FORUM ISASI

Air Safety Through Investigation

OCTOBER-DECEMBER 2019

Journal of the International Society of Air Safety Investigators

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ISASI President Frank Del GandiO, left, presents the 2019 Jerome F. Lederer Award to Capt. Akrivos Tsolakis, Hellenic Air Accident Investigation and Aviation Safety Board, during the 2019 ISASI awards banquet.

FORUM

Air Safety Through Investigation

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Editor J. Gary DiNunno

Design Editor Jesica Ferry

Associate Editor Susan Fager

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AIR SAFETY INVESTIGATORS

INCORPORATED AUGUST 31, 1964

ISASI: ADVANCING AVIATION SAFETY THROUGH THE DECADES

ISASI recently established a committee within our International Council to review the Society's official *Positions on Air Safety Investigation Issues* to determine if any required an update. The committee reported that the Society's adopted policies, practices, and concepts are current. This document can be found on our website under the Guidelines tab. ISASI recently offered members the option of receiving their *Forum* only in a digital format. If you are interested in participating in this option, contact Ann Schull, our headquarters' office manager, and provide a valid e-mail address. Another activity of note is our ongoing Reachout Workshops program that provides training to air safety professionals throughout the world. We recently held our 55th Reachout session. The Pakistan Society held a series of training sessions in that country during June 2019. Since this program began in 2001, nearly 2,900 air safety professionals and government officials have participated in ISASI Reachout Workshops.

ISASI is now 55 years old, and this is an appropriate time to evaluate the effectiveness of the Society over the preceding five decades. Despite two high-profile accidents in 2018 involving the B-737 MAX, aviation safety has persistently improved since the beginning of air travel. For its first 80 years or so, commercial aviation reduced its fatal accident rate by a third to a half every decade. The only change in that long-term trend is that the rate of improvement has accelerated in the past two decades.

I will not try to convince you that ISASI and its members have been the only factor in that century-long achievement, but ISASI members can claim their share of the credit. Since it was established in 1964, ISASI has tried to advance aviation safety by providing a professional forum in which air safety professionals can exchange ideas, experiences, and knowledge. I believe it has succeeded admirably in this goal.

Some basic numbers help to tell the story. From 1963 through 1965—spanning the year before, the year of, and the year after ISASI's founding—the world's then much smaller commercial airline industry suffered 89 fatal hull losses in passenger operations with nearly 3,200 fatalities. Let's compare those numbers to the past three years for which we have complete data, 2016 through 2018. During that time, the world's airlines had just 10 fatal hull losses in passenger operations with 760 fatalities.

Do the math and you will discover that the risk of fatal injury to anyone on board a passenger airliner today is about 0.5 percent of the risk when ISASI began. Equally striking is the change in types of accidents since ISASI started. From 1963 through 1965, CFIT into high terrain accidents accounted for 28 of the 89 fatal passenger hull losses with just more than 1,000 fatalities. Add CFIT into water, obstacles, or the ground, and the numbers jump to 43 fatal hull losses with more than 1,600 fatalities. In contrast, over the past three years, the world's airlines suffered just one fatal accident involving CFIT into high terrain, a DHC-6 with 23 occupants on a scheduled domestic flight in Nepal.

ISASI and its members can take a lot of credit for virtually eliminating CFIT accidents. Don Bateman, a long-time ISASI member, developed the first of several generations of GPWS equipment, and professional investigators continued to make the case for requiring GPWS equipment. In fact, Don Bateman also was instrumental in developing TCAS. Major breakthroughs in safety like GPWS and TCAS are rare, but ISASI members played important roles in other sudden advances. They have been especially important in the steady improvement in areas such as stronger operating procedures, adherence to and quality of checklists, and other incremental enhancements that, over time, add up to major improvements in aviation safety. Our members, while employed by governments, airlines, manufacturers, unions, and consultants, have issued thousands of aviation safety recommendations that have directly and indirectly improved air safety.

The aviation industry continues to rapidly accelerate into the age of automation. ISASI members know well that a primary driver for increased automation is often efficiency rather than safety. So we cannot rest on our past accomplishments. We individually and collectively must continue to maintain and improve aviation's safety record. The areas of future concern—in my opinion—are labor shortages both in pilots and maintenance, cargo accidents, automation, managing rapid growth, unmanned aircraft systems, commercial space operations, and suicide.

Shortly after ISASI's early members established the Society, they chose a motto: *Safety Through Investigation.* Even with notable past success, that motto continues to guide our future path. ◆

Frank Del Gandio
ISASI President

ISASI Goes to the Netherlands

By J. Gary DiNunno, Editor, *ISASI Forum*

Nearly 400 delegates, 30 companions, and invited guests gathered in the World Forum Auditorium in The Hague, the Netherlands, September 1–6 for ISASI's 50th international accident investigation and prevention conference to attend tutorials and a special class about the Dutch Safety Board's investigation of the MH17 event in 2017, to listen to 34 technical programs, to tour the city and surrounding areas, and to meet and greet long-time and new colleagues. The theme for this year's program was "Future Safety: Has the Past Become Irrelevant?" By the end of the seminar, that question was answered—a definite "no."

MH17 master class

On July 17, 2014, a Malaysia Airline B-777/200, traveling from Amsterdam to Kuala Lumpur as Flight MH17, crashed in the eastern part of Ukraine. The accident was fatal to all 298 persons on board; 193 occupants were citizens of the Netherlands.

Ukraine delegated the investigation to the Netherlands. The Dutch Safety Board launched an investigation and determined that the aircraft was brought down by a surface-to-air missile (see *ISASI Forum*, July–September 2017, page 6.) The Dutch Safety Board reconstructed the nose section of the aircraft to further prove its hypothesis.

ISASI President Frank del Gandio said, "The Society seminar in The Hague, the Netherlands, was fortunate in that the Dutch Safety Board made the reconstructed portion of MH17 available to a number of the seminar delegates through a 'master class' held on Sunday preceding ISASI 2019. Sixty selected delegates participated in the class and viewed the reconstruction at Gilze-Rijen Air Base.

