ISASI FORUM

"Air Safety Through Investigation"

JANUARY–MARCH 2007

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ABOUT THE COVER

In November 2001, American Airlines Flight 587's composite stabilizer failed. As a potential harbinger of the failures discussed in "Failure Analysis of Composite Structures in Aircraft Accidents," the failure of this composite structure is discussed in the article on page 17. (Photo: ISASI 2006)

ISASI FORUM

"Air Safety Through Investigation"

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AIR SAFETY INVESTIGATORS
INCORPORATED AUGUST 31, 1964

ISASI Accepts International Human Factor Role

By Frank Del Gandio, President

Our Society has been asked to accept a major role in assisting you, the field accident investigators, in using human factor tools to understand, guide, and report the role the human played in an accident or incident. At our May 2006 Council meeting, Vice-President Ron Schleede reported that he had been contacted by Dr. Randy Mumaw, a human factors specialist for Boeing, with an invitation for ISASI to join the recently formed International Human Factors Working Group. This Working Group had begun to prepare guidance material for accident and incident investigators and others in the field of human factors. The International Human Factors Working Group wanted the endorsement and assistance of ISASI in preparing and distributing the guidance material. The Council considered this a "heads up" contact and asked that more information be provided for the fall meeting.

Accident statistics show that issues associated with human performance are major contributors to incidents and accidents in commercial aviation. Ideally, an investigation will seek to understand the context of human performance and how it contributes to the observed behaviors and decisions. Worldwide, investigations vary significantly with respect to the beliefs about the role of humans and appropriate methods for developing an understanding. Because of this, these investigations can become the subject of controversy. Accident and incident investigation presents a real opportunity to determine how humans have affected the outcome of an operation.

Understanding that improving comprehension of human factors in accident investigation is an important contribution ISASI can make to assist the field investigator in using human factor tools to understand, guide, and report the role the human played in the accident/incident, the Council, at its fall meeting in September, accepted the invitation, but went beyond that.

Our Society has been asked to accept a major role in assisting you, the field accident investigators, in using human factor tools to understand, guide, and report the role the human played in an accident or incident.

Research and discussion showed that this effort directly affected our membership and deserved the fullest participation. Hence, the Council established the ISASI International Working Group on Human Factors (IIWGHF) and proposed to the Boeing contingent that ISASI assume sponsorship of the international industry Working Group that aims to develop better guidance for investigating human performance.

The genesis of this effort is described in Randall Mumaw's article "Enhancing the Investigation of Human Performance Issues," on page 14 of this issue. He also discusses the early-on efforts of the industry Working Group and provides some insight into the role ISASI would play in the effort.

To head our effort, I turned to our long-time Executive Advisor Dick Stone, who has extensive experience in the HF field, dating back to the years he served in the Air Line Pilots Association's air safety structure. He accepted the charge, and with MikeWalker, Australian TSB, and Randy Mumaw acting as members of a steering committee began to structure the IIWGHF in a configuration that could enhance existing guidance documents for investigation of human performance issues in accidents and incidents now available to investigators, and that would help establish clear standards for suitable methods of investigating contributing factors of human performance. While human factors expertise is available, this expertise is not uniformly applied. In the next issue of *Forum,* Capt. Stone will discuss the work of IIWGF. ◆

E. MARTINEZ

Ron Schleede, vice-president (left), prepares to brief the Council and put forward the resolution creating the ISASI International Working Group on Human Factors (IIWGHF). Looking on is President Frank Del Gandio.

'Best in Seminar'

By Dr. Graham Braithwaite, Selection Panel Chairman

(Described below by the panel chairman is the process summary used in the selection of the "Best in Seminar" technical paper presented at ISASI 2006. The panel enlarged the scope of the review and identified three papers for "special commendation." All the papers, as adapted for publication, are presented on the following pages. Readers are encouraged to view the full presentations including all images, references, and acknowledgements on the ISASI website.—Editor)

The "Best in Seminar Award" was established through an anonymous donation by an ISASI member who wished to acknowledge a paper at the annual seminar that made an outstanding contribution to the advancement of technical methodologies in aircraft accident investigation. The Award was to be given on the basis of publication of new or unique application methods to be used by today's accident investigators.

The judging panel was made up of seven ISASI members from civil, military, education, government, and manufacturer backgrounds.

For ISASI 2006, a judging panel was made up of seven ISASI members from civil, military, education, government, and manufacturer backgrounds to grade each paper based on the above criteria and reflecting the overall theme of the seminar, "Incidents to Accidents: Breaking the Chain."

Some presentations would be of particular interest to some of the audience, and the panel recognized that selecting an overall best presentation was going to be difficult. Based on the independent assessment of the papers and subsequent debate by the panel, three papers were selected for special commendation

- Dr. Randy Mumaw's (Boeing) presentation on the ISASI-sponsored initiative to develop guidance material for the investigation of human performance issues was felt to represent a great, practical development for investigators, and the results of the project will be awaited with anticipation.
- Dr. Mike Walker's (ATSB) paper on the ATSB's approach to improving the quality of investigation analysis highlighted the considerable effort that the Australian Transport Safety Bureau has put into developing its approach to investigation and promises a significant increase in capability, particularly with complex investigations.
- Dr. Joseph Rakow also presented a paper that helped many investigators to better understand the nature of composite failure in aircraft structures—a growing area of interest within civil and military aviation.

Doctors Mumaw, Walker, and Rakow

The winning presentation was Stéphane Corcos and Alain Agnesetti's paper detailing the French BEA's investigation of a serious incident that had many parallels with a previous fatal accident investigation. The content was a fascinating insight into the application of a systemic investigation approach in a part of the industry where the "virtual airline" presents growing challenges for safety professionals. Good investigative judgment in understanding the factors behind the incident provided a clear illustration of the Society's aim of "Safety through investigation," and the paper was a worthy winner of "Best in Seminar." ◆

PHOTOS: E. MARTINEZ

ABOVE: Stéphane Corcos, right, on behalf of himself and coauthor Alain Agnesetti, accepts the Award of Excellence from ISASI President Frank Del Gandio during award ceremonies at ISASI 2006, in Cancun, Mexico.
LEFT: Alain Agnesetti.

Applying Learned Investigation Lessons Anew

Virtual airlines, like genuine toadstools, can jeopardize the safety and stability of the air transport industry when insufficient oversight is practiced.

By Stéphane Corcos and Alain Agnesetti, BEA (Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile)

(This article was adapted, with permission, from the authors' presentation entitled Investigating a "Minor" Incident Using Lessons Learned From A Major Accident *presented at the ISASI 2006 seminar held in Cancun, Mexico, September 11-14, which carried the theme "Incidents to Accidents: Breaking the Chain." The full presentation including cited references index is on the ISASI website at www.isasi.org. The authors received ISASI's Award of Excellence for development of the "Best in Seminar" paper. The Award was created in 2005.—Editor)*

Last summer was a terrible one for aviation safety, with several fatal accidents, in which more than 500 passengers died in just 2 months. Most investigations are still ongoing, but it is likely many of them will highlight shortcomings in the way oversight of various operators was performed by their national authorities. The BEA has been involved in a number of investigations to various extents, as state of the manufacturer, state having citizens among the victims, but also by assisting several countries in their investigations, including flight recorder readout.

Although most of these fatal accidents occurred outside the western hemisphere, any given citizen of a western country may one day be a passenger on a domestic flight in a less developed country, or between two of them. Moreover, an investigation into an incident that occurred during takeoff from Paris's Charles-de-Gaulle in July 2005 showed that it is not necessary to travel abroad to be at risk.

In Europe, airlines from countries where safety oversight is weak can operate on a wet-lease basis for national flag carriers from EU states, where leasing conditions are somewhat overlooked. According to ICAO findings (35th assembly, September 2004), there are almost 30 states where safety deficiencies still prevail, where corrective actions have not been implemented. Rogue airlines know this situation and exploit these breaches, eventually making their way into Western countries. "Virtual airlines," made up of parts that are often inconsistent, and which should actually be called "ticket sellers," rather than "airlines," are created there. Then, like genuine toadstools, they jeopardize the safety and stability of the air transport industry.

The world aviation community has identified the problem, but implementation of solutions is very slow. ICAO has limited power, since its system is based on sovereignty. Many states commit themselves to implement ICAO standards but often have not taken appropriate action to enforce the standards through regulations, procedures, and proper staffing.

But, mostly, such states lack the political will to move forward. Instead, technical expertise is often superseded by political considerations for various reasons. Safety regulations are often seen as hindrances to the prosperous operation of an airline, and both authority and airline technical staff are under pressure from politics or financial managers. In such cases, safety is not attractive because it may ultimately confront one with the taboo of canceling a flight. In aviation culture, especially in a fiercely competitive environment, canceling a flight is seen as a failure. Consequently, safety personnel end up being blamed for their actions and are seen as "the bad guys."

Above all, it is our terrible experience in society that sometimes it seems as if a price must be paid in blood before lessons are really accepted and the situation changed, before those concerned are convinced by the lessons derived from other occurrences and are willing to overcome the inevitable costs and putting aside of prestige considerations. When the aviation community says it will improve its level of safety, accident investigators are too often their "efficiency sensor," who demonstrate that the picture remains imperfect.

Stéphane Corcos *at the time of ISASI 2006 was the head of the BEA (Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile) Investigations Department. Prior to joining the BEA, he worked for the DGAC (French civil aviation authority) for 8 years. He was graduated from the French National Civil Aviation School (ENAC) with a masters degree in aeronautical engineering in 1987 including an internship period at the Flight Safety Foundation in Arlington, Va. He is currently employed as head of Safety and Security Oversight for Charles-de-Gaulle and Le Bourget Airports by the DGAC (Direction Générale de l'Aviation Civile).*

Alain Agnesetti *is a former Air Force pilot instructor. As a flight safety officer and accident investigator in the French Air Force, he led various military accident investigations. A retired major with more than 6,000 flying hours, he joined the BEA in 1999 as a safety investigator. He has been IIC on a number of national and foreign investigations and an accredited representative on major investigations abroad.*

According to ICAO findings, there are almost 30 states where safety deficiencies still prevail, where corrective actions have not been implemented. Rogue airlines know this situation and exploit these breaches, eventually making their way into Western countries. "Virtual airlines," made up of parts that are often inconsistent, and which should actually be called "ticket sellers," rather than "airlines," are created there.

Traceability of airplanes can be impossible across borders, except with the help of private companies or individuals, whose websites may include interesting information on a given situation. Thanks to Internet search engines, which are more and more frequently used in difficult investigations, some achievements are possible. But traceability of pilots, their initial and recurrent training, their ratings and their actual experience, is almost impossible especially when, de facto, they act as mercenaries. Such pilots often move from airline to airline and have no time to become familiar with the airline, the working environment, the standard operating procedures, the network, and they are not always in a position to perform at an acceptable safety level.

To illustrate this, we could reiterate the occurrence the BEA presented at ISASI 2005. The investigation into this incident in Nantes (approach flown well below and outside normal final approach path) had shown that the captain lacked knowledge on instrument approach procedure principles and limitations and on the autopilot of his airplane. This pilot, who held a Venezuelan license but flew with an Egyptian airline, was sacked before the investigation was completed. He, quite probably, has now transferred his inadequacies to another country, to another employer who has no reason to believe his knowledge is inadequate. No one has any way of knowing where he is now, much less to have him enrolled in additional training.

Finally, traceability of airline managers, and even of airlines themselves, is no easier, all the while this situation is increasingly becoming a safety concern as well.

Safety oversight

Through safety oversight, a state ensures that national actors in the aviation industry (airmen, operators, maintenance organizations) perform their duty in a safe manner and meet the applicable requirements and standards.

The responsibilities and international obligations of states in relation to safety oversight are derived from the Convention of Dec. 7, 1944, on international civil aviation, known as the Chicago Convention: "in order that international civil aviation may be developed in a safe and orderly manner and that international air transport services may be established on the basis of equality of opportunity and operated soundly and economically." The Convention recognizes (Article 1) that "each state has complete and exclusive sovereignty over airspace above its territory."

Furthermore, the Convention stipulates (Article 12) that a state should ensure that any aircraft flying over its territory or maneuvering thereon, as well as any aircraft with its registration mark, wherever it may be found, should be in conformity with the rules and regulations applicable in the place where the flight or the maneuver is taking place. The Convention also specifies (in Articles 31 and 32) that states of registry must issue certificates of airworthiness to aircraft undertaking international flights and certificates and licenses to their crews. However, Article 83b authorizes the partial or total transfer of these responsibilities, as well as those relating to Article 12, to the state of operator of the aircraft.

To ensure harmony between these various obligations, the Convention introduces, in Article 12, an obligation for national regulations to be in conformity with the rules established pursuant to the Convention and, in Article 33, the international recognition of documents issued by the state of registry insofar as they correspond to the standards.

This implies that each state commits itself to adopt a law or a civil aviation code, completed by the necessary rules of application, to put into place and apply the international standards. This also implies that each state may ascertain that other states are satisfactorily undertaking their commitments. Specifically, if the rules adopted by other states are inferior to international standards, Article 38 stipulates that the council be notified of these differences.

Throughout the past 15 years, aviation has experienced rapid and steady growth and has always been ahead of global economic growth, which it has accompanied effectively, as a fundamental tool for development of exchanges. But this economic growth has been characterized by increased globalization, which has also affected aviation. The system has become so complex that in order to maintain an acceptable level of safety, increasing human, financial, organizational, and technological resources are required. Not all contracting states can cope with this challenge, and ICAO has noted that more and more contracting states are faced with difficulties in exercising their oversight function.

The concern that all states keep up with their responsibilities has been shared by more and more states. In August 1992, the U.S. Federal Aviation Administration (FAA) established the International Aviation Safety Assessments (IASA) program. The foreign assessment program focuses on the ability of a country, rather than that of an individual air carrier, to adhere to international standards and recommended practices for aircraft operations and maintenance established by ICAO. It was recognized that in order to ensure that all foreign air carriers that operate to or from the United States were offering an acceptable level of safety, it was necessary to ascertain that safety oversight of these carriers was provided by a competent civil aviation authority (CAA) in accordance with ICAO standards.

