,000 lbs) to very large (14,000 lbs). A work-class ROV will be your primary tool for recovery operations. These ROVs can perform a complete inspection, then install rigging and lift lines for recovering large items of debris. Smaller items can by carried in the manipulators or slung under the ROV for transport to the surface.

HLS (heavy lift system): The HLS is a mobile recovery system intended for lifting large debris from the sea bottom to the surface. The system consists of a recovery winch, a diesel hydraulic power unit, lift cable (steel or synthetic), and a heave motion compensating system.

Winch: The main component used for both lowering and hauling the recovery line and wreckage to the surface. This winch is typically a low-speed; high line pull hydraulic winch with pressure released brakes. The winch size is dictated by the largest possible size of the wreckage, i.e. in an aircraft recovery—the entire intact aircraft.

Diesel hydraulic power unit (HPU): The HPU is a self-contained power unit that supplies hydraulic power to the recovery winch.

Lift cable: The lift cable is the line that is attached to the wreckage and is used to haul the wreckage to the surface. The size and type of line used is wholly dependant on the size and weight of the expected load, the dynamics of the support vessel, and a safety margin. Lift cables are typically made of steel wire, Kevlar, Spectra, or Dyneema.

Heave motion compensating system: The heave motion compensating system is a hydraulic and gas-compensated dampening system. The recovery line runs through a series of blocks mounted to the base of the unit and to the rod end of a large hydraulic cylinder. The cylinder is plumbed to a gas accumulator that is charged with an inert gas such as nitrogen. The estimated weight of the lift determines the charge pressure so that the rod will stay fully extended at the predicted weight. In the event there is a heave and the drag increases the overall weight of the object being lifted, the rod travels smoothly down into the cylinder to dampen the heave so that snap loading forces to the wreckage and lift cable are minimized.

Spooler: The spooler is a submersible reel fitted with lift cable that is taken down to the bottom by the ROV and placed near the object to be lifted. Once the object has been rigged and hooked into the lift cable, the spooler is raised to the surface by the ROV, and the lift cable is transferred to the winch for recovery.

Tasking and planning

The investigation of an overwater accident should always be considered unique with regard to the planning, preparation, and execution of the investigation. By nature, accidents almost always occur without warning, and it is important that analysis and planning efforts begin as soon as possible before evidence and memories fade or are influenced. This also allows for planning when time is critical and ensures a smooth and successful operation.

During operational planning, which often is racing alongside the actual logistics phase of a fast-response effort, information is critical. Never take for granted what you the investigator thinks we should know. We need all of the available loss information even if the investigator believes it is inconsequential.

Either by news reports or notification by the Navy, we are made aware of all aircraft that have been lost, often within hours of the accident. Even before we are formally requested to start planning a mission, we typically start collecting loss data on the assumption that we will either be tasked by the U.S. Navy or another entity to assist in the eventual effort.

In the case of a U.S. military aircraft loss, the aircraft's squadron (owner) or the Naval Safety Center will request search-and-recovery tasking if they feel that there is some aspect of an accident that is not completely understood, if there has been a suspected equipment failure, or if there are classified assets on board. This request will go to the Chief of Naval Operations (CNO), then to the fleet. If the fleet is unable to perform the task, the CNO will turn to the Office of the Supervisor of Salvage and Diving (00C) for action.

For commercial aviation investigations, we are contacted either directly by the responsible agency or through the SUPSALV office. No matter who initiates the initial contact, the chain of events that is set in place usually follows the same pattern.

In the early stages, we are typically focused on two things: gathering any and all available loss data to define the scope of the effort, and planning the task in order to develop a realistic cost estimate.

During the loss-analysis effort, our Search Project Managers gather every scrap of available evidence and conduct personal interviews as appropriate. We are especially interested in information that will minimize the size of the search area and assist our sonar technicians in analyzing the sonar records during the search.

- Type of aircraft
- Positions of any vessels in the area of the accident and their location relative to the crash position
- Radar data
- Voice communications between the aircraft and ATC
- The presence of an acoustic beacon, its frequency, last date of battery replacement
- Eyewitness reports of the crash
- Floating debris or oil slick sighting positions
- Floating debris recovery positions
- Survivor or body recovery pickup positions

This information is used by Phoenix to determine the operational parameters, which include the type of search/recovery equipment, vessel, and logistic support required. Additional factors that enter into the development of the cost estimate include

- Size of the aircraft and type
- Depth of water—dictates type of equipment to be used
- Local environmental conditions
- Weather
- Resident logistical support
- Vessels of opportunity
- Vessel preparation and use
- Deck equipment
- Vessel duration
- Personnel
- Cranes
- Trucking
- Air transportation
- Customs and vessel agents
- Hazardous material handling
- Time critical issues: cargo
- Human remains

The results of these efforts are briefed to the Navy or commercial customer representative while reviewing the estimate. Many times, a Phoenix Project Manager will then accompany the customer representative to briefings with the fleet representative or the civil agency making the request. A go/no go decision is made as a result of the brief.

In the event that a major event requires a multi-agency effort, as was the case on the space shuttle Columbia accident investigation, Phoenix is often tasked to coordinate these efforts and take the lead in providing local onshore/offshore logistical support.

Fundamental steps should be taken prior to an operation. These steps will have a qualitative effect on the overall operation and potentially the outcome of the investigation.

The first key step, however, is to establish the mission objectives. Ultimately the safety investigators state what the mission objectives and priorities will be. These can range from recovering a critical piece of wreckage to the recovery of an entire aircraft.

The mission

Once a decision is made to go after the aircraft, loss analysis is completed and an operations plan is finalized. If the aircraft is outfitted with a pinger, the TPL system is normally selected as the primary search tool, with the side scan sonar as a back up and mapping tool. The TPL operates on the same cable as the side scan sonar, reducing the amount of equipment that needs to be mobilized.