"Dutch Safety Board investigator Ron Smits, who coordinated recovery and reconstruction of MH17 aircraft parts, gave a presentation on the process of recovering the wreckage in an area where an armed conflict was going on and on the reconstruction itself. I spoke with the attendees, and everyone was truly amazed. They learned of all the problems and costs associated with such an undertaking."

Del Gandio noted, "ISASI is highly appreciative of the Dutch Safety Board for the great job it did and making the MH17 reconstruction available to the selected Society seminar delegates."

Monday tutorials and the president's reception

Preceding the three-day ISASI seminar, participants were able to choose one of three tutorials. They required registration and a fee separate from the seminar.

General tutorial—The Dutch Safety Board hosted this tutorial, which was held in two parts (A morning and B afternoon).

A. Two sections: Aviation Safety Versus Medical Confidentiality and Balancing Medical Confidentiality and Flight Safety Implementation Challenges (morning). Since the Germanwings Flight 9525 accident, a new debate has started on pilots' medical privacy. The investigation showed that the copilot had visited several private physicians and health-care professionals, including a psychiatrist and a psychologist, before the accident. Why did none of them inform the civil aviation authority or his employer? The reporting of unfit pilots is a deliberate breach of medical confidentiality, but it's intended to prevent an unfit pilot from flying. Hence preventing a potential accident and, in the case of commercial aircraft, possible loss of many lives. As in the case of the Germanwings accident investigation, public investigation authorities might encounter difficulties in obtaining information to rule out the pilot's medical condition as a contributing factor. Although both reporting an unfit pilot and investigating aircraft accidents are aimed at improving flight safety, the legal considerations for allowing medical professionals to breach medical confidentiality for these different purposes can vary greatly.

This tutorial provided an insight into various existing international and national legal provisions and policies with regard to medical confidentiality and the use of pilots' medical information in relation to reporting unfit pilots and accident investigation. Attendees were

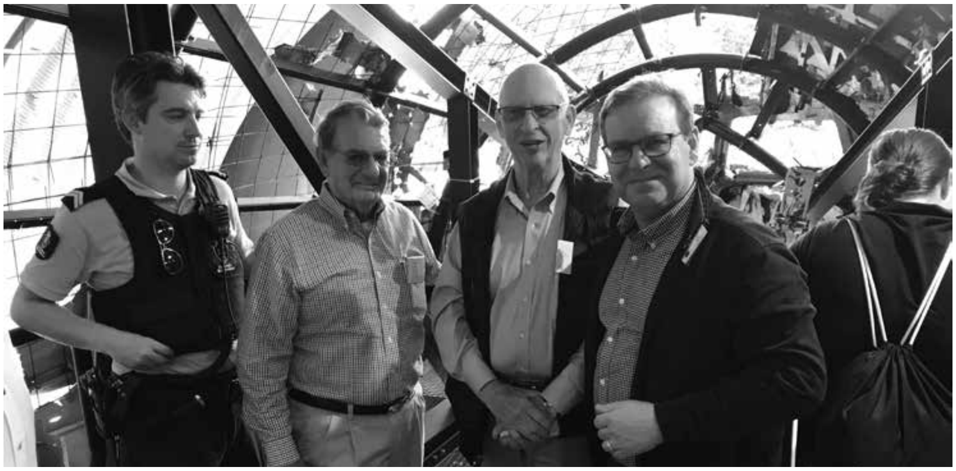

Photo credit: J. Gary DiNunno

From the left, ISASI President Frank Del Gandio, Treasurer Bob MacIntosh, and Seminar Host Committee Chair Dann Zwart view the reconstructed MH17 fuselage.

ISASI 2019 delegates attend seminar presentations in the World Forum Auditorium.

provided with tools derived from this legal framework analyses to help find a balance between aviation safety versus medical confidentiality.

B. Communications with Victims and Relatives (afternoon). A crash has an enormous impact on society, especially on victims and their relatives. Often, they go through a life-changing process of emotions and questions, which they have to deal with in a complex media landscape. In this tutorial hosted by the Dutch Safety Board, the basics and latest developments concerning communication with victims and their relatives was presented. With insights from the field of crisis communication, the media landscape, and victim support, the tutorial aimed to increase confidence when dealing with these contacts.

Military accident investigations—The Military Air Safety Investigators (MASI), which is a subset of ISASI, hosted this tutorial. The all-day session was a forum for international military accident investigators to share knowledge on their respective capabilities, experiences, processes, and procedures with a view to develop future relationships and common practices. The MASI forums/tutorials drew numerous military investigators from across Europe, Australia, North America, and Asia seeking to share their safety lessons.

Hands-on "crash day"—The faculty of Aerospace Engineering Delft University of Technology hosted this tutorial at its campus. Crash day, a real-life

ESASI President Olivier Ferrante leads a discussion during the military tutorial.

The stage and podium are ready for ISASI 2019 to begin.

accident investigation simulation, has attracted press and professionals for more than five years while providing problem-based-learning for aerospace students. The aerospace engineering faculty firmly believes in problem-based-learning and strives to inspire students to go beyond what's learned in text books. For the first time, this real-life accident simulation was provided for ISASI tutorial attendees.

Following the tutorials, seminar participants attended the traditional president's reception during which ISASI's president welcomed delegates and their guests to The Hague and set the stage for the next several days of ISASI 2019.

ISASI 2019 opening day

On Tuesday, September 3, Host Committee Chair Dann Zwart welcomed ISASI 2019 participants to the World Forum King Willem Alexander Auditorium. He then introduced ISASI's president to address the gathering.

Del Gandio said, "Good Morning everyone, and welcome to ISASI's 50th international seminar here in The Hague." He noted that 374 delegates registered for ISASI 2019, 126 participants attended Monday's

ISASI President Frank Del Gandio delivers the seminar opening address.

tutorial program, and that 45 companions were scheduled for tours on Tuesday and Wednesday. Del Gandio observed that representatives from 48 countries gathered for ISASI 2019. He introduced ISASI's executive officers—Chad Balentine, secretary, and Bob MacIntosh, treasurer—and ISASI councilors and Society presidents who were in the meeting auditorium.

"Fifty-five years ago, three investigators from the U.S. Civil Aeronautics Board, now known as the National Transportation Safety Board [NTSB], said let's form a fraternal organization. Six years later, they held their first seminar in Washington, D.C. This is now our golden anniversary. ISASI has come a long way.