In 1996, ICAO set up a voluntary program for safety assessment of national aviation authorities within contracting states. In 1998, this was replaced by a Universal Safety Oversight Audit Program (USAOP), adopted by resolution A32-11 of the 32nd Assembly.

These audits started in 1999 and covered airworthiness, personnel licensing, and operations. Their purpose was to assess whether a given contracting state was implementing critical elements of oversight in pertinent standards and recommended practices or SARPs in an acceptable manner, following established procedures.

Meanwhile, in 1995, the BEA issued a safety recommendation requesting that the French DGAC (French civil aviation authority) play a lead role in the reinforcement of safety oversight of foreign states and carriers, both through ICAO and the European Conference for Civil Aviation (ECAC). The DGAC was designated coordinator of the new European Safety Assessment of Foreign Aircraft (SAFA) program, which started in 1996 as a complement to USOAP audits.

The Puerto Plata accident (a Boeing 757 operated by Birgenair, a Turkish operator with mostly German citizens on board) in 1996 accelerated this process. Both the SAFA and USOAP programs are interrelated through a memorandum of understanding.

Although the SAFA inspections are limited and seldom thorough, they give a general overview of the foreign operator's safety. Furthermore, these inspections may lead to mandatory repairs, which contribute to safety on a given airplane. Finally, inspections foster cooperation between the inspecting state and the competent authority of the inspected operator to solve safety issues almost in real time.

UTA Boeing 727 accident

The above discussed oversight issue was significantly brought to light in the course of the investigation into an accident that occurred in Cotonou (Benin) on Dec. 25, 2003.

History of flight—A Boeing 727-223, registered 3X-GDO and operated by Guinean Airline UTA (Union des Transports Africains), was on its second leg of its Conakry (Guinea)–Cotonou–Kufra (Libya)–Beirut (Lebanon)–Dubai (United Arab Emirates) route. During the takeoff run, the airplane experienced a long, delayed, and shallow angle of liftoff. It struck an ILS building located 118 meters past the runway end on the extended runway centerline and crashed onto the beach with most parts ending up in the ocean. There were at least 160 people on board, among whom 22 survived the accident, including the captain and the airline's general manager. The Benin government delegated the investigation to the BEA.

Accident description—The investigation showed that the airplane weight was 7 to 8 tons above the maximum allowable weight and that the cargo compartments were loaded by poorly managed employees, in an anarchic way. The aircrew was unable to obtain precise data concerning passengers and luggage, nor for possible freight on board.

Furthermore, the aircrew was lacking documentation to establish a precise load sheet: they were not informed that the forward cargo hold had been heavily loaded, which significantly displaced forward the center of gravity. Therefore, the crew took into account a weight of 78 tons with a standard loading, and a configuration of flaps 25°, trim setting 6¾, packs off, brakes release on takeoff thrust. At V1-VR callout, the airspeed was 137, which is in fact a V1-VR for 85.5 tons. On reaching this airspeed, the copilot (who was the pilot flying) pulled back on the column but the airplane failed to pitch up. The airplane rotated slowly and lifted off in the very last meters of the runway. The main landing gear struck a 2.45-meter-high building containing the localizer system. The right main landing gear broke off and ripped off a part of the underwing flaps on the right wing. The airplane banked slightly to the right and crashed onto the beach. It broke into several pieces and ended up in the ocean.

Operational failings—The overall operation of the airplane, both at its base and at the various destinations it served, was not organized, undertaken, or overseen in an appropriate manner.

In Cotonou, the station manager had no aeronautical knowledge. The resources (counters, vehicles, and staff) were rented from a company based at Cotonou airport, but this company was not tasked with any duty related to dispatch or handling, in particular providing the crew with performance data. Basic loading elements (number of passengers, estimated weight of luggage) were provided to the aircrew by a representative of the airline, flying on board the airplane.

At its main base in Conakry, apart from a rented check-in counter, the airline had two containers in which spares, drinking water, and the printed paperwork required for operations were stored.

There was no competent technical management and operational and maintenance activity were non-existent (no maintenance documents could be supplied to the investigators), and no training was provided for ground crew.

History of operations

The airline, UTA, was initially based in Sierra Leone and operated as West Coast Airlines. In 1997, its home base was transferred to Guinea under the name of UTA. It started operating rather light airplanes: a Let 410 and an Antonov 24. Both airplanes belonged to a Russian citizen, who was also the technical director of the airline. The airline was owned by a Lebanese citizen living in Guinea; several family members were among top managers of the airline, including the director general and the operations manager.

UTA performed local flights in western Africa up to 2003. In April 2003, the airline

Satisfactory investigations are essential, since in some cases they now mostly consist of an audit on the safety structures, rather than an identification of previously unknown safety weaknesses. This implies that confidence and cooperation be total between accident investigation authorities and that nobody be influenced during an investigation by economic, political, or image considerations.

elected to extend its range of operations and, in June of the same year, long-distance flights to Lebanon and the UAE were organized using a Boeing 727. When the Boeing 727 was added to the airline fleet, none of the technical staff had any knowledge about the airplane. In April 2003, a request to open a Conakry–Abidjan–Cotonou–Beirut route was made to the authorities in the various countries concerned. On June 28, 2003, the route was opened between Conakry, Cotonou, and Beirut. In November, it was extended to Dubai.

The Boeing 727 was leased from FAG (Financial Advisory Group), formerly based in Miami (Florida), then allegedly based in the Virgin Islands. Except for the airplane lease, the sole interface was through its office in Sharjah (United Arab Emirates). The leasing contract included the aircrew and technical maintenance of the airplane. It also stated that insurance and wages were to be paid by the airline. FAG did not hold an air operator certificate.

- The airplane was first delivered to American Airlines (USA) in 1977. It had normal flying activity in the USA until 2001.
- Between 2001 and 2003, it was stored in the Mojave desert. In 2003, the B-727 became the property of a bank, still with a U.S. registration.
- In January 2003, it was operated by Ariana Afghan Airlines, Kabul (registered YA-FAK). The owner was based in Sharjah (UAE).
- In June 2003, it was operated by Alpha Omega Airways—the same owner, registered in Swaziland (3D-FAK).
- In July 2003, it was "operated by UTA," under wet lease from Alpha Omega, the same registry.
- In October 2003, it was newly leased to UTA, this time from FAG, same registration. Two days later, it was transferred to Guinea registry and became 3X-GDO.
- From October 2003 till the day of the accident, it remained leased by FAG and operated by UTA as 3X-GDO on a Guinea registry.

UTA operations actually began with another B 727, registration 3X-GDM, also the property of FAG, which was grounded in Lebanon at its first flight for a number of major deficiencies. The airplane was then replaced by the 3D-FAK and FAG got it back. The BEA deeply regrets that, due to time constraints and since this was not a part of the investigation, this airplane was not tracked after it returned under FAG responsibility.

Organizational failings—BEA's investigation brought to light the inadequacy of both the airplane's and the airline's mandatory documentation. The airline's operations manual was a "cut-and-paste" job, seemingly based on that of a Jordanian airline. The manual contained descriptions of systems, human resources, and equipment that the airline, UTA, did not possess. As the operator had no knowledge of the world of aviation, it could neither organize nor plan any operational follow-up at all, much less ensure the safety of its flights. The airline's only office was a ticket office in downtown Conakry. Overall, the airline was hardly more than purely a commercial structure.

Oversight—The DNAC (Direction Nationale de l'Aviation Civile), the Civil Aviation Administration of Guinea, exercised oversight of the airline. An air operator certificate was issued in November 2001. When the airline expanded with the leasing of a Boeing 727, the Guinea civil aviation authority stipulated that the airplane had to be maintained according to a program approved by the DNAC and in accordance with the manufacturer's maintenance manual.

The DNAC could get no information on the maintenance for the first of the two Boeing 727s. For the second, 3X-GDO, maintenance had been scheduled to occur in Kabul, Afghanistan, in January 2004, a few weeks after the accident.

The Guinea CAA failed to exercise, in part under pressure from economic and employment issues, its normal duties. It provided almost no safety audit upon application to operate, no checks on operations, documentation, flight time limitation, crew or airplane activity follow-up.

During stopovers in Beirut, the Lebanese civil aviation authority conducted ramp inspections on 3X-GDM and 3D-FAK/3X-GDO. Although limited in time and depth, a ramp check showed such deficiencies that 3X-GDM was banned from flying with passengers and was replaced by 3D-FAK. On this second plane, the ramp check revealed 18 deficiencies. The plane was grounded in turn. It took at least three iterations to the Lebanese CAA to have all deficiencies eventually corrected.

Causes—The direct cause of the accident was a forward center of gravity, unknown to the crew.

The root causes of the accidents were

- The operator's lack of competence, organization, and regulatory documentation, which prevented it from appropriately organizing line operation and checking the airplane's loading.
- Insufficient monitoring exercised by the Civil Aviation Administration of Guinea, and Swaziland prior to it, in the area of safety oversight.

Several contributory factors were noted, among which were a spread of responsibilities between the parties that made checks all the more difficult, as well as the failure to use proper dispatch or handling agents at the Cotonou station.

Safety recommendations—A first set of safety recommendations was addressed to civil aviation authorities, in particular Guinea, to reorganize safety oversight and implementation of ICAO SARPs.

Another set was addressed to ICAO, recommending fostering a comprehensive enhancement of safety oversight within all member states, to include clarification of duties of state of the operator, harmonization between scheduled and non-scheduled flights, identification of one operator so as to limit the spread of responsibilities, publication of guidelines to be used by civil aviation authorities….

Lockheed Tristar incident

In July 2005, almost as a precursor to the tragic summer, an incident to a Lockheed Tristar operated by StarJet, registered A6-BSM, occurred in Paris CDG.

Olympic Airlines was struggling to keep up with its maintenance, and it was short of airplanes. It contracted StarJet on a wet-lease basis through a broker to perform the scheduled flight OA202 from Paris to Athens.

The airplane arrived late at the gate. When passengers boarded, loud bangs could be heard, produced by mechanics literally hammering on the cargo door to close it before flight. Several passengers panicked, some of them rebelled, and half of them left the airplane, which eventually left the gate 4 hours and 40 minutes late. On takeoff, just after gear retraction, loud thumps could be heard. The crew noticed turbine gas temperature rising above limits, along with vibrations from engine No. 3. In several cabin rows, passengers saw a flame behind the engine and panic spread. The flames were also seen from the ground by plane spotters.

The crew applied the appropriate procedure, shut the engine down, requested a visual approach, and returned to Paris CDG, with an uneventful landing. The news media splurge that followed was amplified by residents neighboring the airport. The BEA started an investigation to determine the facts.

Beyond a "mere" engine surge followed by exhaust pipe fire, numerous deficiencies were brought to light. Maintenance was not undertaken by an approved facility, and the lack of documentation made it impossible to conduct a proper follow-up of maintenance operations. More generally, the investigation revealed several shortcomings in the operations as set up by StarJet: no logbook entries for several flights, several pieces of equipment were not airworthy, and the documentation was not appropriate (OPS manual outdated and inadequate, MEL replaced by the MMEL, although this was agreed as an exemption by the CAA of the UAE).

The oversight from the United Arab Emirates, state of registry, and of the operator revealed shortcomings in the area of operations. Although they were aware the operation failed to meet the applicable safety standards, an exemption was granted so they could fly for Olympic. The supervision and checks conducted by the civil aviation authority of Greece and Olympic Airlines could not prevent this airplane from being operated within the European Union.

The history of activity for the Boeing 727 3X-GDO and the Tristar L-1011 A6-BSM are very similar. In both cases, the pattern of the geographical spread of the respective owners, operators, registry, and oversight authorities—and therefore of responsibilities—is similar.

- 1981: BWIA (West Indies Airways), Trinidad
- 2003: stored in Port-of-Spain, then registered in Sierra Leone (9L-LED) with a 1-year validity certificate of airworthiness.
- October 2004: bought by Star Air in Sierra Leone. The base was in Gibraltar and the headquarters in Amman (Jordan). The airplane was ferried to Amman.
- October 2004: withdrawn from Trinidad registry.
- June 2005: registered A6-BSM in the UAE. New owner: StarJet, company based in Sharjah. Same president as Star Air. No formal purchase or sale document formalized this transfer of property.
- July 2005: StarJet was operating on a wet-lease basis for Olympic Airlines (Greece).

Although the aircraft was grounded most of the time, the airplane was registered in more than one state between November 2003 and October 2004. The above are only a few of the failings found, and the investigation is still ongoing; more details will be found in the final report.

The experience gained during the investigation into the Cotonou accident helped investigators operate more effectively and explore more precisely the apparent areas of deficiency, addressing in an even more pertinent way the root issues of failings in the oversight process.

The two investigations showed that aviation safety faces at least two challenges. The first one is a sound and organized implementation of international standards for operation of airplanes, and an appropriate level of supervision to ensure this standard. The second challenge is that Western airlines, usually subject to a more stringent oversight from their authority, may delegate transport activity to operators who are subject to a much weaker monitoring activity. Action taken to guarantee an equivalent level of safety is not robust enough. Ultimately, fare-paying passengers may "legally" end up flying with a much lower degree of safety.

Among the challenges of the coming years, safety oversight is certainly one for which every country has a part to play, and should go beyond the concept of "blacklists": strengthening of oversight, ramp checks extended as far as possible to areas such as aircrew training, cooperation between states, exchange of information, training, assistance to less developed countries, and use of accident or incident investigation reports to be part of the safety assessment, to name but a few.

In this respect, satisfactory investigations are essential, since in some cases they now mostly consist of an audit on the safety structures, rather than an identification of previously unknown safety weaknesses. This implies that confidence and cooperation be total between accident investigation authorities and that nobody be influenced during an investigation by economic, political, or image considerations. ◆

Improving the Quality of Investigation Analysis

This described Safety Investigation Information Management System (SIIMS) developed by the Australian Transport Safety Bureau for its investigation activities holds promises for a significant increase in capability, particularly with complex investigations.