If an emergency pinger is present on the aircraft, time is of the essence in getting to the search area. Typical battery life on the acoustic pingers is 30 days. Given the higher search rate of the TPL as compared to the side scan sonar, it is critical to arrive on location as soon as possible in order to maximize the TPL search time during the battery's life.

We search until we hear the pinger on the TPL's omni hydrophone and directional array. Peak signals are noted and their location recorded. Multiple parallel and perpendicular passes/tracks are made in reciprocal directions to this peak signal to pinpoint the pinger's position. The more time you spend localizing, the more time you save during the recovery phase.

If a pinger was not installed on the aircraft or the pinger was not heard during its anticipated 30-day life, a side scan sonar search will be initiated for the aircraft. Sonar range selection is made based on the expected size of the target and the predicted size and shape of the debris field. Factors to be considered include the overall size of the aircraft, its predicted impact angle with the water, the water depth, and the bottom terrain. Once the range scale has been selected, the track line spacing to be used during the sonar search is determined, and the search area is methodically covered until the aircraft is located.

In the event the TPL has detected the pingers, the side scan sonar is a valuable tool for mapping the debris field precisely. This allows an acoustic picture to be made of the entire debris field.

Recovery

Under certain circumstances when loss data is exceptionally good, both the search-and-recovery assets are mobilized on the same vessel. If this is the case, our search team now becomes the recovery team. However, if the loss data is weak or the expected size of the pieces cannot be predicted, the recovery assets may be mobilized only after a probable contact has been located by the search team. It sometimes is more prudent to "wait and see" how well the search goes. In this case, several of the search team will transfer to the recovery task, bringing the positional information and sonar records with them and providing the continuity to ensure a timely and successful recovery mission.

Once the target is located, the operation will move to the inspection-and-recovery phase. The typical components of this phase would include an ROV system, rigging and recovery assets such as winches, motion compensation equipment, and lift lines.

Probably one of the most important tools in your toolbox besides the experience of the crew is subsea navigation. Normally, an ultra short base line (USBL) acoustic tracking system is used to follow the ROV's path. Its outputs are fed into the same navigation software used on the search. This software combines the GPS information with the relative information from the USBL to give the geographic location of the pieces on the sea floor. This saves time as opposed to "searching" for pieces with the vehicle's scanning sonar. From the side scan sonar search, we have "relative" positions on targets for the ROV to be flown to.

Upon arriving on scene, the first step will be to establish the boundaries of the debris field and attempt to establish a pattern for the wreckage. This will eliminate random searching and allow the ROV to effectively look in the highest probability areas for specific wreckage. Navigational fixes are taken at all major identifiable pieces, i.e., cockpit, engines, tail, etc. This will provide a detailed map of the debris field, which can aid in both the investigation and the location of yet to be identified targets.

Before any salvage operation commences, it is important that any and all available sources of information about the item to be salvaged are examined for planning purposes both for the method in which it is to be salvaged and for recognition by the recovery crew. These sources can range from Department of Defense manuals to manufacturer's information and drawings. After an accident, especially a high-energy impact, a target may be difficult to identify. Trained aviation technicians are an important resource for identification of debris on the bottom.

Any recoveries should be planned with weather as a consideration—larger more difficult recoveries should be conducted during optimal weather windows. Unless very specific information is available about the wreckage or the salvage effort, a full complement of recovery tools should be included in the load out, specific to the type of recovery. Outside of the obvious objective of recovery, it is always a mission objective to conduct a recovery in a safe and organized manner. Phoenix may make recommendations based on past experience in regard to operational scenarios and techniques that will possibly aid the investigators.

The recovery of wreckage is accomplished in a variety of ways, which are tailored to the actual situation. We always give consideration as to what will be the most economical and efficient manner to conduct our recoveries.

After the debris field has been mapped and the client representative has made a final determination on what he wants on his "shopping list," the ROV will proceed with recovery of the identified wreckage.

Small items—typically 200 lbs or less and relatively small in size—are recovered by the ROV either by lifting the object to the surface with the ROV manipulators or by placing the object in a recovery basket. The basket is far more efficient, since the ROV can make numerous short trips to deposit items into the basket. The basket is recovered under the ROV or separately when it is full or all items of interest have been recovered.

The one exception to the rule are the black boxes. These are critical to any investigation and would typically be recovered individually and first. Extreme care is taken in their recovery, and special recovery boxes are often used to minimize any chance of further damage. Upon recovery, they are immediately placed in fresh water to stop any effects of corrosion.

Larger items, i.e., structures such as wings, cockpits, or like items, may be recovered below the ROV with a method called a through frame lift. This method would be used for items that can be calculated safely to weigh less than 2 tons.

For larger structures weighing more than 2 tons or where an estimate cannot be made such as major sections of fuselage, a separate recovery line is used from the surface. The piece would be rigged for recovery by the use of chain or nylon chokers, slings, or clamps. A recovery line would be lowered from the surface and connected to this rigging. Alternatively, the spooler would be lowered to the bottom, and the lift cable would be connected to the rigging. The recovery line would be attached to a recovery winch and run through a heave motion compensation unit that is designed to dampen the surge of the vessel created by wave action.

Difficulties

Understanding the limitations of the search-and-recovery assets is as important as understanding their capabilities. Some typical questions are:

What type of weather can you work in?

Weather is less of an issue with the search portion of any operation. Towing the TPL or side scan sonar behind the vessel is fairly easy, and the main concern is getting the fish over the side or back on deck. However, for ROV (recovery) operations, it is far more difficult in the respect that the vessel is stationary and subject to rolling and pitching by the seas. The ROV is attached to the vessel by its umbilical and any motion may be translated down the cable to the vehicle. The rule of thumb for operational weather conditions is 3-meter seas and 29 knots of wind or less. For recovery of a large heavy, object, this drops to 1 meter and less than 15 knots. However, these rules of thumb all depend on the size of the vessel and the severity of the seas. In any case, the ultimate factor will be the ability of the vessel to hold station in a manner that will be safe for operations.