"We are celebrating other milestones here in the Netherlands. KLM [Royal Dutch Airlines] is celebrating 100 years. The only airline to become 100 years old with the same name. Congratulations to KLM. Ten years after KLM began flying, the KLM pilots organized to become Dutch ALPA. Ten years later, Delft University of Technology-Faculty of Aerospace Engineering was founded. Twenty years ago, the Dutch Safety Board, formerly the Dutch Transportation Safety Board, was founded. The Netherlands has an extremely rich history of service to aviation and the flying public. ISASI is proud to be here and help everyone celebrate their anniversaries and to continue to enhance aviation safety through our various presentations and global networking.

"Despite two recent and high-profile accidents involving the Boeing-737 MAX aircraft, most people in this room recognize that aviation safety has improved consistently for its entire history. For its first 80 years or so, commercial aviation reduced its fatal accident rate by a third to a half every decade. The only change in that long-term trend is that the rate of improvement has accelerated in the past two decades.

"I will not try to convince this audience that ISASI and its members have been the only factor in that century-long achievement, but ISASI and its membership can claim their share of the credit. Since it was established in 1964, ISASI has worked to advance aviation safety by providing a professional forum for the exchange of ideas, experiences, and knowledge acquired by air safety professionals. I believe it has succeeded admirably in that goal.

"In ISASI's early years, major fatal accidents were almost a routine affair, and that was in an era of a far smaller system than we have today. In the interim, of course, the system has expanded exponentially. Today's system manages about 10 times as many passenger aircraft and about 15 times as many flights, each of which carries twice the number of seats and three times as many passengers on average.

"Some basic numbers help to tell the story. From 1963 through 1965, spanning the year before, the year of, and the year after ISASI's founding, the world's much smaller commercial airline industry suffered 89 fatal hull losses in passenger operations with nearly 3,200 fatalities. Compare those numbers to the past three years for which we have complete data—2016 through 2018. In that period, the world's airlines had just 10 fatal hull losses in passenger operations with 760 fatalities.

"Run the arithmetic and you will find that the risk of fatal injury to anyone on board a passenger airliner today is about 0.5 percent of the risk when ISASI began. Equally striking is the mix of accidents when ISASI started. From 1963 through 1965, controlled flight into terrain [CFIT] accounted for 28 of the 89 fatal passenger hull losses with just more than 1,000 fatalities. Add CFIT into water, obstacles, or the ground, and the numbers jump to 43 fatal hull losses with more than 1,600 fatalities. In contrast, over the past three years, the world's airlines suffered just one fatal accident involving CFIT into high terrain, a DHC-6 with 23 occupants on a scheduled domestic flight in Nepal.

"ISASI and its members in fact can take a lot of the credit for virtually eliminating CFIT accidents. A long-time ISASI member, Don Bateman, developed the first of several generations of GPWS equipment, and professional investigators continued to make the case for requiring GPWS equipment. In fact, Don Bateman also was instrumental in developing TCAS, which could have averted three more of the fatal accidents from 1963 through1965.

"Major breakthroughs in safety like GPWS and TCAS are rare, but ISASI members played important parts in other sudden advances, and they have been especially important in the steady improvement in areas like stronger operating procedures, adherence to and

Dutch Safety Board Chair Jeroen Dijsselboem delivers the opening day keynote address.

quality of checklists, and other incremental improvements that, over time, add up to major improvements. Our members, while employed by governments, airlines, manufacturers, unions, and consultants, have issued thousands of aviation safety recommendations that have directly and indirectly improved air safety.

"However, ISASI cannot rest on its past accomplishments. We individually and collectively must continue to maintain and improve the aviation safety record. The areas of future concern, in my opinion, are labor shortages both in pilots and maintenance, cargo accidents, automation, managing rapid growth, unmanned aircraft systems, and suicide. We must all remember that the aviation industry continues to rapidly accelerate into the age of automation and that the primary driver for increased automation is often efficiency rather than safety."

Del Gandio concluded, "I hope that you enjoy the seminar and that you enjoy the Netherlands, a beautiful country."

Opening day keynote address

Jeroen Dijsselboem, Dutch Safety Board chair, outlined the history of aviation in the Netherlands that began with manufacturing at Fokker and commercial flights with KLM in 1919. He discussed the creation and structure of the Dutch Safety Board and some of the activities and investigations that could be disclosed. He observed that the safety investigation agency in various forms was now 20 years old.

Kapustin scholarship presentations

Following the keynote address, Nur Amalina Jumary, a 2019 Kapustin scholarship recipient from the University of New South Wales, Australia, presented her paper *Air Safety Cyber Security: Why Cyber Security Is a Threat for Air Safety*. Next to the podium was Kapustin scholar Stacy Jackson from Embry-Riddle Aeronautical University (ERAU), who urged air safety professionals to *Apply Lessons Learned in Human Factors to Commercial Space Operations* (see page 20).

Kapustin Scholarship recipient Stacy Jackson discusses investigating human factors in commercial space operations.

Kapustin scholarship recipient Nur Amalina Jumary presents her winning essay

ISASI 2019 adopted a new format for technical presentations to accommodate the large number of selected submissions: presentations began simultaneously in both the main auditorium and an adjacent conference room. Delegates chose which presentation to attend. (See page 10 for a complete list of presentations.)

Another keynote address

During Tuesday afternoon, Bruce Landsberg, the NTSB vice chair, provided a second keynote address. He discussed extending the time for CVR recordings beyond the current two hours and the need to simplify the current NOTAM system—specifically providing pilots better notices about runway closures and system management problems. Looking at automation, Landsberg examined how pilots deal with disengaging automatic aircraft functions during an emergency He observed that the collection and proper investigative use of "big data" leads to air accident prevention.

Delegates and companions enjoy a buffet dinner held at the Louwman Car Museum.

NTSB Vice Chair Bruce Landsberg gives the afternoon keynote address.

ISASI 2019 Sponsors

The following organizations were sponsors of ISASI 2019.

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Southern California Safety Institute

Dutch physician and European Space Agency astronaut Andre Kulpers provides the second day opening keynote address.