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

(This article was adapted, with permission, from the author's presentation entitled The ATSB Approach to Improving the Quality of Investigation Analysis, *presented at the ISASI 2006 seminar held in Cancun, Mexico, September 11-14, which carried the theme "Incidents to Accidents: Breaking the Chain." The full presentation including cited references index is on the ISASI website at www.isasi.org. Dr. Walker's paper received "special commendation" in the seminar's "Best in Seminar" screening by the selection panel. The panel said the paper "promises a significant increase in capability, particularly with complex investigations."—Editor)*

In 2004, the Australian Transport Safety Bureau (ATSB) obtained substantial Australian government funding to replace its existing occurrence database (OASIS). There were several reasons for the change: OASIS was based on a very complex data model, which made trend analysis and research difficult; it also had limited functionality beyond being an occurrence database.

The ATSB wanted to take advantage of developments in information technology to build a system that could enhance the quality of the investigation process. To meet this aim, ATSB is developing a Safety Investigation Information Management System (SIIMS) for its investigation activities. A key component of the System is a set of tools for the analysis phase of a safety investigation, which were developed as part of a broader framework for improving the quality of investigation analysis activities.

SIIMS overview

SIIMS will provide a workspace for each investigation with the following components:

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

The System is being developed in consultation with a multidisciplinary team of investigators, and discussions with the Canadian Transportation Safety Board (TSB) have aided in its design. SIIMS's expected operational date is early 2007.

Developing a new analysis framework

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

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

Despite its importance, complexity, and reliance on investigators' judgments, analysis has been a neglected area in terms of standards, guidance, and training of investigators in most organizations. Many investigators seem to conduct analysis activities primarily using intuition rather than any structured process. It also appears that much of the analysis is typically conducted while the investigation report is being written. As a result, the writing process becomes difficult,

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supporting arguments for findings may be weak or not clearly presented, and important factors can be missed.

To help address this situation, the ATSB wanted to introduce a comprehensive framework (including tools in SIIMS) to guide and support the analysis activities of its investigators. The ultimate aims of this framework were to improve the rigor, consistency, and defendability of investigation analysis activities and to improve the ability of investigators to detect safety issues in the transportation system. Such a framework, the ATSB believed, would have a direct role in more effectively "breaking the chain" of accident development.

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

Consequently, the ATSB developed its own analysis framework, borrowing useful ideas from other organizations' existing processes where appropriate, but also substantially adding to this material in many areas. The result is a framework with

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

Standardized terminology

The ATSB recognized the need for clear definitions and consistent usage of analysis-related terms. It determined that rather than use terms based on "cause," which are associated with a range of semantic and communication problems, it would use "safety factor," "contributing safety factor," and "safety issue."

- **Safety factor—**defined as an event or condition that increases safety risk, e.g., something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include a wide range of events and conditions, such as accident events, technical failures, individual actions, local conditions, and a range of organizational or systemic conditions. Safety factors can be classified in terms of whether they contributed to the occurrence of interest or in terms of their future influence on safety.
- **Contributing safety factor—**defined as a safety factor that, if it had not occurred or existed at the relevant time, then (1) the occurrence would probably not have occurred; (2) adverse consequences associated with the occurrence would probably not have occurred or have been as serious; or (3) another contributing safety factor would probably not have occurred or existed. This definition is based on a counterfactual conditional (i.e., if "A" did not happen, then "B" would not have happened), which is a common way of defining cause. However, the ATSB has expanded the definition to more easily allow the reasoning process to move in steps from one contributing safety factor to the next. This mechanism provides a clearer basis for identifying organizational conditions as contributory to an occurrence. The definition also specifically includes the term "probably," which the ATSB defines as meaning a probability of 75% or more. This ensures that the standard of proof used in safety investigations is a practical compromise between a low standard such as "on the balance of probabilities" (which could produce factors that may be considered weak by external parties) and a high standard such as "beyond a reasonable doubt" (which would usually produce few factors other than those involving technical failures or the actions of flight crew).
- **Safety issue—**is defined as a safety factor that (1) can reasonably be regarded as having the potential to adversely affect the safety of future operations and (2) is a characteristic of an organization or a system, rather than a characteristic of a specific individual or characteristic of an operational environment at a specific point in time.

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

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

Accident development model

Many different proposals of models or theories exist of how accidents develop. Such models can play a useful role during an investigation by helping investigation teams identify potential safety factors and by providing a framework for classifying safety factors in a database. Unfortunately, some analysis methods provide no guiding model to assist with the identification of factors, while other methods focus too much on a model and not enough on the identification process.

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

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

The resulting model can be arranged into a series of levels, as

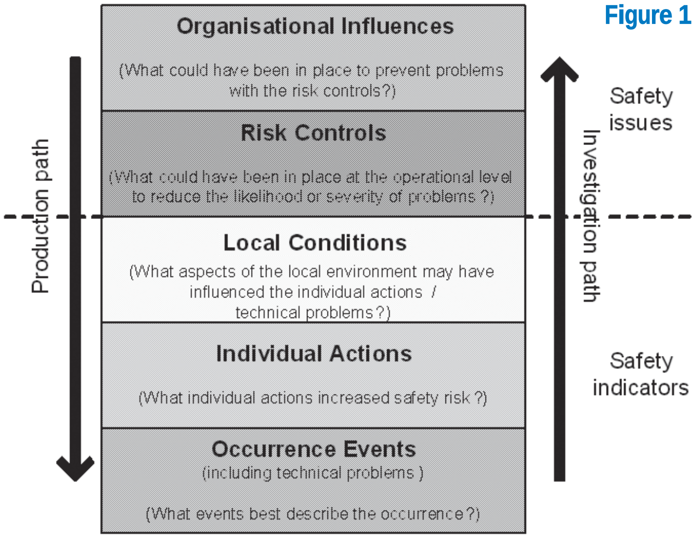


Figure 1

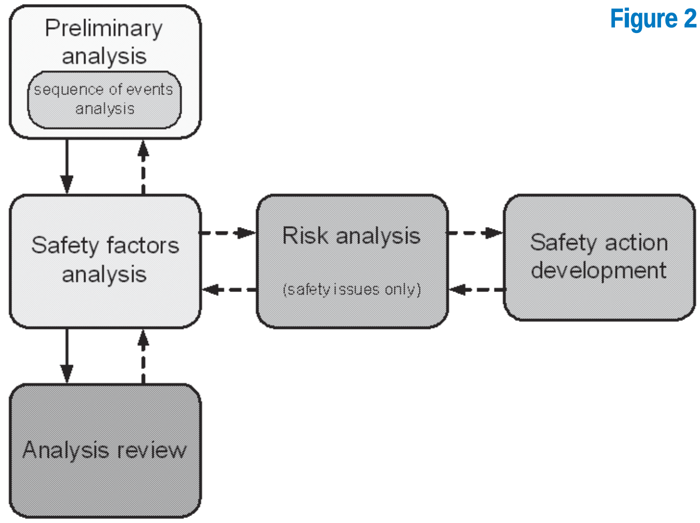


Figure 2

shown in Figure 1. Representing the model in this format facilitates the identification of safety factors, and can also help the investigation team maintain awareness of their progress when identifying potential factors during the investigation.

The analysis process

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

• Preliminary analysis: A range of activities to convert data into a format suitable for the analysis of safety factors. This involves the use of techniques to interpret and organize data, including the systematic review of the sequence of events associated with an occurrence. Preliminary analysis may require the use of arguments to develop intermediate findings on a range of topics (e.g., angle of impact, handling pilot, wind speed during approach).

• Safety factors analysis: A structured process to determine which events and conditions were safety factors, with an emphasis on determining the contributing safety factors and safety issues. Further information on safety factors analysis is provided below.

• Risk analysis: A structured process to determine the risk level associated with any verified safety issues. This involves determining the worst feasible scenario that could arise from the safety issue and ranking the consequence and likelihood levels associated with such a scenario. The resulting risk level is classified as "critical," "significant," or "minor."

• Safety action development: A structured process of facilitating safety action by communicating safety issues to relevant organizations. The nature and timeliness of the ATSB communication is determined by the risk level associated with the safety issue.

• Analysis review: A review of the analysis results to identify gaps or weaknesses. This process involves checking the investigation findings for completeness and fairness. It also involves reorganizing the findings into a more coherent format and sequence (if required).

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

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

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

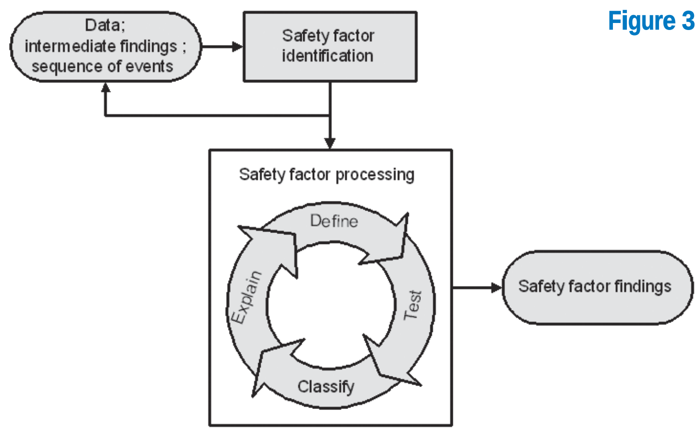
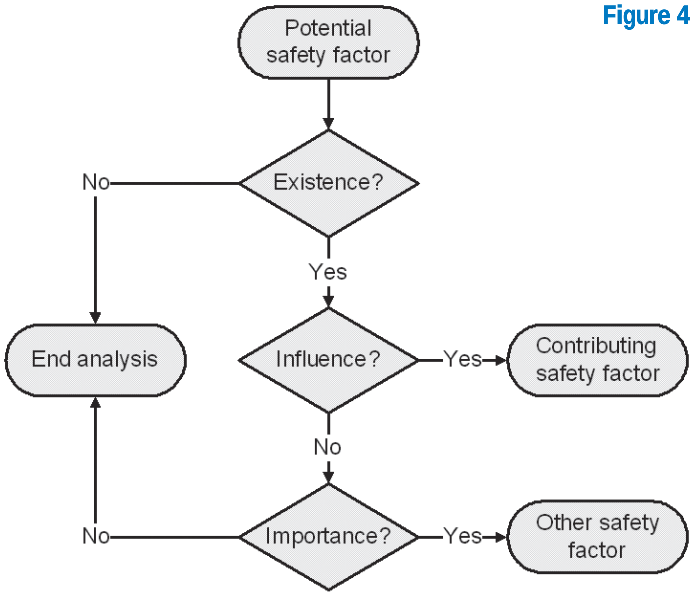


Figure 3

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

The "test" stage of safety factor processing is an area where the ATSB framework has placed substantially more emphasis than other analysis frameworks. For every potential safety factor that is identified as needing further analysis, a series of tests are per-

Figure 4



formed to determine whether the factor can be "verified." These tests include the test for existence, test for influence, and test for importance. An overview of the flow of the testing process is presented in Figure 4.

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

Table 1

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

SIIMS analysis tools

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

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

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

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

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

Evidence table development

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

Basic evidence tables are used to test proposed "other key findings" and proposed intermediate findings. The tables consist of three columns: one for the items of evidence or information that may be relevant to the finding, one for clarifying comments about each item, and one for rating how the item may impact on the finding (i.e., supports, opposes, no effect, or unsure). Based on the information in the three columns, an overall assessment can be made as to whether the proposed finding is supported. A simple example of a basic evidence table is provided in Figure 5. In SIIMS, investigators will also be able to provide links to supporting evidence in

(continued on page 29)

Enhancing the Investigation Of Human Performance Issues

An industry working group is formed to develop better guidance for investigating human performance.

By Dr. Randall J. Mumaw, Aviation Safety, Boeing

(This article was adapted, with permission, from the author's presentation entitled Industry Working Group for Enhancing the Investigation of Human Performance Issues, *presented at the ISASI 2006 seminar held in Cancun, Mexico, September 14-17, which carried the theme "Incidents to Accidents: Breaking the Chain." The full presentation including cited references index is on the ISASI website at www.isasi.org. Dr Mumaw's paper received "special commendation" by the panel selecting the "Best in Seminar" paper. The panel said the paper "represented a great, practical development for investigators…."—Editor)*

Each new or revised summary of accidents and incidents in commercial aviation reemphasizes the significance of the role of humans. Accidents attributed to failures in airplane systems have decreased over the years as those elements have become more reliable. Flight crews, maintenance technicians, air traffic controllers, airplane system designers, and others are identified as significant contributors to an event 60-70% of the time (e.g., see Boeing annual statistical summary as one index: http://www.boeing.com/news/techissues/pdf/statsum.pdf).

In fact, even in cases where there are failures in airplane systems that precede a tragedy, accident investigations have revealed that human performance contributed to degraded system performance. This is not only true in commercial aviation; mishaps in other highly complex sociotechnical systems also reveal the important role of humans in the accident chain. This influence on the accident chain may have links to system design, operational procedures, training, and organizational policies and practices.

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

To understand the current situation better, a small research team at Boeing surveyed major accident investigation agencies to document their approaches to HP issues in accidents and incidents. Below are some key results from this survey, after which is described a proposed response to the current situation—specifically, the establishment of an industry working group to develop better guidance for investigating human performance.

Dr. Randy Mumaw *is a human factors specialist and associate technical fellow in the Aviation Safety Group at Boeing Commercial Airplanes. Dr. Mumaw received his M.S. and Ph.D. in cognitive psychology from the University of Pittsburgh. He has studied human performance and safety in nuclear power plant control room operations, air traffic control, and military and commercial aviation. He is the author of more than 80 technical papers, most of which address human performance and error in complex, high-risk systems.*

Current practice

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

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

Each interview covered a range of topics, including the following:

- The framework used for addressing HP issues.
- Existing guidelines, checklists, and procedures used for investigating HP issues.
- Types of HP expertise available to them.
- How they assign HP specialists to investigations.