How long will it take to find it?

Search time is directly related to the quality of the information regarding the loss and the tools used. If there are eyewitnesses who are able to provide a precise position, then a search should be relatively quick—24 hours or less. An aircraft lost out-of-sight of land, but within reliable radar tracking range, could also be quick—several days or less. In the case where little or no loss data is available, it is impossible to predict search time. In all of these cases, the search times will be lowest if the aircraft is outfitted with an acoustic pinger, since the TPL can search many times faster than a side scan sonar.

How long will it take to find the target with the ROV after a search position is given?

The side scan sonar will give good data; however the side scan sonar fish is trailing behind the vessel. In deep water this could be as much as 6 miles. The position of the fish is calculated so that when the first dive is made, it is made based on a relative calculated position. In most cases the ROV will not drop directly on the wreck, but will travel to the bottom and conduct a search of its own with the onboard sonar. With skilled navigators providing accurate positions of sonar targets, the ROV should be able to acquire the target quickly, often within just a few hours of arriving on bottom.

What are the limitations of the ROV?

The best analogy I have heard is that searching with an ROV is the equivalent of searching a football field on a foggy, moonless night with a penlight looking for a foil wrapper. It is not easy. Line of sight for the ROV cameras ranges from 5 to 25 meters in clear water. This only underscores the need for good planning and acoustic navigation.

The ROV is pulling around an umbilical that has drag in the water column. The deeper the operation and the longer the distance the ROV has to travel, the greater the drag. This slows the ROV down when traveling over long distances such as flying around a large debris field.

Finally, good piloting is critical. Anytime the ROV sits on the bottom, sediment is stirred up, which usually obscures the ROV's cameras. Bottom current will negate this problem to a certain extent, but the best solution is not to come in contact with the bottom.

Can we pick up that piece?

Unless the investigator is absolutely positive that he wants to recover a specific piece immediately upon discovery, holding to the survey plan of mapping the debris field is highly recommended. Inordinate amounts of time have been spent picking up pieces then discarding them shortly thereafter.

Equipment break downs

This equipment is working under harsh conditions and requires attention. We work to ensure that all of our equipment is in good order; however, like any complex device, the ROV is subject to wear and tear. Think for a moment of the number of maintenance hours an aircraft requires per flight hour. Our subsea equipment may be required to operate continuously for days at a time and does. Breakdowns do occur, but we do everything in our power to minimize this.

Conclusion

These types of investigations require the participation of specialists who have many years of experience in diving, remote technology, logistics and marine operations. There are many diving/ROV contractors, but few have the specialized experience to best serve you. Phoenix personnel have spent their careers focused on aircraft search and recovery—not simple mapping, surveying for a pipeline or cable route, not placing templates or BOP stacks (oil field). We can tell an aircraft debris field from an oyster bed, real time, on scene! We have mobilized to the far corners of the world and brought home the aircraft, i.e., CH-46, 17400 fsw, Wake Island; CH-46, 5000 fsw, Somalia; SAA 747, 14350 fsw, Mauritius.

It is essential for emergency response teams to be aware of the specific capabilities and expertise that are available to their agencies. Visiting the Phoenix facility in Landover can help to better define your options.

I would like to challenge your community to archive the "lessons learned" from each of your investigations. This will provide for consistent expectations and not having to relearn techniques, mistakes or results. ◆

National Transportation Safety Board Recommendations Relating to Inflight Fire Emergencies

By Mark George

PHOTO NOT AVAILABLE

***Mark George** began his career as a statistician at the FAA Civil Aeromedical Institute in Oklahoma City in 1982. For the next 16 years, he worked on numerous aircraft evacuation and water survival research projects. In addition, he served as coordinator for CAMI's Cabin Safety Workshop program for 12 years. George joined the NTSB in 1998 as a Survival Factors Investigator in the Office of Aviation Safety. [This paper served as an alternate selection for the seminar but was not orally presented.—Editor]*

The National Transportation Safety Board has a long history of advocating safety improvements pertaining to inflight fires on commercial airplanes. This paper chronicles the Safety Board's activities in this area, which began more than 20 years ago, and focuses on recent accidents and incidents that initiated five safety recommendations that were issued in 2002. The recommendations and FAA responses to them are also discussed.

Air Canada Flight 797 accident

On June 2, 1983, about 1920 Eastern Daylight Time, a McDonnell Douglas DC-9, C-FTLU, operated by Air Canada as Flight 797, experienced an inflight fire and made an emergency landing at the Greater Cincinnati International Airport (since renamed Cincinnati and Northern Kentucky International Airport) in Covington, Ky. The fire was initially detected when a passenger noticed a strange smell and a flight attendant saw smoke in one of the lavatories. Another flight attendant saw that the smoke was coming from the seams between the walls and ceiling in the lavatory. Although neither flight attendant saw any flames, the second flight attendant discharged a CO_2 fire extinguisher into the lavatory, aiming at the paneling and seams and at the trash bin. He then closed the door. When the first officer came back to assess the situation, he found that the lavatory door was hot, and he instructed the flight attendants not to open it. The first officer then informed the captain that they "better go down," and an emergency descent was initiated.

During the descent, the smoke increased and moved forward in the cabin. After the airplane landed, flight attendants initiated an emergency evacuation. Of the 41 passengers and five crewmembers on board, 23 passengers were unable to evacuate and died in the fire. The airplane was destroyed.