ISASI national societies conducted business meetings at 1600 to discuss regional and local activities, introduce new officers, and review other organizational matters as needed.

Delegates, companions, and guests were then bussed to the nearby Louwman Car Museum for an informal buffet dinner and a chance to view classic and antique automobiles from all over the world, period dioramas of auto mechanic repair shops, and a collection of antique fuel pumps.

Day 2, Wednesday, September 4

The conference opened with keynote speaker Andre Kulpers, a Dutch physician and a European Space Agency astronaut, who discussed accidents and incidents occurring during space flights and what investigations and remedies space agencies and suppliers conducted to mitigate or correct problems. A technical presentation titled "Do We Need an Annex 13 for Commercial Space Accident Investigation" followed the keynote address to discuss how safety and accident investigators might become necessary participants in global space flight programs.

Kapustin scholarship presentations

Kapustin scholarship recipient Elise Vondra presented her winning essay *Remembering Before the Crash: How Nonvolatile Memory Can Change the Course of an Investigation*. She was followed by Kapustin scholar Alex Hall who discussed *The Challenges of Investigating Language in Aviation Accidents: How Applied Linguistics Can Reveal Subtle Communications Errors*.

Elise Vondra gives her essay selected for a Kapustin scholarship.

Kapustin scholar Alex Hall observes that language differences can cause miscommunication that leads to aviation accidents.

Technical presentations

ISASI 2019 delegates divided into two groups at 1100 to attend simultaneous technical presentations. They then gathered in the main auditorium at 1130 for an ISASI business meeting during which ISASI executive officers discussed Society working group and committee actions, representation at International Civil Aviation Organization meetings, ISASI's financial status, and other ongoing administrative matters.

Delft University professor Jacco Hoekstra presents the final keynote address about the concept of "free flight."

Following the lunch break, at 1300 delegates again broke into two groups to attend simultaneous technical presentations. They rejoined in the auditorium at 1500 to hear the two final presentations of the day. At 1600, the overall conference disbursed so that ISASI working groups could hold informational meetings for interested participants. That evening, the Seminar Host Committee held a "pub quiz" in the World Forum cafe to engage a friendly competition among teams to correctly answer trivia questions.

Day 3, Thursday, September 5

The day began at 0900 with a keynote address. Jacco Hoekstra, a Delft University professor, discussed the concept of "free flight" in congested airspace. He suggested that aircraft separation could be possible using an independent surveillance system such as the Airborne Separation Assurance System (ASAS) with a central control at airports. ASAS could lead to increased airspace capacity and reduced congestion.

Technical presentations

Following the keynote, delegates listened to presentations covering SMS at Amsterdam's Schiphol Airport and the importance of high-load event reporting. Seminar participants then broke into two groups to attend parallel sessions until 1600.

Closing session

Del Gandio thanked the delegates for participating in ISASI 2019, hoping they had an enjoyable and productive week and wishing them a safe journey home. Zwart, ISASI's 2019 Host Committee chair, introduced Barbara Dunn, ISASI 2020 Host Committee chair, who discussed plans for the next seminar to be held Sept. 1–3, 2020, in Montréal, Qué., Canada, at the

From left, ISASI President Frank Del Gandio, Treasurer Bob MacIntosh, and Secretary Chad Balentine during a "business meeting" provide Society members information and news about ISASI's financial position and current activities. Vice President Ron Schleede didn't attend ISASI 2019.

Seminar participants attend the annual ISASI awards banquet at the Kurhaus Scheveningen, a magnificent beachside hotel on the North Sea.

Le Centre Sheraton Montréal and provided a promotional video shown to all seminar attendees.

That evening, delegates and their guests attended the traditional reception and awards dinner held at Kurhaus Scheveningen, a palatial hotel on the shores of the North Sea. The highlight of the evening was the presentation of the Jerome F. Lederer Award, ISASI's highest honor for lifetime contributions to air safety, to Capt. Akrivos D. Tsolakis of the Hellenic Air Accident and Aviation Safety Board (see page12).

Companion Activities

Tuesday, September 3: Old and New Holland

Upon meeting their professional guide in front of the World Forum, the ISASI 2019 "companion" participants traveled to Delft, a picturesque town with one of Holland's most perfectly preserved city centers that has not changed since Vermeer painted his *View of Delft*. The group walked through the historic city center viewing many almshouses and along the canals. Afterwards, the tour visited the Royal Dutch Delftware manufacture De Porceleyne Fles. Established in 1653, it is the last remaining Delftware factory from the 17th century. Delftware is still hand painted according to a century-old tradition.

The group them traveled to Rotterdam, the city that was destroyed in World War II and later rebuilt—now with the largest harbor in Europe. The companions also visited Euromast, an observation tower that offers a spectacular view of Rotterdam center, the port area, and nearby cities. At the top of the tower is the Euroscoop, a rotating glass elevator that takes visitors 185 meters into the air, turning slowly while providing a 360-degree view of the city and information about Rotterdam. After lunch, the companions embarked on a tour of the harbor.

Wednesday, September 4: Water, Windmills, and Cheese

On this day, the ISASI companions discovered some unique sights of Holland. First, they traveled to Zaanse Schans, a 40-house community on the banks of the river Zaan that in the 18th century had more than 700 windmills Now only five remain.

The group then went to the city of Edam, famous for its cheese. For centuries, the well-known round Edam cheeses have been sent from this town to all corners of the world. The cheese market, once again restored to its place of honor, is open weekly on Wednesdays during the summer months. Neighboring cheese warehouses keep alive the memory of a colorful past. Edam is a city with a rich history.

In the early afternoon, the group continued on to Monnickendam, a former fisherman's village with a long history. During the city walk, the companions visited the historic city hall and De Waag, where shiploads coming in from overseas used to be weighed.

The companion tour includes a visit to the royal Dutch Delftware manufacturer, De Porceleyne Fles.

The seminar companions gather for a photo during the awards banquet.

Companions visit a working windmill.