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

- HP-related data-gathering techniques.
- HP-related analysis techniques.
- How HP accident data are structured for input to an accident database.
- What gaps have been identified in investigating HP issues.

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

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

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

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

What types of training do agencies provide their investigators on HP issues? Most agencies reported that all investigators receive some HF-related training. For four agencies, the HF training is part of a broader investigation course. Four other agencies expose each investigator to a dedicated HF course (usually a week in length). The remaining four agencies have no HF training that is required of all investigators; instead, a few investigators may get some HF training. So, the overall picture is a mixed bag—some pockets of strong HP expertise and other agencies with little training or in-house expertise.

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

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

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

One potential solution to this apparent dilemma is to get guidance from an outside source. However, when we looked at potential sources—the ICAO HF Digest (ICAO 1993) and several recent books on the topic (Dekker 2002; Strauch 2002)—we found little guidance that could be readily adopted by an investigation agency.

The ICAO document provides guidance at a very high level and focuses on the checklist from the SHELL Model. Strauch's book provides some background knowledge on a number of potentially relevant topics (e.g., computer displays) but little in the way of guidance for conducting an investigation. He does offer some practical guidance for various aspects of field work. The Dekker book focuses on describing inappropriate ways to conduct an investigation but offers little guidance on conducting an investigation.

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

Boeing response

Our data gathering reinforced our beliefs that

- HP expertise exists primarily within the larger investigation agencies and is not readily acquired from a consistent source when it is needed. Those with training both in accident investigation and HP issues are too rare for today's needs.

By limiting our topics to those that can be backed up with data, we hope to avoid the speculative arguments made about what "may have" influenced actions and decisions.

- HP guidance is either insufficiently detailed or is being developed within the agencies that have the most expertise (and it is not formally shared outside of that agency).
- There is no shared framework across agencies for understanding and describing HP issues; the Reason (Swiss cheese) Model has been influential but falls short of creating a unifying approach. Without this shared framework, the findings from individual accidents cannot be easily compiled and analyzed as a set.

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

- Data-collection techniques (e.g., cognitive interview).
- Human performance issues (e.g., spatial disorientation).
- Factors that contribute to human performance problems (e.g., fatigue, stress).
- Analysis techniques (e.g., speech frequency analysis).
- Safety-assessment techniques (e.g., barrier analysis).

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

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

Industry working group

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

- Airplane manufacturers.
- Accident investigation agencies.
- Aviation regulators.
- Those representing the people who may be "blamed" (pilots, ATC, maintenance technicians).
- Airlines.
- Aviation safety organizations.
- Training organizations.

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

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

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

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

As of this writing, the IIWGHF is just ramping up. We plan to deliver a number of guidance modules by mid-2007. After a core set of materials is developed and approved, we will use ISASI to distribute the materials to key industry stakeholders. If these materials achieve a good level of acceptance within the industry (and perhaps within other areas of accident investigation), they will start to shape how investigations are conducted and reports are written. Ideally, we will eventually establish a well-defined set of expectations about the policies and practices of HP investigations. ◆

(Acknowledgments: Many thanks to the following Boeing people who made significant contributions to this project: Simon Lie, Hans-Juergen Hoermann, Richard Kennedy, and Rich Breuhaus.)

Failure Analysis of Composite Structures in Aircraft Accidents

The authors introduce some of the basic concepts involved in analyzing failed composites under a variety of fundamental loading conditions such as tension, compression, bending, impact, and fatigue.

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

(This article was adapted, with permission, from the authors' presentation entitled Failure Analysis of Composite Structures in Aircraft Accidents*, presented at the ISASI 2006 seminar held in Cancun, Mexico, September 11-14, which carried the theme "Incidents to Accidents: Breaking the Chain." The full presentation including cited references index is on the ISASI website at www.isasi.org. This paper received "special commendation" in the seminar's "Best in Seminar" screening by the selection panel. The panel said the paper "helped many investigators to better understand the nature of composite failure in aircraft structures—a growing area of interest within civil and military aviation."—Editor)*

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

Historically reserved for control surfaces and secondary structures, composites are now being employed for primary structures in major aircraft programs. The airframe of the Boeing 787, currently scheduled to enter service in 2008, will be approximately 50% composite structure by weight, with nearly 100% of the skin, entire sections of the fuselage with integral stiffeners, and the wing boxes constructed of composites. This can be compared to the Boeing 777, which entered the market just more than a decade ago with an airframe of 10% composite structure by weight. Powering the B-787 will be the GEnx turbofan engine with fan blades and containment casing made of composites, rather than traditional metals.

The Airbus 380 is scheduled to enter service in the coming year with an airframe that is approximately 25% composite structure by weight. One notable feature of the A380 is an all-composite central wing box. Complementing this transition in the large transport market are the all-composite airframes for very light jets, such as the Adam A700 and parallel advances with military aircraft. The F-22, for example, contains

Historically reserved for control surfaces and secondary structures, composites are now being employed for primary structures in major aircraft programs.

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

Dr. Alfred Pettinger *is a managing engineer with Exponent Failure Analysis Associates. He specializes in the evaluation and design of metal as well as composite aerospace components. Dr. Pettinger has been retained in numerous accident investigations and design reviews for transportation-category aircraft. (Photo not available)*

Figure 1 (the 3 photos above). The ductility of metal structures provides macrostructurally visible information regarding an accident (Wanttaja 1994).

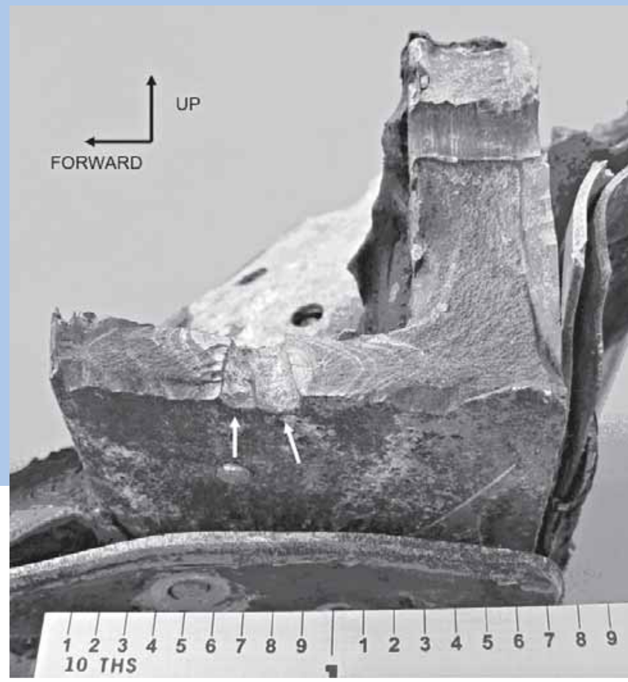


Figure 2. Indications of fatigue cracking in the lower right wing spar cap of the Chalks Ocean Airways Grumman Mallard G73 that crashed during takeoff Dec. 19, 2005. This is an example of using accumulated knowledge and experience with metallic structures to identify potential factors in an accident (NTSB 2005).

approximately 60% composite structure, compared with slightly more than 20% for the F/A-18C/D, which entered production just a decade earlier.

With the increased use of composites in primary structures, accident investigators will likely encounter failed composite structures with increasing frequency in the coming decades, and these structures may be primary structures of significance to the investigation. Why may these composite structures fail? First, we are building composite structures on a scale never before achieved. The B-787 fuselage will be the largest composite pressure vessel ever built. Second, we are building composite structures through relatively new, automated techniques rather than relying on traditional methods of constructing composites by hand (conversely, automation will eliminate some sources of error associated with traditional construction methods). And third, our inspection and maintenance requirements will no longer be driven by fatigue and corrosion performance, as they are for metallic structures, because composites are not as susceptible to these failure mechanisms (accidental subsurface damage and subsequent failure progression will be more important).

These advances, a collective departure from applications, techniques, and methods of the past, may lead to landmark lapses in safety with subsequent "lessons learned" for composites, in the manner that the Comet accidents provided lessons learned regarding stress concentrations and metal fatigue and Aloha Airlines Flight 243 provided lessons learned regarding aging aircraft structures and multiple-site damage. Through more than 80 years of accidents involving metallic aircraft, the community of aircraft accident investigators has developed a considerably mature understanding of failure in metallic structures. This accrued knowledge and experience must be extended to composite structures.

This article is intended to contribute to that effort by introducing some of the basic concepts of failure in composite structures as a result of a variety of loading conditions—tension, compression, bending, impact, and fatigue. The analysis is frequently discussed with respect to corresponding failures in metallic structures. Select failure characteristics are then illustrated through a discussion of the failure of the composite vertical stabilizer of American Airlines Flight 587.

Examination of failed metallic structures

The science and art of analyzing failed metallic structures has matured in part as a result of the analysis of accidents involving metal aircraft. Employing knowledge accrued during this period of time, investigators often rely heavily on their ability to analyze failed structures in an effort to determine the cause and events of an accident. Some investigators, such as M.P. Papadakis, S. Taylor, and B.W. McCormick, have emphasized the role of such analysis as "The bent metal speaks." "The story is written in the wreckage." "You have to learn how to read the bent metal."

This article refers to the evidence contained within the wreckage in two categories—macrostructural evidence and microstructural evidence. Macrostructural evidence refers to the overall deformation of failed structures—a buckled fuselage panel, a twisted propeller blade, a dented leading edge. Figure 1 shows an example of macrostructural evidence, deformation of the spinner, vertical stabilizer, and leading edges.

The value of macrostructural evidence in failed metal structures is enhanced by the fact that typical aircraft metals, such as aluminum, are ductile, which means they undergo significant deformation prior to final failure. Ductility allows for the permanent bending, twisting, and denting of structures, which essentially records evidence of events in the accident. The evidence contained in Figure 1 (deformation of the spinner, vertical stabilizer, and leading edges) immediately identifies impact as a factor in this accident. The evidence also identifies the possible size, shape, and energy associated with the impactor or impactors. According to the NTSB, this aircraft impacted a set of power lines on approach (NTSB 1995).

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

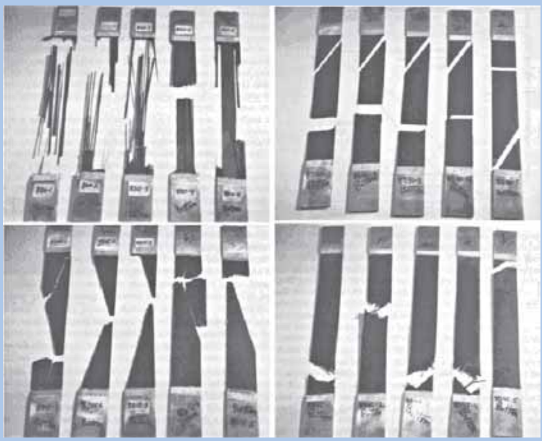


Figure 3. Tension failure in composites. Macroscopically, even simple tension can produce fractures with a wide variety of features. Microscopic analysis becomes important (Ginty and Chamis 1987).

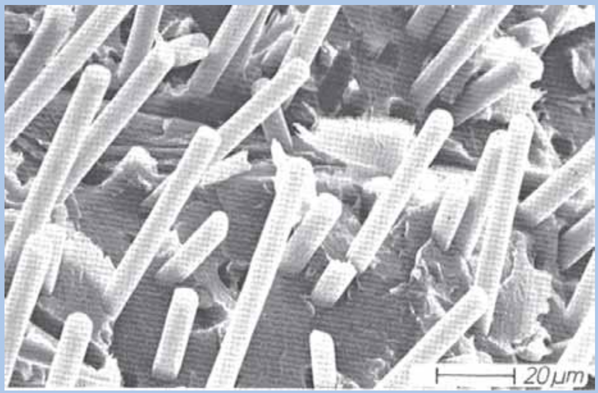


Figure 4. Example of fiber pullout as a result of tensile loads (Friedrich and Karger-Kocsis 1989).

edges away from the explosion, and the stretching and unzipping of panels along rivet lines all indicate the presence of an explosion in an accident.

Typical aircraft composites, however, are not ductile; they are brittle, which means they undergo relatively minor permanent deformation prior to final failure. Without ductility, without permanent deformation, the macrostructural evidence from an accident, such as the examples discussed above, may no longer be available. What evidence would be produced by a GEnx engine, with its composite fan blades, impacting the ground? What evidence would be produced by an explosion inside a B-787 composite fuselage?

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

One example is the recent crash of Chalks Ocean Airways Flight 101 in December 2005 off the coast of Miami, Fla. Initial evidence indicated that the right wing had separated in flight. Within days, the NTSB had identified fatigue damage in metallic structural components in the right wing (Figure 2), with corresponding damage in the structure of the left wing. As shown in Figure 2, an unaided visual inspection of the wing spar cap reveals beach marks, which is evidence widely accepted to be indicative of fatigue failure. As a result of this established analysis, the microstructural evidence, supported by an accrued body of knowledge regarding the interpretation of fracture surfaces in metals, rapidly established the wing spar cap as a critical component to consider in this investigation.