In its final report, the Safety Board determined that the flight attendant's discharge of a fire extinguishing agent into the lavatory "had little or no effect on the fire," noting that "[i]n order for the extinguishing agent to be effective, it must be applied to the base of the flames." The Board determined that the probable cause of the accident was "a fire of undetermined origin, an underestimate of fire severity, and conflicting fire progress information provided to the captain. Contributing to the severity of the accident was the flight crew's delayed decision to institute an emergency descent."[1]

As a result of the Air Canada accident, the Safety Board issued several recommendations to the Federal Aviation Administration (FAA), including Safety Recommendation A-83-70, which asked the FAA to expedite actions to require smoke detectors in lavatories; Safety Recommendation A-83-71, which asked the FAA to require the installation of automatic fire extinguishers adjacent to and in lavatory waste receptacles; and Safety Recommendation A-83-72, which asked the FAA to require that the hand-operated fire extinguishers carried aboard transport-category airplanes use a technologically advanced agent, such as halon. All three of these recommendations were classified "Closed—Acceptable Alternate Action" on Jan. 15, 1986, after the FAA completed rulemaking to require that all airplanes operated under 14 *Code of Federal Regulations* (CFR) Part 121 be equipped as follows: each lavatory and galley has a smoke or fire detector system that provides a warning light in the cockpit or an audio warning in the passenger cabin that would be readily detected by the flight attendant; each lavatory trash receptacle is equipped with a fire extinguisher that discharges automatically if a fire occurs in the receptacle; and, of the required hand-held fire extinguishers installed in the airplane, at least two contain halon 1211 or equivalent as the extinguishing agent.

In its final report on the Air Canada accident, the Safety Board also issued Recommendation A-84-76, which recommended that the FAA "require that air carrier principal operations inspectors review the training programs of their respective carriers and if necessary specify that they be amended to emphasize requirements for flight crews to take immediate and aggressive action to determine the source and severity of any reported cabin fire and to begin an emergency descent for landing or ditching if the source and severity of the fire are not positively and quickly determined or if immediate extinction is not ensured; for flight attendants to recognize the urgency of informing flight crews of the location, source, and severity of fire or smoke within the cabin; for both flight crews and flight attendants to be knowledgeable of the proper methods of aggressively attacking a cabin fire by including hands-on-training in the donning of protective breathing equipment, the use of the fire ax to gain access to the source of the fire through interior panels that can be penetrated without risk to essential aircraft components, and the discharge of an appropriate hand fire extinguisher on an actual fire."

In its Nov. 2, 1984, response to the Safety Board, the FAA explained that 14 CFR 121.417 required crewmembers to be trained for fire emergencies, and further required them to perform emergency drills and "actually operate the emergency equipment during initial and recurrent training for each type aircraft in which the crewmember is to serve." The FAA concluded that the regulations were adequate, stating that "the safety record of U.S. carriers is a testimony to the adequacy of the current regulations." In its April 12, 1985, letter, the Board disagreed, stating that "current firefighting training is directed primarily toward 'exposed' fires, which are relatively easy to control. This does not prepare crews to assess effectively the hazard of or to fight hidden fires." The Board also reiterated its belief that crew training programs should emphasize that if the source of a fire cannot be immediately identified or cannot be extinguished immediately, the aircraft should be landed immediately. In its March 7, 1986, letter, the FAA responded that "due to requirements of 14 CFR 121.417, the various Air Carrier Operations Bulletins (ACOBs), and the guidance in the Air Carrier Operations Inspector's Handbook,"[2] further action by the FAA was unwarranted. The Safety Board disagreed and on May 12, 1986, classified Safety Recommendation A-84-76 as "Closed—Unacceptable Action," stating that, "[a]lthough we have closed this recommendation, our concern for the safety issue involved has not diminished, and we will continue to voice our concern in future accident investigations."

The FAA's response to the Air Canada recommendations resulted in some changes that improved aircraft fire safety; in particular, requirements for smoke detectors and halon-type fire extinguishers have provided crewmembers with better methods of locating and suppressing fires. However, the FAA did not issue additional advisory material emphasizing the importance of training crewmembers to recognize, locate, and fight hidden fires on airplanes. Subsequent events illustrated that the need for such training still existed.

Delta Air Lines Flight 2030

On Sept. 17, 1999, about 2230 Eastern Daylight Time, a McDonnell Douglas MD-88, N947DL, operated by Delta Air Lines as Flight 2030, experienced an inflight fire and made an emergency landing at the Cincinnati and Northern Kentucky International Airport in Covington, Ky. After landing, an emergency evacuation was performed. The airplane sustained minor damage, and none of the two flight crewmembers, three flight attendants, three off-duty flight attendants, or 113 passengers were injured.

Shortly after takeoff, several flight attendants detected a sulphurous or "lit match" smell and reported it to the flight crew. Following the captain's instructions, flight attendants checked the lavatories but were unable to locate the cause of the smell. Two off-duty flight attendants retrieved halon fire extinguishers when flight attendants noticed smoke in the forward section of the coach cabin. Flight attendants reseated a passenger in Row 11 to another row when he stated that his feet were hot. This individual's carry-on bag, which had been on the floor beside him, next to the right sidewall and above the floor vent, was scorched. Flight attendants also reported seeing an orange or red, flickering glow beneath the vent at that location.

Flight attendant No. 1 went to the cockpit to inform the flight crew of these observations and asked the captain whether to spray halon into the vent where she had seen the glow. The captain instructed her not to use the halon extinguisher, indicating he was concerned about spraying halon in the cabin. Meanwhile, another flight attendant had already discharged a halon fire extinguisher into the vent and observed that the glow was no longer visible. Thereafter, the smoke began to dissipate and did not return. When flight attendant No. 1 returned from the flight deck, she became alarmed that a halon fire extinguisher had been discharged because the captain had instructed her not to do so.