ISASI 2019 Technical Program

Tuesday, September 3

0900

AM Moderator: Dann Zwart, Dutch ALPA

Welcome Speech: ISASI President, Frank Del Gandio; Dutch Safety Board Chair Jeroen Dijsselbloem

0930

Small Country/Big Accident, PNG AIC Chief Commissioner H.H. Namani

1000

Kapustin Scholarship Presentations

1100

Black Swan Events—Examples from Airbus History, S. Cote, Airbus SAS

1100

The Head Injury Criteria and Future Accident Investigations, J.M. Davies, University of Calgary, Canada; W.A. Wallace; C.L. Colton; O. Tomlin; T. Payne

1130

Comparisons and Lessons Learned from UA232 Sioux City and AA383 Chicago Uncontained Events, David Chapel, GE Flight Safety Director, and Dan Kemme, Aviation Safety Lead, GE Aviation

1130

LAMIA Flight 2933: Who Lived, Who Died, and Why, Anthony Brickhouse, ERAU; D.M. Garcia; and J.E. Echeverri

1300

PM Moderator: Nuno Aghbassi, NETJETS

Airmanship 2.0: Innovating Aviation Human Factors Forensics to a Necessarily Proactive Role, F. Mohrmann, Netherlands Aerospace Centre; J. Stoop

1300

Analysis of Aviation Accident Videos at NTSB, D.T. Horak

1330

The Paradox of Intuition—A Neuroscience Approach to Training Pilots for Unexpected Events, L. Earl, Coventry University; J. Sheffield

1330

Why Did the Helicopter Collide with Trees? Approach the Cause from Analysis of Images and Sounds, K. Fukuda, Japan Transport Safety Board

1400

Inattentional Blindness During Visual Approach, Capt. A. Singh, Royal Aeronautical Society, India

1400

Analyzing Large and Complex Image Collections During a Safety Investigation, F. Gisolf, Dutch Safety Board

1500

Challenges of Accident Investigation in Africa, Aircraft Accident and Incident Division, Rwanda, Manager C. Bagabo; J. Smeitink

1530

Keynote Speech, NTSB Vice Chair B. Landsberg

1600

National Society Meetings

1800–2145

Offsite Dinner: Louwman Museum

Wednesday, September 4

0900

AM Moderator: Mario Colavita, EASA

Keynote Speech: Dutch Physician and European Space Agency Astronaut A. Kulpers

0930

Do We Need an Annex 13 for Commercial Space, J. Sedor, NTSB

1000

Kapustin Scholarship Presentation

1100

Improving the Investigation of Takeoff and Landing Incidents/Accidents, D. Gleave, chair ISASI Airport Working Group, Loughborough University; D. Pitfield

1100

Investigation of the In-Flight Failure of the Stratos III Sounding Rocket, R. Wubben, TU Delft University; E. Gilleran; M. Van Heijningen, et al

1130

ISASI Business Meeting

1300

PM Moderator: Frank Hilldrup, NTSB

Takeoff Performance Incidents: Do We Need to Accept Them or Can We Eliminate Them? G. van Es, Netherlands Aerospace Centre; M. Nijhof; B. Bernard

1300

Human Factors Panel Discussion

William Bramble, NTSB, Chair ISASI Human Factors Working Group; M. Walker, Australian Transport Safety Board; Fanny Rome, BEA; T. Flint, AAIB, UK

1500

Updating the Concept of Cause in Accident Investigation, N. Leveson; Capt. D. Straker, Hong Kong

1530

Investigating Accidents in Highly Automated Systems—Systemic Problems Highlighted by Analysis of AF 447, Capt. S. Malmquist, RAeS, Florida Institute of technology; N. Leveson

1600

ISASI Working Group Meetings

1700–1900

Pub Quiz

Thursday, September 5

0900

AM Moderator: Pablo Soares Oliveira Filho, Embraer

Keynote Address: Professor K. Hoekstra, Delft University of Technology

0930

Integral Safety Management System Schiphol, J. Daams, Schiphol

1000

The Importance of High-Load Event Reporting, A. Dika, AAIC, Republic of Kosovo

1100

Breaking Airlines' Flight Data Monitoring Barriers—A Pilot's Perspective, Capt. B. de Courville, Air France (Ret.)

1100

New Safety Investigator Profile, E. Zambonini, LARSA Council, JIACC, Argentina

1130

Themes and System Safety Investigation—Proactively Investigating for System Safety Improvements, D. Foley, CAA, New Zealand

1130

Competency-Based Education and Framework for a More Efficient and Safer Aviation Industry, F.A.C. Mendonca, Purdue University; J. Keller; B. Dillman

1300

PM Moderator: Chong Chow Wah, Transportation Safety Investigation Bureau of Singapore

Research-Based Insights: The Importance of Lightweight Data Recorders for General Aviation Aircraft, B. Harvey, TSB of Canada; C.M. Rudin-Brown

1300

Accidents Past, Accidents Future: Safety in the Age of Unmanned Aviation, T.A. Farrier, Chair, ISASI Unmanned Aircraft Systems Working Group

1330

Does What Happened in the Aircraft Matter Anymore? N. Boston, ATSB Australia

1330

Evolution of Mishap Prevention: Application of Human Factors Evaluation Techniques for UAS, E. Lagerstom, Insitu, Inc., U.S.A.

1400

Flying Over Conflict Zones—Follow-up Recommendations MH17 Crash, M. van Hijum, Dutch Safety Board

1400

Review of Aviation Safety Regulation and Practices of Remotely Piloted Aircraft Systems in China, L. Yang, China Academy of Civil Aviation Science and Technology, P.R. China

1500

Safety Promotion at the Manufacturer—Acknowledging the Past Helps Establish the Future, E.J. East, Boeing Commercial Aircraft, U.S.A.

1500

Flying Over or Near Conflict Zones—The Way Forward, K. Beumkes, Ministry of Infrastructure and Water Management, Civil Aviation Directorate, Aviation Safety and Security Division, the Netherlands

1530

How to Achieve a High Safety Level with Dual-Mode Fly & Drive Vehicles, M. Stekelerburg, PAL-V, the Netherlands

1600–1630

Closing Remarks and Looking Forward to ISASI 2020

1800–2200

President's Reception and Awards Dinner

The high point of the awards banquet is the presentation of the Jerome F. Lederer Award, ISASI's highest recognition for contribution to air safety, to Capt. Akrivos Tsolakis.