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

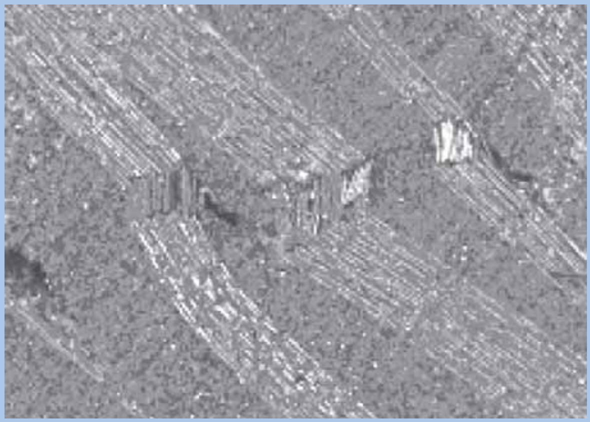
Examination of failed composite structures

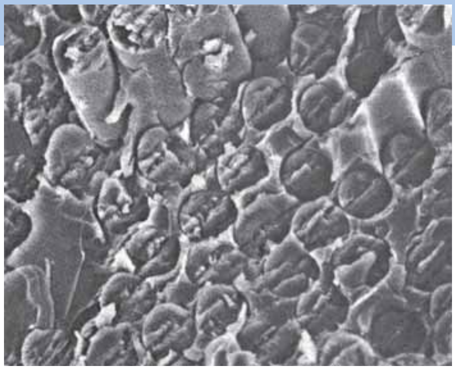
Transitioning from failed metallic structures to failed composite structures requires, in many ways, a new mindset. Although composites are often considered to be materials and are generally classified as engineered materials, composites are actually structures, made of multiple materials. Typical aircraft composites are made of two materials: (1) long fibers that are stiff and strong (typically carbon or glass) and (2) a matrix, essentially hardened plastic glue, that holds the fibers together. The glued fibers are typically assembled layer by layer, called plies. The fibers in each ply typically run parallel to each other or are woven together in the manner of a textile. Ply-wise variations in fiber orientation and other variables often exist in a composite.

In contrast to typical aircraft metals, the physical properties of composites vary from

Transitioning from failed metallic structures to failed composite structures requires, in many ways, a new mindset.

Figure 5. (right) Example of fiber kinking as a result of compressive loads (Bolick et al 2006). Figure 6. (below) Chop marks can be produced on the ends of broken fibers that have buckled and failed under compressive loads (Stumpff 2001).





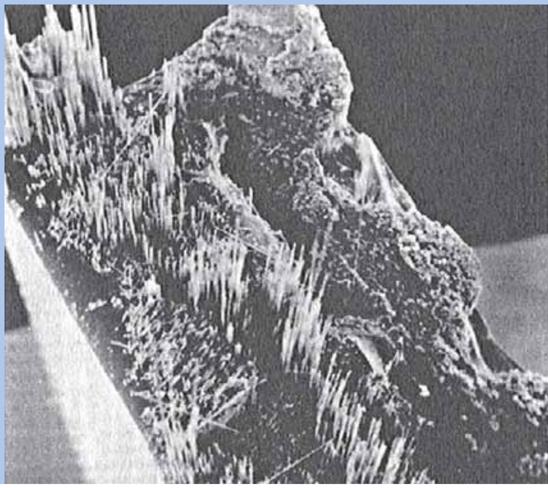


Figure 7. (above) Composite specimen that failed in bending. The relatively rough area of tension failure and the relatively smooth area of compression failure are clearly identifiable (Beaumont and Schultz 1990).

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

Composites have design variables that are not available in metals. Some of these variables are fiber orientation, fiber-to-matrix volume ratio, ply thickness, and ply stacking sequence, among others. With new variables come new opportunities for manufacturing errors or imperfections. Some of these imperfections are fiber waviness, poor adhesion between fibers and matrix, poor adhesion between plies, excessive voids in the matrix, and an improperly cured matrix, among others. Changes in design variables and accumulated imperfections directly affect the failure of a composite.

As an example, consider Figure 3, which shows 20 failed composite specimens. Each specimen was subjected to simple tensile loading. Despite the similarity in loading, the failure in each specimen has a unique appearance. Some of the failed specimens have a shredded appearance with a very rough fracture surface; some of the specimens have a smoother, angular appearance. Some specimens even broke into several pieces, while others broke into only two.

The differences in the appearance of these failures are a result of two primary sources of variation among the specimens. The first source of variation is the intentional variation in design variables among the specimens, such as fiber orientation. The second source of variation is the accumulation of imperfections, as discussed above. The result is that these composites, all of which failed in tension, demonstrate a wide variety of appearances. This is one of the challenges of analyzing failed composites. In many cases, this challenge can be addressed by performing a microscopic analysis of the failure surfaces to identify common features that indicate failure in tension. These features, along with features associated with other loading conditions, are introduced below.

Tension

Tensile fractures of fibrous composites typically exhibit common characteristics that can help identify failure under tensile loads, even in the presence of large variations in the macroscopic appearance. One characteristic is that the fracture surface generally has a rough appearance, as can be seen in the failed specimens in Figure 3.

Figure 4 shows a microscopic view of a fracture surface of a composite that failed under tensile load, with the fibers aligned with the direction of the load. One clear characteristic of the fracture surface is that fractured fibers are sticking out of the fractured matrix, contributing to the rough appearance of the fracture surface. Called fiber pullout, this characteristic is a typical indication of tension failure in a composite. Fiber pullout is the result of a fiber breaking and being extracted from the matrix. Close inspection of Figure 4 reveals, in addition to pulled-out fibers, holes in the matrix that were created by other pulled-out fibers.

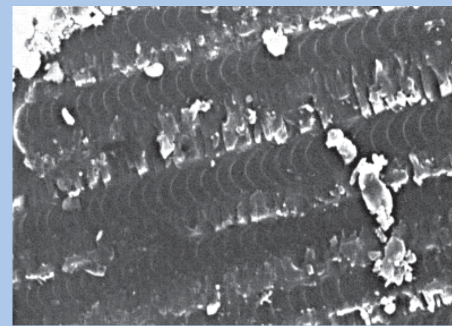
In some cases of tensile failure, the fibers do not completely fracture and only the matrix completely fractures. The fibers then span the matrix fracture in a phenomenon called fiber bridging. In either case, the investigator can use the pulled-out fibers to identify tensile loading, and in the case of stacked laminates, identify those plies that have been loaded in tension. The length of the pulled-out fibers can indicate important conditions present in the composite at the time of fracture, such as temperature, exposure to moisture, and rate of loading.

As long, thin members, the fibers are designed to carry tensile loads, and composites are nominally designed such that the fibers run parallel to the tensile loads. However, in the common case of composites with ply-wise variations in fiber orientation, tension loads do not run parallel to the fibers, and failure can occur in the matrix. Common matrix failures associated with such loading conditions are tension failures between fibers, particularly at the fiber-matrix interface, and shear failures in the matrix-rich region between plies, typically associated with rough features on the fracture surface called hackles. Such inter-ply shear failures can also be produced under compression.

Compression

Under compression, the fibers are structurally less effective than they are in tension. One common characteristic of the compres-

Figure 8. (right) Composite wing that reportedly failed in bending. The relatively rough area of tension failure with significant fiber pullout, and the relatively smooth area of compression failure are clearly identifiable (Stumpff 2001).



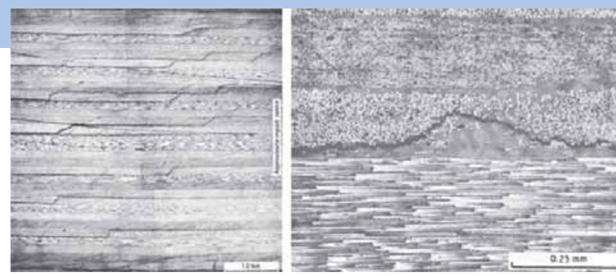


Figure 9. (right) Example of composite failure involving delamination (Bascom and Gweon 1989). Figure 10. (right above) Striations at the interface between fibers and matrix (Stumpff 2001).

sive failure of fibrous composites is the formation of kink bands, as shown in Figure 5. Kink bands are a result of structural instability, much like a person standing on and eventually crushing a soda can. The fibers buckle as the compressive load approaches a critical level, which is primarily a function of material and geometric factors.

Fiber buckling can also be identified by examination of the fiber ends. As shown in Figure 6, chop marks indicate fibers that have buckled and have bent to failure. The chop marks coincide with the neutral axis of the fiber in bending, separating the tension side from the compression side of the fiber.

Often associated with kink bands is matrix splitting, which can be seen in Figure 5 as gaps in the matrix. Matrix splitting occurs at weak points in the matrix or at areas of high stress concentration, such as at the fiber-matrix interface and the interface between plies. Matrix splitting at the interface between plies is referred to as delamination and is discussed further in the paragraphs below regarding impact.

Bending

The difference between tensile and compressive fracture surfaces is readily demonstrated in composites that have failed in bending, such as the specimen shown in Figure 7. Divided by a neutral bending axis, one part of the fracture surface contains pulled-out fibers and the other part is relatively flat. This is a result of the fact that, in bending, one part of the cross-section is in tension and the other part is in compression.

The characteristics of bending failure can readily translate to a macroscopic level. Figure 8 shows a composite aircraft wing that has reportedly failed in bending (Stumpff 2001). The bottom surface of the wing, which was subjected to tension in bending, has a very fibrous texture relative to the top side of the wing, which was subjected to compression in bending.

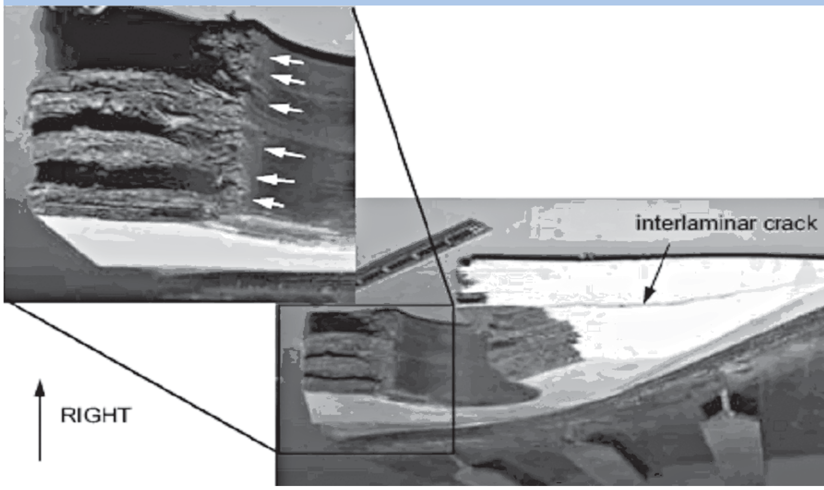
Impact

As discussed above, ductile metal structures undergo relatively high levels of permanent deformation prior to final failure, and this deformation provides information regarding the events preceding structural failure. The metallic aircraft discussed above and shown in Figure 1 clearly indicates impact by a foreign object. Since composites, on the other hand, exhibit relatively little permanent deformation prior to final failure, such impact evidence may not be as readily observed in a composite aircraft.

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

One common type of sub-surface damage from impact is delamination. A delamination is a split between plies in a composite. The split can propagate along the inter-

Impact loading can cause damage to a composite without any visible evidence on the surface.



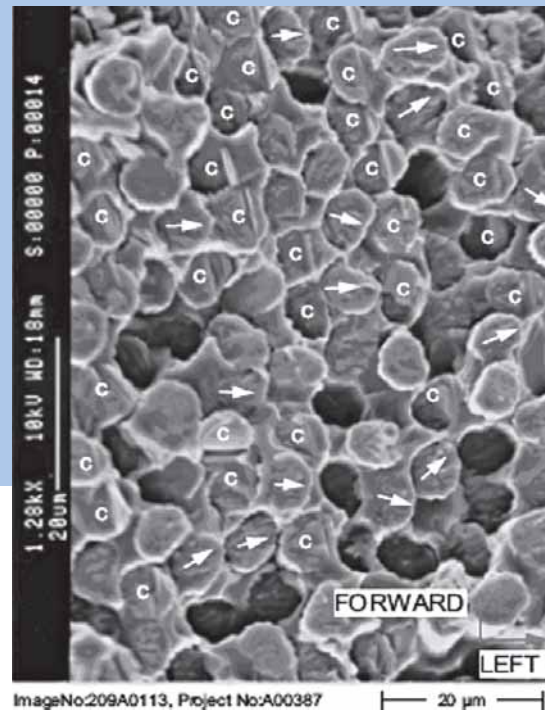


Figure 11. (above) Along with several other fractures, the fractures of the right aft lug were rough, consistent with tensile loading (NTSB 2002). Figure 12. (right) Fractures in multiple locations exhibited chop marks (marked with a "c") on the ends of fractured fibers, consistent with compressive loading and buckling of fibers (NTSB 2002).

face at which neighboring plies were joined during manufacturing or it can propagate along the fiber-matrix interface. Figure 9 shows a couple views of the cross-section of a composite plate after impact.

As indicated in the figures, the impact caused extensive delamination among multiple plies. Such damage can dramatically degrade the load-bearing capability of the composite even though the fibers may remain intact. Moreover, the damage, if unnoticed, can continue to propagate upon further loading of the composite.

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

Fatigue

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

Fatigue failure in metals can be readily identified, in many cases, by an unassisted visual inspection. A typical fatigue failure in metals will produce a fracture surface with beach marks, an example of which was already discussed and shown in Figure 2. Fatigue fracture surfaces in composites, on the other hand, do not typically have visible beach marks. In fact, fatigue fractures in composites typically do not appear any different from a corresponding overload failure.

While fatigue fractures lack macroscopic evidence, some evidence may be identified microscopically. Figure 10 shows striations at the fiber-matrix interface of a composite.

One striation typically corresponds to one load cycle. Although these striations indicate fatigue failure, they can be difficult to find. Areas containing striations are typically small in size, few in number, and may be dispersed over multiple locations in the composite. In addition, the striations are often identifiable only under high magnification and oblique lighting (Figure 10 was captured under a magnification of 2000x). In short, the identification of fatigue failure in composites can be very challenging. One macroscopic feature that can provide evidence of fatigue is abrasion between mating fracture surfaces. With repeated loading, the growing fracture surfaces may rub against each other and leave abrasive marks on the ends of broken fibers and in the matrix.

American Airlines Flight 587

Soon to be eclipsed by the center wing box of the A380 and the fuselage of the B-787, the vertical stabilizer of the Airbus A300-600 is one of the largest composite primary structural elements in commercial aviation. Although the structure was originally designed with metallic materials, the metallic design was eventually replaced by a composite design employing carbon fibers in an epoxy matrix. Since that time, the composite stabilizer has accumulated more than 20 years of service. In November 2001, American Airlines Flight 587's composite stabilizer failed. As a potential harbinger of the failures discussed in this article, the failure of this composite structure is discussed in the paragraphs below. The discussion frequently refers to the features of failed composites discussed above.