During its investigation of this incident, Safety Board staff discovered that the source of the smoke in the cabin was a smoldering insulation blanket in the cargo compartment adjacent to a static port heater. Electrical arcing from the heater had ignited the blanket, and the smoldering had become a self-sustaining fire that was growing in size.[3]

AirTran Flight 913

On Aug. 8, 2000, about 1544 Eastern Daylight Time, a McDonnell Douglas DC-9-32, N838AT, operated by AirTran Airways (AirTran) as Flight 913, experienced an inflight fire and made an emergency landing at the Greensboro Piedmont-Triad International Airport in Greensboro, N.C. An emergency evacuation was performed. The airplane was substantially damaged from the effects of fire, heat, and smoke. Of the 57 passengers and five crewmembers on board, three crewmembers and two passengers received minor injuries from smoke inhalation, and eight other passengers received minor injuries during the evacuation.

Shortly after takeoff, flight attendants No. 1 and No. 2, who were seated on the forward jumpseat, both smelled smoke. Flight attendant No. 1 went to the cockpit, where she saw smoke "everywhere" and noticed that the crew had donned their oxygen masks. The captain told her that they were returning to Greensboro. She closed the cockpit door and returned to the cabin. She and flight attendant No. 2 reseated themselves in empty seats in business class because of the rapidly accumulating smoke in the galley area around their jumpseats.

Flight attendant No. 1 reported that the smoke became so dense she could no longer see the forward galley. However, neither flight attendant made any effort to locate the source of the smoke or to use any of the firefighting equipment available to them. Flight attendant No. 1 saw a large amount of electrical "arcing and sparking" and heard "popping noises" at the front of the cabin. She told investigators that she "debated whether to use the halon" fire extinguisher but was unsure where to aim it. She decided not to use the halon fire extinguisher because she "did not see a fire to fight."[4] An off-duty AirTran pilot seated in first class considered using a halon fire extinguisher, but decided against it because he was concerned that the halon "would take away more oxygen."

Preliminary findings indicated that the smoke in the forward cabin was caused by electrical arcing in the bulkhead behind the captain's seat. The arcing ignited interior panels, which continued burning after the airplane landed and the passengers were evacuated. The fire was eventually extinguished by airport rescue and firefighting personnel.

American Airlines Flight 1683

On Nov. 29, 2000, about 1753 Eastern Standard Time, a McDonnell Douglas DC-9-82 (MD-80), N3507A, operated by American Airlines as Flight 1683, was struck by lightning and experienced an inflight fire that began shortly after takeoff from

Reagan National Airport in Washington, D.C. The flight crew performed an emergency landing and ordered a passenger evacuation at Dulles International Airport. The airplane sustained minor damage. None of the two pilots, three flight attendants, and 61 passengers were injured.

After takeoff, the three flight attendants saw a flash of light and heard a boom on the right side of the airplane. Flight attendant No. 1, who was seated on the forward jumpseat, saw white smoke coming from a fluorescent light fixture in the forward entry area. She shut the light off and called the cockpit. The captain told her to "pull the breaker" for the fluorescent light. She pulled the circuit breaker, and smoke stopped coming out of the fixture.

When flight attendant No. 1 went aft to check on the passengers, she observed "dark, dense, black" smoke coming from the ceiling panels above Rows 7 and 8. She went to the cockpit and notified the flight crew while the other two flight attendants retrieved halon fire extinguishers and brought them to the area near Rows 7 and 8. The smoke detectors in the aft lavatories sounded. The smoke worsened in the midcabin area, and a ceiling panel above Row 9 began to blister and turn yellow.

A flight attendant began discharging a halon extinguisher toward the blistered ceiling panel. Flight attendant No. 1 asked the passengers if anyone had a knife that could be used to cut the ceiling panel. A passenger produced a knife and cut a circular hole in the blistered area of the ceiling panel. Flight attendant No. 1 then fully discharged a halon fire extinguisher into the hole, assessed the results, and found that the smoke appeared to be diminishing. Before taking her seat for the emergency landing, another flight attendant gave the passenger in Seat 9E a halon fire extinguisher, instructed him on its use, and told him to "use it if it was needed." However, the smoke did not recur.

The Safety Board investigation concluded that a lightning strike caused arcing in the airplane wiring above the cabin ceiling panels, which ignited adjacent materials.

United Airlines Flight 32

On Jan. 11, 2003, at 0045 Mountain Standard Time, a Boeing 757-222, operating as United Airlines Flight 32 enroute from San Francisco International Airport (SFO), Calif. to Boston Logan Airport (BOS), Mass., experienced a fire in the aft lavatory. The fire was extinguished, an emergency declared, and an uneventful landing was made at the Salt Lake City International Airport (SLC), Salt Lake City, Utah. There were no injuries to the two flight crew, five flight attendants, or 133 passengers.

About an hour and 20 minutes into the flight, a passenger went into the aft lavatory, and upon exiting, told a flight attendant that it "smelled like smoke" in the lavatory. The flight attendant went into the lavatory and smelled an odor of "burning plastic," but saw no smoke. She saw part of the plastic toilet shroud "bubbling." The flight attendant opened the door to the water heater near the sink and saw flames. The flames were surrounding the water heater, but did not extend outside the compartment. Another flight attendant retrieved a fire extinguisher and handed it to her. She placed the nozzle of the fire extinguisher into the area around the water heater and continued discharging halon until the extinguisher was empty. After that, she did not see fire again. A third flight attendant called the purser and the cockpit to let them know what was happening. The captain declared an emergency and diverted to SLC.

As of the date of this paper, investigation of this event is ongoing. Preliminary examination of the airplane revealed the lavatory toilet water level sensor was charred and melted. The inside aft wall of the toilet shroud, in the area over the sensor, was also charred and melted.

Based on information gained through investigation of these accidents and incidents,[5] the Safety Board issued several recommendations to the FAA pertaining to crewmember training, access to areas behind interior panels, and the merits of halon extinguishers.