Recognition for the best presentation during ISASI 2018 went to Kåre Halvorsen and Tor Nørstegård, AIB Norway, for their paper *The EC 225 LP Accident Near Turøy in Norway* (see *ISASI Forum*, April–June 2019, page 4). The best presentation for ISASI 2019 went to David Chapel and Dan Kemme for their paper *Comparison and Lessons Learned from UA232 Sioux City and AA383 Chicago Uncontained Events* (see page 15). Del Gandio welcomed and gave plaques to representatives from new ISASI corporate members: the Netherlands Defence Safety Inspectorate, Ministry of Infrastructure (Rwanda AAIB), Bell, EUROCONTROL, and the University of Management Technology (Pakistan). ISASI's president gave Kapustin scholarship certificates to the four 2019 recipients: Alexander P. Hall, ERAU; Stacey Jackson, ERAU; Nur Amalina Jumary, University of New South Wales; and Elise Maria Vondra, University of Southern California Aviation Safety Program. He observed that ISASI 2019 participants had donated nearly $2,900 to the 2020 Kapustin Memorial Scholarship Fund.

At the end of the evening, Del Gandio thanked everyone present "for attending and participating in the 2019 seminar." He added, "I hope you enjoyed and benefited from our program, the tutorials, and the social activities. I look forward to seeing you in Montréal, Québec, Canada, next year for ISASI 2020. Good night and have a safe trip home." ◆

Optional Tour

Friday, September 6: Amsterdam

Following the close of ISASI 2019, conference participants and companions had an optional opportunity to visit Amsterdam. First, they toured the national museum of Amsterdam, the Rijksmuseum. This museum is world famous and includes the largest collection of paintings by the Dutch "Old Masters," including works by Frans Hals, Jan Steen, and Rembrandt (*The Night Watch*).

Following a quick lunch on the museum's square, participants either took off on their own itinerary or joined hosts Dann and Karen Zwart for a walking tour of the city—including sites that tourists do not normally frequent.

At the end of the afternoon, tour participants rejoined at Haesje Claes for a typical Dutch dinner. Afterwards, the group met for an evening canal cruise to see Amsterdam in its full glory from the water.

Among the sights of a postseminar optional tour are Amsterdam's national museum, the Rijksmuseum.

From left, delegates from the Nigerian Accident Investigation Board are engineer Francis Odita, commissioner/CEO engineer Akin Olateru, engineer Mohammed H.I. Wali, and engineer Henry Nwanyanwu.

A scenic view of Rotterdam from the Euromast, a 185-meter-high observation tower.

ISASI HONORS CAPT. AKRIVOS TSOLAKIS WITH 2019 JEROME F. LEDERER AWARD

By J. Gary DiNunno, Editor, *ISASI Forum*

Capt. Akrivos Tsolakis, right, accepts the 2019 Jerome F. Lederer Award for lifetime excellence in promoting air safety from Frank Del Gandio, ISASI president.

During the ISASI 2019 annual awards banquet, held in The Hague, the Netherlands, on September 5 (see page 4), the Society presented its highest recognition for lifetime air safety achievement to Capt. Akrivos Tsolakis. Frank Del Gandio, ISASI's president, noted that Tsolakis has had "a unique aviation and aviation safety career over the last 70 years."

The Hellenic Air Accident Investigation & Aviation Safety Board (AAIASB) was established in 2001. From 2001 to 2011, Tsolakis was its first president. And from 2014 through 2023, he's serving as a senior member of the board to guide his younger colleagues and is still actively involved in promoting aviation safety within Greece and the Balkan region. Under the leadership of Tsolakis, the Hellenic AAIASB was organized as an independent accident investigation agency with full capacity to investigate major accidents with a well-trained investigator staff. Throughout his terms with the AAIASB, Tsolakis has been dedicated to improving aviation safety in Greece, the Balkans, Europe, and throughout the world.

"Under the leadership of Capt. Tsolakis," Del Gandio said, "the AAIASB investigated over 250 accidents and serious incidents, and over 250 safety recommendations were made. The Hellenic AAIASB became an ISASI corporate member, and Capt. Tsolakis became an individual ISASI member and subsequently a life member. Recognizing that not many safety investigators from the Balkan region had the opportunity to attend ISASI seminars to learn from and network with world-class safety experts, Capt. Tsolakis hosted three ISASI Reachout Workshops, two in Athens—in 2005 and 2015—and one in Cyprus in 2006. He facilitated an ISASI Reachout in Istanbul, Turkey, in 2010.

"Capt. Tsolakis worked closely with the Flight Safety Foundation [FSF] and attended 43 FSF international seminars. He hosted five FSF seminars in Athens and became a friend of Jerry Lederer. He became an FSF life member in 2009. He was also president of FSF South Eastern Europe, and he founded the Greek Flight Safety Organization.

"Capt. Tsolakis received his military flight training in the U.S.A. at Randolph Field, Texas, in 1949 and Nellis Air Force Base, Nevada, in 1950. He flew 160 combat missions in the Korean War from 1950–1953 with the Greek unit. He retired from the Hellenic Air Force in 1965 as a lieutenant colonel with several air medals and decorations for distinguished service.

"Capt. Tsolakis joined Olympic Airways in 1965. He flew 18,200 hours in 24 types of aircraft, including the DC-3, Comet 4B, B-727, B-707, Airbus A300, and B-747. During his time with Olympic Airways, he established the flight safety department, a safety magazine, an anonymous safety reporting program, wind shear prevention programs, CRM, and LOFT. He retired from Olympic Airways in 1990. For Athens International Airport, he established a flight safety department in 2000, a council for flight safety, and a 'foreign object' day, as well as an airport safety manual.

"During his 70 years in aviation safety, of which 11 years [were] as head of the AAIASB and another 10 years as senior member of the board, Capt. Tsolakis has been and continues to be a strong visionary supporter of international cooperation, including ISASI activities. He developed the Hellenic AAIASB into a professional accident investigation agency respected by colleagues all over the world.