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

As discussed above, tensile failures in composites generally produce rough fracture surfaces. Figure 11 shows the fracture surface

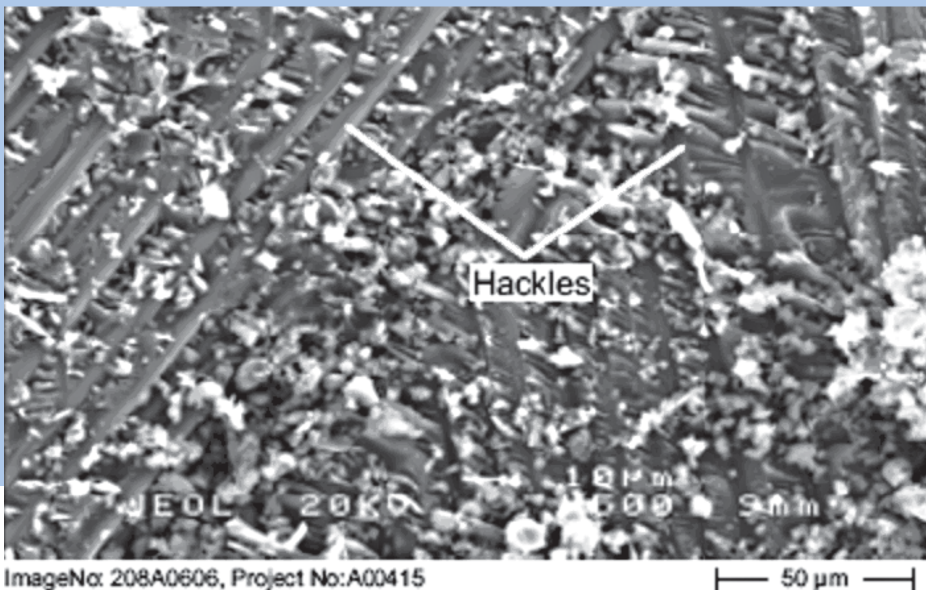


Figure 13. Interlaminar fractures in multiple locations exhibited hackles, consistent with failure in shear (NTSB 2002).

of the right aft composite lug. Similar rough fracture surfaces were found on the other two lugs on the right side of the stabilizer. As a result, the NTSB concluded that the lugs on the right side of the stabilizer failed due to overstress under tensile loading.

According to the analysis by the NTSB, after the lugs on the right side failed, the damaged stabilizer deflected from right to left, loading the lugs on the left side of the stabilizer in bending. In bending, tension developed on the inboard side of the lugs and compression developed on the outboard side of the lugs. The NTSB identified evidence consistent with tension failure on the inboard side and compression failure on the outboard side of the lugs on the left side of the stabilizer. This is consistent with failure in bending.

As discussed above, when fibers are subjected to compressive loads, they can buckle and the fracture surface on the end of a failed fiber may indicate chop marks. The left aft, left center, and left forward lugs of the failed stabilizer each contained fractured fibers with chop marks, as shown in Figure 12. Also found on the left aft lug were hackles associated with shear failure in the matrix-rich region between plies (Figure 13). Hackles were found on the left forward lug as well.

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

Looking ahead

With the impending generation of composite aircraft, the analysis of failed composite structures will be of significance to aircraft accident investigators. The introduction of composites presents new variables, such as fiber orientation, geometric variations among plies, and curing processes, which in turn present new failure modes, such as fiber pullout, fiber kinking, and delamination. Contributing to these relatively new concepts is the prevalence of brittle failure in composites, as opposed to ductile failure in metals, and the potential reduction in macrostructural evidence. Consequently, the analysis of failed composite structures cannot rely solely upon the body of accrued knowledge and experience related to failed metallic structures.

This article has introduced some of the basic concepts involved with analyzing failed composites under a variety of fundamental loading conditions. Fractographic details have been presented and subsequently illustrated by a brief discussion of the analysis by the NTSB of the failed composite vertical stabilizer from American Airlines Flight 587. With a broad range of associated design variables, the investigation of composite structural failures requires particular expertise. It is likely that, given such complexity, future investigations involving composite primary structures will require significant input from accident investigators with expertise in the analysis of failed composite structures, as was required in the investigation of Flight 587. ◆

With a broad range of associated design variables, the investigation of composite structural failures requires particular expertise.

Singapore AAIB Hosts ISASI 2007

ISASI 2007, the Society's 38th annual international seminar, will be held in Singapore from Monday, August 27 to Thursday, August 30. Hosted by the Air Accident Investigation Bureau of Singapore (AAIB), the seminar will carry the theme "International Cooperation: From Investigation Site to ICAO."

Chan Wing Keong, seminar chairman, says that the seminar will follow the established format of past seminars, with 1 day devoted to tutorial workshops and 3 days of technical paper presentations. The technical program will address current safety and investigation issues, including recent air safety occurrences and investigations, with particular emphasis on international cooperation efforts demonstrated during the various investigative endeavors.

The issued "Call for Papers" seeks abstracts by March 31 with final electronic submission in early July. Members of the technical papers selection committee include Chan Wing Keong (AAIB Singapore, chair), Michael Toft (AAIB Singapore), Caj Frostell, Jim Stewart, Keith McGuire, Ken Smart, Capt. Mohammed Aziz, Dr. Rob Lee, and Y.P. Tsang (Hong Kong CAD).

Tutorials to be presented are aftermath of a sea crash and investigation in a litigious environment. The tutorial day will be held at the Singapore Aviation Academy. Arrangements have been made to also provide tutorial participants a tour of the Academy's excellent facilities, which received the 1996 Flight International Aerospace Industry Award for training. In addition, the Academy was presented the prestigious Edward Warner Award by the ICAO Council in 2000.

The venue for the seminar will be the Swissôtel The Stamford, Singapore, in a city that is billed as being dynamic and rich in contrast and color where one finds a harmonious blend of culture, cuisine, arts, and architecture. A bridge between the East and the West for centuries, Singapore, located in the heart of fascinating Southeast Asia, continues to embrace tradition and modernity today. Singapore is slightly more than 3.5 times the size of Washington, D.C. Its climate is tropical. The wetter northeast monsoon season is from December to March, and the drier southwest monsoon season is from June to September. Singapore is also considered the Asia Pacific air hub, as it is connected to more than 180 cities in 57 countries by more than 80 airlines with over 4,100 weekly flights. Singapore will be a convenient gateway to the many interesting tourist destinations in Southeast Asia, for example, Angkor Wat in Cambodia, Bali and Borobudur in Indonesia, Langkawi and Malacca in Malaysia, and Cebu in the Philippines.

Registration for ISASI 2007 is expected to open by March. Final details are now being completed. It is expected that registration fees will be between US$400-500 and tutorial fees about US$80-100. Delegate registration will include breakfasts, lunches, and morning/afternoon teas on the 3 days of the seminar, as well as the off-site visit/dinner and the awards banquet. A CD-ROM of the technical papers will also be provided to the delegates.

The social program and the optional tour scheduled for Friday are also being finalized and will be reported in the next issue. ISASI 2007 went on line at press time. It can be accessed at www.isasi07.org. ◆

International Council Meets in Cancun

The Society's International Council met in Cancun on Sept. 10, 2006, in conjunction with its 37th annual international seminar. Among its actions was acceptance of a certified copy of the Society election ballot results (see page 24 of the October/December *Forum*,) selection of the venues for ISASI annual seminars through 2010, adoption of a new human factors effort (see page 3 and 14), review of ISASI By-Laws revision, acceptance of a comprehensive review of Reachout Program history and current status. Routine reports of Executive members, societies, and working groups and committees were also received.

Representatives of the Singapore AAIB discussed preparations for ISASI 2007. The Canadian Society's bid to host ISASI 2008 in Halifax, Nova Scotia, Canada, was accepted as was Japan's Aircraft and Railway Accidents Investigation Commission bid to host ISASI 2010 in Sapporo, Japan. The ISASI Florida Regional Chapter provided an update on its previously accepted bid to host ISASI 2009 in Orlando, Fla.

Jim Stewart, chairman of the Reachout Program, provided a comprehensive review of the Program's history and its current status. He reported that there are now five instructors, the original "core" of himself, Caj Frostell, and Ron Schleede, plus the recent addition of Steve Corrie and Vic Gerden. Stewart and Corrie are now "ICAO certified" SMS instructors.

Stewart said the goal of Reachout remains getting accident investigation expertise and the Society's affiliation to parts of the world that are *not* affected by ISASI's annual seminar. The Program length is tailored and has evolved into a variable length—from 2 days to 2 weeks. ICAO is committed to the Reachout process. Program successes have been well noted on pages of the *ISASI Forum*. He stated that Reachout has, in general, exceeded initial expectations and urged all the councillors and international officers to participate.

In addition to a detailed roundup of Society activities since the last meeting, President Frank Del Gandio set the next International Council meeting for May 4, 2007, in the Washington, D.C., area to be

Call for Papers—ISASI 2007

The International Society of Air Safety Investigators Presents its 38th International Seminar Aug. 27-30, 2007
Swissôtel The Stamford, Singapore

Theme: *"International Cooperation: From Investigation Site to ICAO"*

The Technical Committee is looking for 20-30 papers on current investigation experience, techniques, and lessons learned with particular emphasis on international investigation cooperation, coordination, and challenges.

If you wish to offer a presentation in line with the seminar's theme, please provide a brief abstract (approximately 200 words) plus personal details by **March 31, 2007**. *Please indicate in your abstract the key points you wish the audience to take away with them from your presentation.*

You are welcome to indicate your interest before you provide the abstract.

Selected papers should be provided in electronic format no later than **July 5, 2007**. Please note that PowerPoint presentations are not acceptable for publication in seminar *Proceedings* or seminar CDs. Submittal of an abstract implies an agreement that the author authorizes publication of the complete paper in the seminar *Proceedings* and the *ISASI Forum*.

Selected papers will be produced on a CD-ROM before the seminar commences. Please note that although a presenter may need to withdraw at short notice from a scheduled presentation, the written material will remain part of the CD-ROM if already produced.

Please send indication of interest and abstract to

Chan Wing Keong
Technical Program Chair
E-mail: chan_wing_keong@isasi07.org
Telephone: (65) 6541-2800

or mail to

Air Accident Investigation
Bureau of Singapore
Changi Airport Post Office
P.O. Box 1005
Singapore 918155
Republic of Singapore

held in conjunction with the May 3 MARC dinner and meeting.

Treasurer Tom McCarthy reported a current bank balance of $63,443.65 in the primary CAP account. The ISASI Rudy Kapustin Memorial account has a balance of $4,308.00. He also reported on the final proceeds of ISASI seminars from 1997 through 2005, which can be found on the appropriate section of the ISASI website. Mike Hynes, audit chair, reported that his review of accounting data for the years 2004 and 2005, including an on-site review of ISASI records in 2006, showed that the data reviewed reflected proper accounting practices and successful management of funds.

The full minutes of the September 10 meeting are available to the membership on the ISASI website: www.isasi.org. ◆

Kapustin Scholarship Issues Application Call

The ISASI Rudolf Kapustin Memorial Fund has issued its call for scholarship applications to universities and colleges whose students are eligible to participate in the program, according to the Fund's administrators, ISASI Executive Advisor Richard Stone and ISASI Vice-President Ron Schleede. The deadline for applications is April 3, 2007.

The purpose of the Fund is to encourage and assist college-level students interested in the field of aviation safety and aircraft occurrence investigation. Applicants enrolled as full-time students in a recognized (note ISASI recognized) education program, which includes courses in aircraft engineering and/or operations, aviation psychology, aviation safety and/or aircraft occurrence investigation, etc., with major or minor subjects that focus on aviation safety/investigation are eligible for the scholarship. A student who has received the annual ISASI Rudolf Kapustin Memorial Scholarship will not be eligible to apply for it again. This year the seminar will be held at the Swissotel The Stamford, Singapore, **August 27–31.**

Continued funding for the Memorial Fund is through donations, which in the United States are tax-deductible. An award of $1,500 is made to each student who wins the competitive writing requirement, meets the application requirements, and who registers to attend the ISASI annual seminar. The award will be used to cover costs for the seminar registration fees, travel, and lodging/meals expenses. Any expenses above and beyond the amount of the award will be covered by the recipient. In addition, the following are offered to the winner(s) of the scholarship.

- A 1-year membership to ISASI.
- The Southern California Safety Institute (SCSI) offers tuition-free attendance to ANY regularly scheduled SCSI course to the winner of the ISASI Scholarship. This includes the 2-week aircraft accident investigator course or any other investigation courses. Travel to/from the course and accommodations are not included. More information can be found at http://www.scsi-inc.com/.
- The Transportation Safety Institute offers a tuition-free course for the winner of the scholarship. Travel to/from the course and accommodations are not included. More information is available

at http://www.tsi.dot.gov/.

Last year, two awards were presented. They went to Leonardo Ferrero, Politeenico di Torino, Italy, and Sheena D. McCune, Embry-Riddle Aeronautical University, Florida, USA.

The Fund is administered by an appointed committee and oversight of expenditures is done by the ISASI treasurer. The committee ensures that the education program is at an ISASI-recognized school and applicable to the aims of the Society, assesses the applications, and determines the most suitable candidate(s). Donors and recipients will be advised if donations are made in honor of a particular individual.

Students who wish to apply for the scholarship may acquire the application form and other information at the ISASI website: www.isasi.org. Students may also request applications by e-mail to isasi@erols.com. The ISASI office telephone number is 1-703-430-9668.