Crewmember training

Title 14 CFR 121.417 requires that crewmembers receive training on firefighting equipment and procedures for fighting inflight fires. The regulation specifies that airlines must provide individual instruction on, among other things, the location, function, and operation of portable fire extinguishers, with emphasis on the type of extinguisher to be used for different classes of fires, and instruction on handling emergency situations including fires that occur in flight or on the ground. As part of their initial training, each crewmember must accomplish a one-time emergency drill while fighting an actual fire[6] using the type of fire extinguisher that is appropriate for the type of fire being demonstrated in the drill

Although 14 CFR 121.417 also requires crewmembers to perform certain drills biannually during recurrent training, including one that demonstrates their ability to operate each type of hand-operated fire extinguisher found on their airplanes; the regulation does not require recurrent training in fighting an actual or simulated fire. As a result, crewmembers are required to fight an actual or simulated fire during initial training only.

Further, although the emergency training requirements specified in 14 CFR 121.417 require instruction in fighting inflight fires, they do not explicitly require that crewmembers be trained to identify the location of a hidden fire or to know how to gain access to the area behind interior panels. Safety Board investigators evaluated the firefighting training programs of several air carriers and found that the actual "fire" crewmembers fight during initial training is typically an open flame that requires little effort to extinguish and that does not demonstrate the problems inherent in fighting a hidden fire on an airplane. AirTran's initial training program for flight attendants, for example, includes a firefighting drill in which students are required to extinguish an actual fire consisting of a visible, open flame. The accident and incident descriptions in this paper demonstrate that inflight fires on commercial airplanes can present themselves not as visible, localized flames, but in less obvious ways, such as smoke or heat from hidden locations. Therefore, the Safety Board noted in its recommendation letter that crewmembers should be trained to quickly identify the location of the fire, which may require removing interior panels or otherwise accessing the areas behind the panels before they can use fire extinguishers effectively.

The results of a series of experiments conducted by the FAA Technical Center to evaluate the ability of flight attendants to extinguish cargo fires in small Class B cargo compartments also indicated that the FAA's current training requirements were inadequate.[7] Technical Center staff conducted 13 tests in which trained crewmembers attempted to extinguish cargo fires located in a cabin-level compartment using firefighting equipment identical to the types on which they had been trained. The report noted that, although the fires could have been extinguished using proper techniques, in most cases the crewmembers did not act quickly or aggressively enough to successfully extinguish the fires. The report concluded that "improved and more realistic training procedures would better prepare flight attendants to more effectively fight inflight fires."

The Safety Board's recommendations in this area were based on a concern that, as a result of limited training, crewmembers may fail to take immediate and aggressive action in locating and fighting inflight fires, as demonstrated in the Air Canada accident and other events cited in this paper. In the Air Canada accident, flight attendants did not apply extinguishing agent directly to the flames, either because they had not been trained to do so or because they could not access the area behind the interior panels. In the Delta Flight 2030 incident, the flight attendant asked for the captain's permission before discharging a fire extinguisher. This course of action delayed an immediate firefighting response. Further, if the captain's order not to use the fire extinguisher had been carried out, the fire would likely have progressed and could have resulted in death or serious injury, as well as possible loss of the airplane. In the AirTran Flight 913 accident, flight attendants made no effort to locate the source of the smoke or to use any of the firefighting equipment available to them. In contrast, in the American Flight 1683 incident, a flight attendant, working with a passenger, successfully extinguished the fire by cutting a hole in the overhead panel and applying extinguishing agent. In the United 32 incident, the flight attendant quickly began searching for the source of the odor, and discovered flames behind an access door. She then extinguished the fire by discharging halon into the area surrounding the water heater.

Access to areas behind interior panels

Interior panels of airplanes are not designed so that crewmembers are able to easily and quickly locate and extinguish hidden inflight fires. In the Air Canada accident, one flight attendant discharged a CO_2 extinguisher into the lavatory, aiming at the seams between the walls and the ceiling where smoke had been observed. This action had little effect on the fire because the extinguishing agent was not applied to the base of the flames. In the American incident, the flight attendants did access the area behind the ceiling panel, but the method used (i.e., having a passenger cut a hole in the ceiling) risked damage to electrical wiring and other cables that may have been covered by the paneling. In addition, although the flight attendant's action successfully extinguished the fire, access to the area behind the panel should not have been dependent on the actions of a passenger, either to provide a sharp instrument for cutting or to cut the hole itself. In the United incident, the flight attendant opened the access door to the water heater in an attempt to locate the source of the odor. Fortunately, the proximity of the fire source to the water heater was such that flames were visible in the area, and halon could be indirectly applied to the fire through the space around the water heater.

The Safety Board issued one recommendation aimed at addressing the problem of gaining access to areas behind interior panels.

Properties of halon and the merits of halon extinguishers in fighting inflight fires

In two of the occurrences described in this paper, crewmembers hesitated to use halon extinguishers. In the Delta incident, the captain specifically ordered a flight attendant not to use the halon extinguisher because he was concerned about halon being sprayed in the cabin. In the AirTran accident, an off-duty crewmember chose not to use the halon extinguisher because of his concern that it "would take away more oxygen" from the cabin.

FAA AC 20-42C, *Hand Fire Extinguishers for Use in Aircraft*, states that halon-type extinguishers are three times as effective as CO_2 extinguishers with the same weight of extinguishing agent, have a gaseous discharge and therefore a more limited throw range, leave no chemical residue to contaminate or corrode aircraft parts or surfaces, have fewer adverse effects on electronic equipment, and do not degrade visual acuity. However, AC 20-42C also states the following: "Tests indicate that human exposure to high levels of halon vapors may result in dizziness, impaired coordination, and reduced mental sharpness. . . . Exposure to undecomposed halogenated agents may produce varied central nervous system effects depending upon exposure concentration and time. Halogenated agents will also decompose into more toxic products when subjected to flame or hot surfaces at approximately 900° F (482° C). However, unnecessary exposure of personnel to either the natural agent or to the decomposition products should be avoided."