"The aviation safety achievements of Capt. Tsolakis, and his encouragements and support to others," Del Gandio concluded, "have been tremendous and outstanding on an international scale and dimension. ISASI is proud to have such a truly internationally spirited, worldwide recognized

PAST LEDERER AWARD WINNERS

1977—Samuel M. Phillips
1978—Allen R. McMahan
1979—Gerard M. Bruggink
1980—John Gilbert Boulding
1981—Dr. S. Harry Robertson
1982—C.H. Prater Houge
1983—C.O. Miller
1984—George B. Parker
1985—Dr. John Kenyon Mason
1986—Geoffrey C. Wilkinson
1987—Dr. Carol A. Roberts
1988—H. Vincent LaChapelle
1989—Aage A. Roed
1990—Olof Fritsch
1991—Eddie J. Trimble
1992—Paul R. Powers
1993—Capt. Victor Hewes
1994—UK Aircraft Accidents Investigation Branch
1995—Dr. John K. Lauber
1996—Burt Chesterfield
1997—Gus Economy
1998—A. Frank Taylor
1999—Capt. James A. McIntyre
2000—Nora C. Marshal
2001—John W. Purvis and the Transportation Safety Board of Canada
2002—Ronald L. Schleede
2003—Caj Frostell
2004—Ron Chippindale
2005—John D. Rawson
2006—Richard H. Wood
2007—Capt. Thomas McCarthy
2008—C. Donald Bateman
2009—Capt. Richard B. Stone and the Australian Transport Safety Bureau
2010—Michael Poole
2011—Paul-Louis Arslanian
2012—Curt L. Lewis
2013—Frank Del Gandio and Myron Papadakis
2014—David King
2015—Ladislav (Ladi) Mika
2016—Eugene (Toby) Carroll
2017—Chan, Wing Keong
2018—Capt. Mohammed Aziz

accident investigation expert as a life member. Capt. Akrivos Tsolakis is…a most deserving recipient of the prestigious ISASI Jerry Lederer Award."

In accepting the Lederer Award, Tsolakis said, "This night is for me and my family full of intense feelings of gratitude and pride for the unique honor you have bestowed on me and my beloved country." He acknowledged the presence of Vassilki, his wife; Constantine, his son; Gen. Antonios Athanasiou, board president; and Nikolaus Tika, board member.

Tsolakis said, "It was the summer of 1959, a day in August, when I stood at attention, facing USAF Gen. Joseph Caldara, the first deputy inspector general, USAF, in front of the entrance of the University of Southern California. He was holding a small model of a republic F-84 Thunderstreak, a plane the Hellenic Air Force was flying in Greece. The model was a special award for me as the top graduate from a class of 32 officers—the class of 1959. The course we had completed was designed to teach us, according to the general, how to prevent airplanes from falling from the sky." Tsolakis observed that this was when he became "infected with the incurable virus of flight safety—60 long years ago, which, I confess to you, has gone by too fast for my taste."

He noted that "during the subsequent six years with the Hellenic Air Force, we applied many of those USC lessons with significant results, saving lives, reputations, and equipment. After leaving the air force, I joined the national Hellenic air carrier, Olympic Airlines, during its golden era under the leadership of Aristotle Onassis. I found him to be a very strong proponent of air safety. Aware of my background, he directed me to establish a modern safety department at the airline. I was ecstatic for the opportunity to use my experience and ideas with his full, no-nonsense support. In a short time, Olympic became a flight safety operator and a very active member of the Flight Safety Foundation.

"It was during those years at an early Flight Safety Foundation seminar that I met Jerry Lederer. He was medium height, with deep blue eyes, white hair, and had a strong handshake. He was an outstanding speaker and communicator. For me, he was and still is the only prophet I have ever met. In every gathering where he was present, everyone was trying to engage him to ask for advice and to sit next to him. He was what young people today call a 'rock star.' I noticed that he particularly preferred to speak with the younger participants. With me, he specifically liked to hear about the exploits and ideas of my legendary boss, Onassis.

"But when our discussion turned to flight safety matters, he would immediately stop what he was doing, close his eyes, and stay silent for a few seconds. When he opened his eyes, you saw fire, and his normally friendly—even festive—voice would change to an angry, ominous, tone. He said, 'In the beginning everyone was blaming the pilots, but young man remember that there are many who are involved in this miracle called flight. Beware the designers, the builders, the regulators, and the stock market—on both sides of the Atlantic. Be ready to face complicated accidents. Every accident has its deep causes that at times are latent. So always go deep in your investigation.'

"In half a century," Tsolakis observed, "I have never forgotten that advice. Through the years, while investigating some of the, thankfully, few aviation accidents, I frequently had an opportunity to remember Jerry's angry manner and words. And now, you have also heard him.

"Tonight, we are here, during ISASI 2019, to celebrate the Society's 50th international seminar. With feelings of appreciation and gratitude to all those brave souls who created and have nurtured this magnificent Society, I raise a glass to wish ISASI many more successful seminars and Reachouts—our most effective programs to spread the word of flight safety to committed aviation professionals in every corner of the world. Aviation needs ISASI, and we will always be there when that call comes in. Let us remain as our Founding Father wanted, 'the Conscience of Aviation Safety.' Thank you from my heart." ◆

The 2019 Lederer Award recipient, Capt. Akrivos Tsolakis, right, addresses attendees during the annual ISASI awards banquet.

COMPARING UA232 AND AA383 UNCONTAINED EVENTS

By David Chapel, GE Flight Safety Director, and Dan Kemme, Aviation Safety Lead, GE Aviation


David Chapel


Dan Kemme

(Adapted with permission from the authors' technical paper Comparisons and Lessons Learned from UA232 Sioux City and AA383 Chicago Uncontained Events *presented during ISASI 2019, Sept. 3–5, 2019, in The Hague, the Netherlands. The theme for ISASI 2019 was "Future Safety: Has the Past Become Irrelevant?" The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations. This paper received recognition as the best paper presented during ISASI 2019.—Editor)*

Nomenclature

The notation UA232 refers to United Airlines Flight 232, which crash landed at the Sioux Gateway Airport in Sioux City, Iowa, on July 19, 1989. AA383 refers to American Airlines Flight 383, which conducted an aborted takeoff at Chicago O'Hare International Airport on Oct. 28, 2016. Reference to the "UA232 disk" refers to the fractured Stage 1 fan disk, and reference to the "AA383 disk" refers to the fractured high-pressure turbine (HPT) second-stage disk. The UA232 disk was made of a titanium alloy (Ti-6-4), and the AA383 disk was made of a nickel-based alloy (Inconel 718), both workhorse alloys for the gas turbine engine business.