Application requirements

- Applicants must be enrolled as full-time students in a recognized (note ISASI recognized) education program, which includes courses in aircraft engineering and/or operations, aviation psychology, aviation safety and/or aircraft occurrence investigation, etc., with major or minor subjects that focus on aviation safety/investigation are eligible for the scholarship.
- The student is to submit a 1,000 (+/- 10 percent) word paper in English addressing "The Challenges For Air Safety Investigators."
- The paper is to be the student's own work and must be countersigned by the student's tutor/academic supervisor as authentic, original work.
- The papers will be judged on their content, original thinking, logic, and clarity of expression.
- The student must complete the application form and submit it to ISASI with the paper by April 3, 2007.
- Completed applications should be forwarded to ISASI, 107 Holly Ave., Suite 11, Sterling, VA 20164-5405 USA. E-mail address: isasi@erols.com; Telephone: 1-703-430-9668.
- The Judges' decision is final. ◆

Lederer Award Nominations Sought

The ISASI Awards Committee is seeking nominations for the 2007 Jerome F. Lederer Award. For consideration this year, nominations must be received by the end of May, noted Committee chairman, Gale Braden

He added that "the purpose of the Jerome F. Lederer Award is to recognize outstanding contributions to technical excellence in accident investigation. The Award is presented each year during our annual seminar to a recipient who is recognized for positive advancements in the art and science of air safety investigation."

The nomination process allows any member of ISASI to submit a nomination. The nominee may be an individual, a group of individuals, or an organization. The nominee is not required to be an ISASI member. The nomination may be for a single event, a series of events, or a lifetime of achievement. The ISASI Awards Committee considers such traits as duration and persistence, standing among peers, manner and techniques of operating, and of course achievements. Once nominated, a nominee is considered for the next 3 years and then dropped. After an intervening year, the candidate may be nominated for another 3-year period. **The nomination letter for the Lederer Award should be limited to a single page.**

This award is one of the most significant honors an accident investigator can receive; therefore, considerable care is given in determining the recipient. ISASI members should thoughtfully review their association with professional investigators, and submit a nomination when they identify someone who has been outstanding in increasing the technical quality of accident investigation.

Nominations should be mailed or e-mailed to the ISASI office at 107 Holly Ave., Suite 11, Sterling, VA 20164-5405 USA. E-mail address: isasi@erols.com; Telephone: 1-703-430-9668.

Nomination may also be sent directly to the Awards Committee Chairman, Gale Braden at 13805 Edmond Gardens Drive, Edmond, OK 73013-7064 USA; e-mail address, alebraden@cox.net. Home phone: 1-405-359-9007, cell: 1-405-517-5665. ◆

In Memorium

Samuel E. Brodie (MO22504), Bakersfield, CA, USA

George D. Butler (Life Member 2831), April 10, 2006, Sun City, FL, USA

Capt. Harold R. Miller (Life Member 0169), July 2006, Dallas, TX, USA

Frank T. Taylor (Life Member 2513), August 2006, Ellicott City, MD, USA

Frances M. Wokes (AO4025), Nov. 11, 2006, Winnipeg, Manitoba

Reachout Program Continues Winning Ways

The ISASI Reachout Program that began in May 2001 with the goal of getting accident investigation expertise, as well as the ISASI name, to parts of the world that are *not* affected by the Society's annual seminars ended its sixth year with continued success in its final two training workshops, held in Larnaca, Cyprus, and Jeddah, Saudi Arabia, according to reports filed by the two lead ISASI trainers, Ron Schleede and Caj Frostell. Other recent successes were recorded in India; Sri Lanka; Pakistan; China; and Helsinki, Finland (for the Nordic countries).

Schleede reported that the Air Accident and Incident Investigation Board (AAIIB) of Cyprus hosted the 17th ISASI Reachout Workshop, held on May 29-June 9. It was organized under the leadership of AAIIB Chairman Costas *(continued on page 28)*

Airliner Accident Statistics 2006

(Reprinted from Airliner Accident Statistics 2006, Jan. 1, 2007, with permission of Harro Ranter, Aviation Safety Network; Copyright 1996-2007. Source of data is regulatory transportation safety boards, including ICAO, insurance companies, and regional news media. The full document is available on the ASN website, which can be accessed at http://www.aviation-safety.net/pubs.—Editor)

The year 2006 in historical perspective

From a historical perspective, 2006 was an average year. Although the number of fatal accidents (27) was significantly lower than the 10-year average (36), the number of fatalities was almost equal to the 1996-2005 10-year average.

- The 2006 death toll of 888 was far below the 1986-2005 average death toll of 1,088 casualties.
- The 2006 death toll of 888 was well below the 1996-2005 average death toll of 1,005 casualties.
- The 2006 number of occupants involved in fatal airliner accidents of 1,156 was lower than the 1996-2005 average of 1,379.
- The 2006 fatality rate (percentage of occupants killed in fatal airliner accidents) of 77% was slightly lower than the 1996-2005 average of 79%.
- The 2006 number of 27 fatal airliner accidents was far below the 1986-2005 average number of fatal airliner accidents of 43.2 per year.
- The 2006 number of 27 fatal airliner accidents was far below the 1996-2005 average number of fatal airliner accidents of 36.3 per year.
- The 2006 number of accidents resulting in 100 or more fatalities was high: 4, which is the ninth highest number in aviation history.
- The 2006 number of 9 fatal jet airliner accidents was below the 1976-2005 average of 15.3 accidents per year.
- The 2006 number of 18 fatal prop airliner accidents was lower than the 1976-2005 average of 23.3 accidents per year.
- The 2006 number of 0 fatal piston airliner accident was far below the 1976-2005 average of 8.5 accidents.
- The 2006 number of 0 fatal piston airliner accident was below the 1996-2005 average of 2.9 accidents.

Statistical summary regarding fatal multiengine airliner accidents

The year 2006 recorded 27 fatal airliner hull-loss accidents, causing 888 fatalities and 4 fatalities on the ground. Last year recorded the first Boeing 737NG written off in a fatal accident. Around 1,700 Boeing 737-600, -700, -800 and -900 series have been built since 1997. Below, statistics shown in the following order: Date, Aircraft Type, Operator, Location, Fatalities.

1. February 5, Shorts 360, Air Cargo Carriers, near Watertown, 3
2. February 8, Swearingen Metro II, TriCoastal Air, near Paris, 1
3. March 18, Beechcraft C.99, Ameriflight, near Butte, 2
4. March 31, Let 410, TEAM, near Saquarema, 19
5. April 16, Fokker F-27, TAM, Guayaramerín, 1
6. April 24, Antonov 32, U.S. Department of State, Lashkar Gah, 2+3
7. April 27, Convair CV-580, LAC-SkyCongo, Amisi, 8
8. May 3, Airbus A320, Armavia, off Adler/Sochi, 113
9. May 14, Convair CV-580, Saskatchewan gov., near La Ronge, 1
10. May 23, DHC-6 Twin Otter, Air São Tomé, off São Tomé Island, 4
11. June 21, DHC-6 Twin Otter, Yeti Airlines, near Jumla, 9
12. July 7, Antonov 12, Mango Airlines, near Sake, 6
13. July 9, Airbus A310, S7 Airlines, Irkutsk, 125
14. July 10, Fokker F-27, PIA, near Multan, 45
15. July 29, DHC-6 Twin Otter, Quantum Leap Skydiving, Sullivan, 6
16. August 3, Antonov 28, TRACEP, near Bukavu, 17
17. August 4, Embraer 110 Bandeirante, AirNow, near Bennington, 1
18. August 13, Lockheed L-100, Hercules Air, Algérie near Piacenza, 3
19. August 22, Tupolev 154, Pulkovo near Donetsk, 170
20. August 27, Canadair CRJ100ER, Comair, Lexington, 49
21. September 1, Tupolev 154, Iran Air Tours, Mashad, 28
22. September 29, Boeing 737-800, GOL, near Peixoto Azevedo, 154
23. October 10, BAe 146-200, Atlantic Airways, Stord, 4
24. October 26, CASA 212 Aviocar, Kustbevakning, Falsterbokanalen, 4
25. October 29, Boeing 737-200, ADC Airlines, Abuja, 96+1
26. November 17, DHC-6 Twin Otter, Trigana Air Service, Puncak Jaya, 12
27. November 18, Boeing 727, Aerosucre, Colombia, near Leticia 5

Total Fatalities 888+4

Other fatal occurrences

One occurrence resulted in a ground casualty, without any fatal injuries to the occupants of the airplane. This accident has not been included in the analysis.

Date, Aircraft Type, Operator, Location, Fatalities
1. November 9, Let 410, Goma Air, Walikale, 0+12. December 8, Boeing 737-700, Southwest Airlines, Chicago, IL, 0+1

Number of fatal airliner accidents per country [where the accident happened] 2006 (2005, 2004, 2003, 2002 in parentheses)

In 2006, the United States suffered the highest number of fatal airliner accidents: six. Despite the measures taken by the Congolese Ministry of Transport in 2005, three aircraft still crashed in the Democratic Republic of Congo. Having suffered two serious accidents in 2005 and another one in 2006, Nigerian authorities continued taking steps to make aviation safer. A new civil aviation act was signed into law. The new law seeks to establish aviation safeguards, enforce safety guidelines, improve security checks, prescribe ministerial powers during emergencies, define offenses that endanger safety, and also enact penalties for violation. Almost immediately four airlines had their air operator certificates (AOC) suspended pending recertification.

Afghanistan 1 (2 0 0 0)
Algeria (0 1 1 0)
Argentina (0 0 1 0)
Australia (1 0 0 0)
Azerbaijan (1 1 0 0)
Benin (0 0 1 0)
Bolivia 1
Brazil 2 (0 2 0 2)
Canada 1 (0 1 1 0 1)
Central African Rep. (0 0 0 1)
China (0 2 0 1)
Colombia 1 (1 1 1 3)
Comoros (0 0 0 1)
Congo (Brazzaville) (1 0 0 0)
Congo (Dem. Rep.) 3 (4 0 0 0)
Djibouti (0 0 0 1)
East Timor (0 0 1 0)
Egypt (0 1 0 0)
Equatorial Guinea (1 0 0 0)
Estonia (0 0 1 0)
France—incl. overseas (1 0 1 0)
Gabon (0 1 1 0)
Germany (0 0 0 1*)
Greece (1 0 0 0)
Guyana (0 0 1 0)
Haiti (0 0 1 0)
Indonesia 1 (2 1 1 2)
Iran 1 (1 0 0 2)
Italy 1 (3 0 0 0)
Kenya (0 1 2 1)
Liberia (0 0 0 1)
Luxembourg (0 0 0 1)
Mexico (0 0 0 1)
Morocco (0 0 0 1)
Nepal 1 (0 1 0 2)
New Zealand (1 0 1 0)
Nigeria 1 (2 0 0 2)
Norway 1
Pakistan 1
Papua New Guinea (1 1 0 0)
Peru (1 0 1 0)
Philippines (0 0 0 1)
Romania (1 0 0 0)
Russia 2 (1 1 1 2)
Sao Tomé et Principe 1
Spain (0 0 0 2)
South Africa (0 0 0 1)
South Korea (0 0 0 1)
Sudan (3 3 2 0)
Sweden 1
Taiwan (0 0 0 1)
Tanzania (1 0 0 0)
Tunisia (0 0 0 1)
Turkey (0 0 2 0
Uganda (1 0 0 0)
Ukraine 1
United Arab Emirates (0 1 0 0)
USA 6 (2 4 3 3)
Uzbekistan (0 1 0 0)
Venezuela (1 1 1 0)
Atlantic Ocean (0 1 0 0)
Pacific Ocean (0 0 0 1)
Total 27 (35 26 25 37)
*) collision

Number of fatal airliner accidents per region 2006 (2005, 2004 2003, 2002, 5-yr avg, 10-yr avg in parentheses)

The moving 10-year average trends show a decrease in the average number of fatal accidents for all regions. All regions have recorded a steadily decreasing accident rate over the past 7 years, except for Africa. In 2006, Africa was again the most unsafe continent: 18.5% of all fatal airliner accidents happened in Africa, while the continent only accounts for approximately 3% of all world aircraft departures.

Africa 5 (13 7 7 10 8 7.4)
Asia 5 (6 7 2 10 5.8 8.3)
Australia 0 (3 1 1 0 1 1.2)
Central America 0 (0 1 1 0 0.6 1.2)
Europe 6 (7 1 5 7 5.8 6.5)
North America 7 (3 5 4 4 4.2 5.9)
South America 4 (3 4 5 5 4.6 5)
Int'l waters 0 (0 0 0 1 0.6 0.8)
Total 27, 35, 26, 25, 37, 30.6, 36.3

Flight nature [number of fatal airliner accidents per flight nature] 2006 (2005, 2004, 2003, 2002, 5-yr avg, 10-yr avg in parentheses)

Eleven fatal passenger flight accidents in 2004 was an all-time low. After a brief spike in 2005, the number of accidents in 2006 decreased to 15, which is below the 5-year average of 17 accidents. Where in 2004 cargo planes were reason for concern, 2006 showed a continuing decrease in cargo plane crashes to 6.

Scheduled passenger 11 (14 8 8 13 10.4 13.8)
Non-scheduled passenger 3 (5 3 5 4 4.8 5,8)
Passenger 2) 1 (2 0 0 4 1.8 1.3)
Cargo 6 (8 13 7 9 8,4 10,4)
Ferry/positioning 1 (0 1 2 5 1.6 1.7)
Training 2 (1 0 0 0 0 0.6 0.5)
Other 3) 3 (2 1 3 2 2.2 1.9)
Unknown 3 (1 0 0 0.8 0.9)
Total 27, 35, 27, 25, 37, 30.6, 36, 3

Flight phase: Number of fatal airliner accidents per flight phase 2006 (2005, 2004, 2003, 2002, 5-yr avg, 10-yr avg in parentheses)

The number of approach and landing accidents decreased to nine. As the September 1 accident involving an Iranian Tupolev 154 showed, the survival rate of approach and landing accidents is relatively high. The airplane swerved off the runway in landing and caught fire. Of the 148 occupants, 120 survived the crash. Statistics show that in the last 10 years 33% of all occupants survived approach and landing accidents. Most accidents happened in the enroute phase of flight; 14 accidents was higher than the 5- and 10-year averages.