The AC also specifies maximum concentration levels for halon agents under various conditions that should not be exceeded in ventilated and non-ventilated passenger compartments on aircraft. However, it is not obvious from the AC that the maximum levels cannot be achieved by discharging a single hand-held extinguisher in a transport-sized cabin.

Even though the AC also states, "generally, the decomposition products from the fire itself, especially carbon monoxide, smoke, heat, and oxygen depletion, create a greater hazard than the thermal decomposition products from halon," the potential hazards posed by halon gas are overemphasized in the AC, especially when compared to the potentially devastating effects of an inflight fire. Indeed, the statement quoted above is buried in the paragraph warning against exposure to halon gas.

The Safety Board issued one recommendation aimed at improving crewmembers' understanding of the benefits of halon gas.

Recommendations

On the basis of the concerns discussed above, on January 4, 2002, the Safety Board issued the following recommendations to the FAA:
Issue an advisory circular (AC) that describes the need for crewmembers to take immediate and aggressive action in response to signs of an inflight fire. The AC should stress that fires often are hidden behind interior panels and therefore may require a crewmember to remove or otherwise gain access to the area behind interior panels in order to effectively apply extinguishing agents to the source of the fire. (A-01-83)

Require principal operations inspectors to ensure that the contents of the advisory circular (recommended in A-01-83) are incorporated into crewmember training programs. (A-01-84)

Amend 14 *Code of Federal Regulations* 121.417 to require participation in firefighting drills that involve actual or simulated fires during crewmember recurrent training and to require that those drills include realistic scenarios on recognizing potential signs of, locating, and fighting hidden fires. (A-01-85)

Develop and require implementation of procedures or airplane modifications that will provide the most effective means for crewmembers to gain access to areas behind interior panels for the purpose of applying extinguishing agent to hidden fires. As part of this effort, the FAA should evaluate the feasibility of equipping interior panels of new and existing airplanes with ports, access panels, or some other means to apply extinguishing agent behind interior panels. (A-01-86)

Issue a flight standards handbook bulletin to principal operations inspectors to ensure that air carrier training programs explain the properties of halon and emphasize that the potential harmful effects on passengers and crew are negligible compared to the safety benefits achieved by fighting inflight fires aggressively. (A-01-87)

FAA responses to the recommendations

On March 8, 2002, the FAA responded to each of these recommendations.

Regarding the recommendations for the issuance of guidance (A-01-83 and A-01-87) the FAA stated: "The FAA agrees with the intent of these recommendations and will issue an advisory circular (AC) to address the safety issues identified in these safety recommendations. The AC will include guidance from the research efforts outlined in response to Safety Recommendation A-01-86. The AC will emphasize the need for an immediate response to an inflight fire and address the importance of investigating fires hidden behind interior panels and the techniques for effective application of extinguishing agents. The AC will also address the properties of halon and emphasize its negligible harmful effects on passengers versus its overriding benefit of combating and extinguishing fires. It is anticipated that this AC will be issued by February 2003. The AC will also address the effective means for conducting recurrent training of flight crewmembers in combating fires, including simulated fire drills with emphasis on recognizing potential signs of cabin fire and locating fires hidden behind interior panels. The FAA believes that this alternate approach will allow the safety information to be implemented more quickly into air carrier training programs."

The Safety Board responded to the letter from the FAA on June 28, 2002, stating that, pending the development and issuance of the AC, the recommendations were classified "Open Acceptable Response." To date, the FAA has not issued the AC.

Regarding the recommendation to improve crewmember training (A-01-84), the FAA responded by stating: "Once the AC is issued in response to Safety Recommendations A-01-83, -85, and -87, the FAA will send a memorandum to its principal operating inspectors (POI) directing them to inform their respective air carriers of the availability of the AC. The POIs will also be directed to stress to their operators the importance of including the information contained in the AC into their approved air carrier training program. This memorandum will include PTRS tracking codes for the purpose of determining notification to air carriers and will be incorporated into the next version of Order 8400.10, Air Transportation Operations Inspector's Handbook."

The Safety Board responded to the letter from FAA on June 28, 2002, stating that, pending the issuance of the memorandum, Safety Recommendation A-01-84 was classified "Open Acceptable Response."

Regarding the recommendation asking the FAA to require participation in firefighting drills that involve actual or simulated fires (A-01-85), the FAA stated: "The FAA agrees with the intent … and will issue an advisory circular (AC) to address the safety issues identified …. The AC will include guidance from the research efforts outlined in response to Safety Recommendation A-01-86. The AC will emphasize the need for an immediate response to an inflight fire and address the importance of investigating fires hidden behind interior panels and the techniques for effective application of extinguishing agents. The AC will also address the properties of halon and emphasize its negligible harmful effects on passengers versus its overriding benefit of combating and extinguishing fires. It is anticipated that this AC will be issued by February 2003. The AC will also address the effective means for conducting recurrent training of flight crewmembers in combating fires, including simulated fire drills with emphasis on recognizing potential signs of cabin fire and locating fires hidden behind interior panels. The FAA believes that this alternate approach will allow the safety information to be implemented more quickly into air carrier training programs."

The Safety Board responded to the letter from FAA on June 28, 2002, stating that "The Safety Board does not believe that the proposed AC will adequately address the intent of Safety Recommendation A-01-85. The Board notes that 14 CFR Section 121.417(1)(ii) states that initial training must include an approved firefighting drill in which the crewmember combats an actual fire using at least one type of installed handheld fire extinguisher. Section 121.417(2)(B) requires each crewmember to demonstrate that he or she can operate each type of installed fire extinguisher during recurrent training. However, crewmembers are not required to perform a firefighting drill during recurrent training. The intent of Safety Recommendation A-01-85 is to require all crewmembers to fight an actual or simulated fire during recurrent training using handheld fire extinguishers carried on aircraft. The Board believes that without a change to Section 121.417, this goal will not be accomplished. The Board asks the FAA to reconsider its decision not to revise Section 121.417. Pending the change to Section 121.417, Safety Recommendation A-01-85 is classified 'Open Unacceptable Response.'"

Finally, with regard to the recommendation for improved access to areas behind interior panels (A-01-86), the FAA responded by stating: "The FAA agrees that there should be an evaluation of the feasibility of fighting fires behind interior panels. The FAA has initiated efforts to address inflight fire accessibility, detection, and suppression issues. The FAA has initiated research programs through the William J. Hughes Technical Center (Technical Center). The Technical Center, in association with the International Systems Fire Protection Working Group, is currently researching the feasibility of developing methods to improve the means of detection and inflight firefighting techniques. The research will explore the various areas of the aircraft and analyze the techniques for dealing with inflight fires in different areas. In response to this safety recommendation, the FAA and the Technical Center will be expanding the current research to include the study of using handheld fire extinguishers in combination with access panels/ports as a means of effectively fighting inflight fires in inaccessible areas. Once the results of the research have been assessed, the FAA will consider the applicability of these methods of firefighting and extinguishing in inaccessible areas. The FAA has also developed new acceptance criteria for evaluating fire-extinguishing agents that will replace halon 1211 in handheld and lavatory fire extinguishers. The new criteria include a test to determine the ability of the agent and extinguisher to fight fires in inaccessible areas of the aircraft. Underwriters Laboratories' Fire Safety Section is currently using the new acceptance criteria in the qualification of these new extinguishing agents."

The Safety Board responded to the letter from FAA on June 28, 2002, stating that, pending completion of the research at the Technical Center and the required implementation of the procedures or airplane modifications identified, Safety Recommendation A-01-86 was classified "Open Acceptable Response."

Conclusion

The impetus for the safety recommendations issued by the Safety Board in 2002 began with the 1983 investigation of the Air Canada Flight 797 inflight fire, and has been strengthened in recent years by additional inflight fire events. In most of these cases, shortcomings in crew response were attributed to inadequate emergency training, unfamiliarity with safety equipment, and inaccessibility to fire sources. The recent safety recommendations were intended to remedy these problems.

The FAA's responses to the recommendations have been generally positive; however, implementation of A-01-85, which would require a change to CFR Part 121.417, has not been forthcoming. Safety Board staff will continue to monitor the FAA's responses to these safety recommendations. ◆

Footnotes

[1] National Transportation Safety Board. 1984. *Air Canada Flight 797, McDonnell Douglas DC-9-32, C-FTLU, Greater Cincinnati International Airport, Covington, Kentucky, June 2, 1983.* Aircraft Accident Report. NTSB/AAR-84/09. Washington, D.C.

[2] See FAA Order 8400.10.

[3] As a result of this incident, on February 6, 2001, the Safety Board issued to the FAA three recommendations (A-01-003, A-01-004, and A-01-005) regarding the inspection and design of static port heaters and the possible replacement of existing insulation blankets with an alternate that would be less likely to propagate a fire.

[4] The AirTran initial flight attendant training program includes a firefighting drill in which students are required to extinguish an actual fire. The fire used in the drill is a visible, open flame.

[5] The UAL Flight 32 incident occurred after the recommendations were issued.

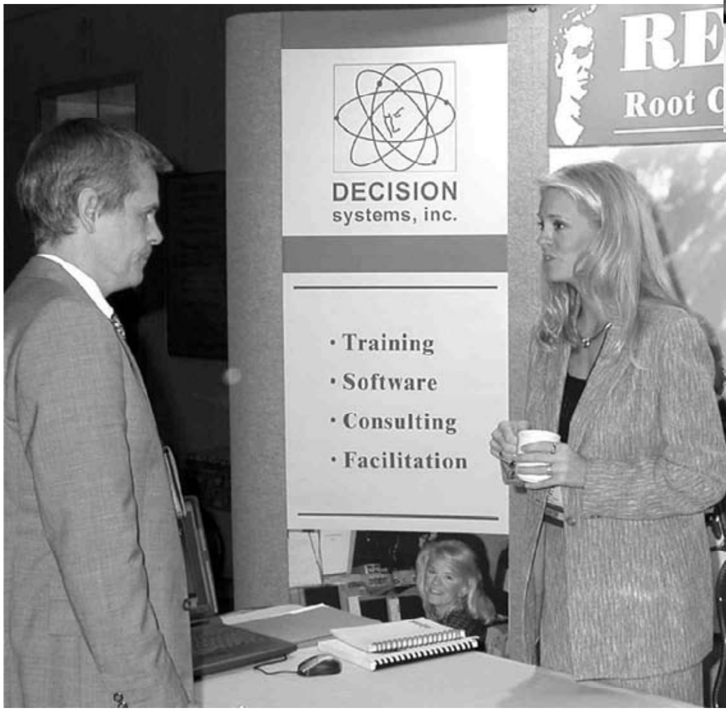
[6] 14 CFR 121.417 provides a definition of an actual fire: "An *actual fire* means an ignited combustible material, in controlled conditions, of sufficient magnitude and duration to accomplish the training objectives...."

[7] See *Effectiveness of Flight Attendants Attempting to Extinguish Fires in an Accessible Cargo Compartment*, DOT/FAA/AR-TN99/29, April 1999.

ISASI 2003 Pictorial Review

Photos by Esperison Martinez


Aviation
Aviation


RE
Root C
DECISION
systems, inc.
· Training
· Software
· Consulting
· Facilitation