Standing (STD) 0 (0 0 0 0 0.2 0.1)
Takeoff (TOF) 1 (1 2 2 2 2.2 2.3)
Initial climb (ICL) 3 (5 2 4 0 2.4 3)
Enroute (ENR) 14 (14 8 9 14 10.8 11.9)
Maneuvering (MNV) 0 (1 0 2 2 1 1.1)
Approach (APR) 4 (8 9 8 17 11 13.2)
Landing (LDG) 5 (4 3 0 2 2 3.5)
Unknown (UNK) 0 (2 2 0 0 1 1.2)
Total 27, 35, 26, 25, 37, 30.6, 36.3

Average survival percentage per flight phase: Phase 2006, 10-yr avg

Standing (STD)
Takeoff (TOF) 2%, 50.1%
Initial climb (ICL) 7%, 14.5%
Enroute (ENR) 0.5%, 9.2%
Maneuvering (MNV) 0%, 31.4%
Approach (APR) 0%, 17.7%
Landing (LDG) 61.3% 82%
Total 23.2%, 25.9%

Accident classification: Type 2006 (2005, 2004, 2003, 2002, 5-yr avg, 10-yr avg in parentheses)

Number of fatal airliner accidents per accident type. The probable cause for most accidents has not been established yet. However, for most accidents the factual information known at this stage makes it possible to classify these accidents. The number of "loss of control" accidents shows a marked increase to 17. Controlled flight into terrain (CFIT) accidents remained very low at 5.

Loss of control 17 (13 14 11 15 12.6 [54%] 15.6 [59%])
CFIT—hill, mountain 4 (6 3 5 12 5.6 [24%] 5.4 [21%])
CFIT—level ground 1 (2 2 4 1 2.8 [12%] 2.8 [11%])
CFIT—water 0 (0 0 0 0 0 0.3 [1%])
Emergency/forced landing—ditching 0 (1 2 0 2 1.2 [5%] 0.9 [3%])
Emergency/forced landing—outside airport 0 (0 1 2 2 1 [4%] 0.5 [2%])
Runway mishap 0 (1 0 0 0 0.2 [1%] 0.8 [3%])
Unknown 5 (12 4 3 5)
Total 27, 35, 26, 25, 37

New Members

Individuals

Muñoz, Juan, M., MO5322, Mexico D.F., Mexico
Nicholl, Heath, K., MO5274, Wayne, MI, U.S.A.
Nicolaou, Nicos, P., AO5305, Latsia, Cyprus
Obumselu, Julie, N., AO5283, Logos, Nigeria
O'Donnell, James, P., ST5317, Bay Village, OH, U.S.A.
O'Donnell, Jennifer, ST5264, South Wirral, United Kingdom
Onken, Jenna, E., ST5339, Lawrenceville, GA, U.S.A.
Öztürk, Ahmet, ST5273, Istanbul, Turkey
Pafitis, Kyriakos, P., MO5296, Limassol, Cyprus
Papanastasiou, Georgios, MO5297, Paphos, Cyprus
Park, Won Beom, ST5279, Daytona Beach, FL, U.S.A.
Pattides, Andreas, C., MO5298, Nicosia, Cyprus
Pilalis, Dina, FO5321, Melbourne, VIC, Australia
Pitsillides, Constantinos, MO5302, Larnaca, Cyprus
Rahman, Iad, MO5335, Mississauga, Canada
Reed, Jeffrey, J., AO5320, Spokane Valley, WA, U.S.A.
Reinhart, Paul, S., AO5327, Pensacola, FL, U.S.A.
Renshaw, Robert, MO5325, Thornton, CO, U.S.A.
Ribeiro, Paulo, M., MO5324, Davie, FL, U.S.A.
Ryan, John, R., FO5286, Robertson, OLD, Australia
Salvestrini, Jarrod, A., ST5265, Daytona Beach, FL, U.S.A.
Schwarz, Scott, A., MO5275, Ocean City, NJ, U.S.A.
Slaven, Walter, J., MO5266, Glen Forrest, W.A., Australia
Tagarino, Bose, T., AO5271, Lagos, Nigeria
Tehrani, Morteza, AO5333, Castle Hill, NSW, Australia
Tritschler, Kristjof, AO5269, Bonn, Germany
Wandall, Edward, H., MO5290, North Wales, PA, U.S.A. ◆

Orphanos and his team, with considerable assistance from Capt. Akrivos Tsolakis, chairman of the Hellenic Air Accident Investigation & Safety Board (HAAISB). Workshop sponsors included Olympic Airways, Cyprus Airways, and Air BP.

Content of the workshop was about equally divided into accident/incident investigation and prevention (AIIP) conducted by Schleede and safety management systems (SMS) conducted by Jim Stewart. Other instructors providing considerable support included Dr. Loukia Loukopolous from Greece (NASA employee), who covered human factors; Dr. Ioannis Markou from Greece, who covered aeromedical factors; Capt. Vangelis Demosthenos from Cyprus, who covered SMS and related topics; and Capt. Elias Nikolaides from Greece, who addressed European regulatory requirements and operational safety oversight (internal and external audits).

In all, 45 persons attended representing the Cyprus AAIIB, the Cyprus DCA, Hellenic AAIASB, an aviation magazine from Greece, the Egyptian Air Traffic Services, Cyprus Airsports Federation, Cyprus Intercollege, Cyprus Fire Service, Cyprus Ministry of Defence, Helios Airways, Eurocypria Airlines, Cyprus Airways, Cyprus Police Department (aviation department), and the Ministry of Communications and Works.

Mike Dorion cuts the ISASI logo cake as Dr. Osama Bahannan—director, Aviation Medicine, General Authority of Civil Aviation, Saudi Arabia (3rd from left)—and Capt. Talal Ageel—vice-president, Flight Operations Department (with plate in hand)—look on.

All participants received certificates of training completion at a closing dinner, which featured the minister of Communications and Works, and the director-general of the DCA, as guest speakers, among others.

Recruiting effectiveness of ISASI's effort was again proven by the gain of 22 new ISASI members. Also proven was the workshop's value, as the trained group now plans to "organize a future meeting among themselves and is considering forming a local chapter," said Schleede.

Eighteenth Workshop

Caj Frostell noted the 18th ISASI Reachout workshop ran from November 4 to 15 and was hosted by Saudi Arabian Airlines (SVA) in Jeddah. Capt. Fareed Alshingiti, general manager–Flight Operations Standards and Quality Assurance, opened the program held in the facilities of Saudi Arabian Airlines, the CRM and human factors training auditorium of the Prince Sultan Aviation Academy. It was Reachout's second visit to the group.

The technical content of the workshop comprised three modules: aviation medicine conducted by Dr. Anthony Evans, chief of the Aviation Medicine Section in ICAO; safety management systems (SMS), conducted by Mike Doiron; and aircraft accident investigation, conducted by Frostell and assisted by Alain Guilldou from BEA, France, and Mike Dorion.

A majority of the 31 participants were from within Saudi Arabian Airlines. Other attendees included inspectors with the

Improving the Quality of Investigation Analysis *(from page 13)*

the document-management system for each of the items or comments in the table.

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

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

Policies, guidelines, and training

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

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

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

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

Figure 5

Basic Evidence Table (Hypothetical Example)

Title: Flight crew qualifications / fitness

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

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

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

Supported? Yes   Add to key findings? No

Concluding comments

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

The new ATSB analysis framework is just a starting point. The intention is that, as investigators become more familiar with it, they will actively contribute to its ongoing improvement. In other words, the framework is a platform for documenting the ATSB's organizational learning about analysis methods. Any feedback anyone has for enhancing the quality of the ATSB framework would be gratefully received. ◆

ISASI Roundup

Continued . . .

General Authority of Civil Aviation (GACA). The participants received ISASI certificates for the combined accident investigation and safety management systems workshop.

At the closing ceremony completion certificates were presented by Capt. Talal Ageel (vice-president–Flight Operations Department). Other executive and managerial-level participation from SVA included Capt. Fareed Alshingiti (general manager–Flight Operations Standards and Quality Assurance) and Capt. Mohammed Hersi (manager–Technical Quality Assurance). During the workshop, ISASI membership forms and corporate membership forms were made available to the participants who were not already ISASI members. ◆

MOVING?

Please Let Us Know

Member Number____________________

Fax this form to 1-703-430-4970 or mail to
ISASI, Park Center
107 E. Holly Avenue, Suite 11
Sterling, VA 20164-5405

Old Address (or attach label)

Name ____________________

Address ____________________

City ____________________

State/Prov. ____________________

Zip ____________________

Country ____________________

New Address*

Name ____________________

Address ____________________

City ____________________

State/Prov. ____________________

Zip ____________________

Country ____________________

E-mail ____________________

*Do not forget to change employment and e-mail address.

ISASI By-Laws Being Revised

At its fall 2005 meeting the Society's International Council, noting that the last revision to the important document was in August 1993, established a committee, chaired by Darren Gaines, to undertake the daunting task of revising the document, which contained a significant number of outdated requirements. The By-Laws set goals, philosophy, give direction, and provide intent. Council and office procedures to implement the By-Laws requirements are more appropriately spelled out in the *ISASI Policy Manual*.

The By-Laws Committee work is near completion, and the process to present the revised document to the membership for approval is being put into place. The voting vehicle, Vote Net, can be accessed through the Internet, and eligible members will be able to vote through a link from the ISASI website. Members without access to the Internet will be provided with a printed ballot and a copy of the By-Laws revision upon request to the ISASI office. Dates for posting the revision have not yet been determined; however, the Council wants all members to be aware of this important work product so they may be prepared to act. ◆

NTSB Names Clark, Haueter to New Posts

National Transportation Safety Board Chairman Mark V. Rosenker has named John Clark, formerly director of Aviation Safety, as the agency's chief scientist for aeronautical engineering. Tom Haueter, deputy director of aviation safety, has been named acting director of the office.

Clark joined the Board in 1981 as an aeronautical engineer and served in several investigative capacities. He has served as director of aviation safety for the last 6 years. Haueter came to the Board in 1983 and has served as a structures investigator, an investigator-in-charge, as head of the major investigations division, and as deputy director of aviation safety for 6 years. ◆

ISASI Information

UNITED STATES REGIONAL CHAPTER PRESIDENTS

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Arizona, Bill Waldock (wwaldock@msn.com)
Dallas-Ft. Worth, Curt Lewis (lewis@curt-lewis.com)
Florida, Ben Coleman (ben.coleman@faa.gov)
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Los Angeles, Inactive
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Air Accident Investigation Unit—Ireland
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Australian Transport Safety Bureau
Aviation Safety Council
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Board of Accident Investigation—Sweden
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Flight Safety Foundation—Taiwan
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Honeywell
Hong Kong Airline Pilots Association
Hong Kong Civil Aviation Department
IFALPA
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Int'l. Assoc. of Mach. & Aerospace Workers
Interstate Aviation Committee
Irish Air Corps
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Japanese Aviation Insurance Pool
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South African Civil Aviation Authority
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Transportation Safety Board of Canada
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UND Aerospace
University of NSW AVIATION
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Volvo Aero Corporation
WestJet ◆

Transportation Safety Board of Canada (Bureau de la Sécurité des Transports du Canada)

(Who's Who is a brief profile of, and prepared by, the represented corporate member organization to enable a more thorough understanding of the organization's role and functions.—Editor)

The Transportation Safety Board of Canada (TSB) is an independent agency, created by an act of Parliament (the Canadian Transportation Accident Investigation and Safety Board Act). The TSB's mandate is to advance transportation safety

- by conducting independent investigations into selected transportation occurrences in order to make findings as to their causes and contributing factors,
- by identifying safety deficiencies, as evidenced by transportation occurrences,
- by making recommendations designed to eliminate or reduce any such safety deficiencies, and
- by reporting publicly on its investigations and on the findings in relation thereto.

In making its findings as to the causes and contributing factors of a transportation occurrence, it is not the function of the Board to assign fault or determine civil or criminal liability, but the Board shall not refrain from fully reporting on the causes and contributing factors merely because fault or liability might be inferred from the Board's findings.

In respect to aviation occurrences, the Act applies in or over Canada, in or over any place that is under Canadian air traffic control, and in or over any other place, if Canada is requested to investigate the aviation occurrence by an appropriate authority, or if the aviation occurrence involves an aircraft in respect of which, or that is operated by a person to whom, a Canadian aviation document has been issued under Part I of the Aeronautics Act.

To instill confidence in the public regarding the transportation accident investigation process, it is essential that the TSB be independent and free from any conflicts of interest when investigating accidents and incidents. TSB's independence enables it to be fully objective in making findings as to causes and contributing factors, and in making transportation safety recommendations.

The TSB consists of up to five Board members, including a chairperson, and has approximately 220 employees. The TSB head office is located in Gatineau, Quebec; however, most investigation staff are located in various regional and field offices across Canada, where they are better able to respond quickly to transportation occurrences anywhere in the country.

Approximately 2,000 aviation transportation occurrences (accidents and incidents) are reported to the TSB each year. Practical considerations dictate that only a small proportion of these be investigated. Consequently, when notified of an occurrence, the TSB will assess the circumstances to determine if an investigation is warranted. An individual occurrence will be investigated when there is high probability that the investigation will advance Canadian transportation safety, and that doing so has the potential for reducing future risk to persons, property, or the environment.

In effect, the TSB, for the most part, will focus its efforts on occurrences in the Canadian federally regulated, commercial transportation sector. In addition, in accordance with ICAO Annex 13 standards and recommended practices, the TSB is responsible for ensuring Canadian safety interests in foreign investigations involving aircraft that are registered, licensed, operated, or manufactured in Canada. In this regard, the TSB supports foreign investigations and international aviation safety by contributing its expertise and resources.

The TSB also contributes to international flight safety through its close association and involvement with ICAO, the International Transportation Safety Association, the Nordic Accident Investigation Group, and ISASI; through its participation in aviation safety working groups, seminars, and meetings; and by providing training opportunities to other investigation agencies and safety associations.

For more information on the TSB, its investigations, recommendations, and subscription services, visit its website at http://tsb.gc.ca. ◆

AIR SAFETY INVESTIGATORS
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