Background

On July 19, 1989, a DC-10-10 powered by three CF6-6 engines suffered an uncontained separation of the Number 2 (tail) engine Stage 1 fan disk during cruise, which compromised all three aircraft hydraulic systems. The only control that the flight crew had over the aircraft was by modulating the throttles for the Number 1 and Number 3 wing-mounted engines. The DC-10-10 attempted to land at the Sioux Gateway Airport, but the right wing dropped at the last moment causing the aircraft to tumble down the runway resulting in the fuselage breaking apart. Of the 296 people on board, there were 111 fatalities yet 185 survived. The investigation later found that a hard-alpha inclusion in the fan disk forging served as a crack initiation site on the bore surface. This led to fatigue propagation, which ultimately resulted in the disk failure. In addition, it was determined that a liberated disk fragment severed the two backup hydraulic systems, which combined with the Number 2 engine failure resulted in no available hydraulics to fly the aircraft.

United Airlines Flight 232
Sioux Gateway Airport, Sioux City, Iowa
July 19, 1989

American Airlines Flight 383
Chicago O'Hare Field
October 28, 2016

Figure 1. Event images.

On Oct. 28, 2016, a B-767-323 powered by two CF6-80C2B6 engines suffered an uncontained separation of the Number 2 (right-hand) engine high-pressure turbine second-stage disk during takeoff. A segment of the disk penetrated the right wing, severing a fuel line and breaching the wing fuel tank. The flight crew rejected the takeoff and quickly stopped the aircraft on the runway. There was a ground fire on the right-hand side of the aircraft. The passengers and crew exited the left-hand side of the aircraft. The Chicago O'Hare International Airport Fire Department responded rapidly and extinguished the fire. All 170 people survived, most with no injuries.

Figure 1 shows two snapshots of the respective events. These events reflect two very different scenarios. UA232 was at altitude (37,000 feet) when the initial disk burst occurred. The remainder of this flight was a struggle to maintain control of the aircraft. The AA383 event flight was over in a matter of seconds with an aborted takeoff and subsequent evacuation. AA383 was fortunate to have the wind blowing in the right direction or it could have been reminiscent of the Manchester, UK, 1985 accident. A similarity of UA232 and AA383 is that both events occurred in direct proximity of emergency personnel and equipment, which was critical to the postevent survival aspects for those on board.

Purpose

There are many aspects of these two events that could be compared: crew resource management, emergency checklists, evacuation procedures, and disaster preparedness to name a few. This paper will strictly focus on the UA232 and AA383 disks themselves from their original fabrication to actions taken after their respective failures. It is important to note that with these events occurring roughly 27 years apart, there are some key differences in the industrial, media, and regulatory environments in which they occurred. In addition, we will discuss the importance of cross-enterprise safety initiatives, which are critical to ensure that lessons learned are applied across the entire business enterprise and industry.

U.S. National Transportation Safety Board (NTSB) Investigations

Table 1 (see page 16), summarizes the key parameters related to the two event engines. There are several things worth noting.

1. The UA232 engine was in for maintenance inspection less than a year before the event. The investigation

Item	UA232	AA383	Comments
Engine Type	CF6-6	CF6-80C2B6	
Engine Serial Number	451-243	690-373	
Time Since New (hrs)	42436	68785	
Cycles Since New	16899	10984	Fan Life Limit 18000 cycles, HPT S2 Life Limit 15000 cycles
Time Since Last Disk Inspection (hrs)	2170	19139	
Cycles Since Last Disk Inspection	760	3057	
Time Since Last Shop Visit (hrs)	2170	8998	Reliability Improvement Program (RIP) SV for AA383, HPT module not disassembled, HPT S2 disk not inspected
Cycles Since Last Shop Visit	760	1451	RIP SV for AA383, HPT module not disassembled, HPT S2 disk not inspected
Installation Date (initial)	6/23/1972	4/30/1998	
Installation Date (final position)	10/25/1988	12/4/2013	

Table 1: Comparison of Event Engine Parameters

would conclude that the crack in the disk was of sufficient size that it should have been detected using the fluorescent penetrant inspection (FPI) process.

2. Both disks did not reach their respective life limits before failing. The UA232 disk was short by 1,101 cycles, and the AA383 disk was short by 4,016 cycles.
3. While rotating component lives are measured in cycles (every takeoff is a cycle), it is interesting to note that in terms of calendar time the UA232 and AA383 engines had initial installations that went back 17 and 18 years, respectively.

Disk anomalies

In both events, nearly all of the fractured pieces of the disks were recovered (see Figure 2), and most importantly these pieces included the primary fracture surfaces. Figure 3 (see page 17) shows the fracture surface of each disk, and Figure 4 (see page 17) shows the close-up of the fracture areas highlighting their respective "anomalies."

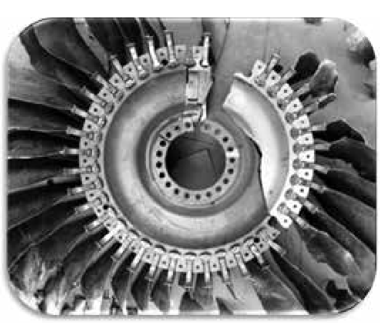
The UA232 disk developed a crack due to a melt-related hard-alpha inclusion on the bore surface. This inclusion was not detected during manufacture due to its subsurface nature and likely uncracked and nonvoided condition, making detection difficult. The AA383 disk developed a crack due to an anomaly called a discrete dirty white spot (DDWS). Like the UA232 disk hard-alpha inclusion, this DDWS was not detected during manufacture because it was subsurface and likely was not cracked or voided.

The UA232 disk was subjected to FPI six times during its service life. It was determined that the crack had broken the surface of the fan disk and should have been detectable at least at the last FPI. The AA383 disk underwent FPI and eddy current inspection (ECI), inspection techniques used primarily to detect surface cracks, twice after entering service. Multiple cracks were observed emanating from the DDWS propagating at various rates with unknown initiation times. Therefore, it could not be determined when the crack broke the surface of the disk bore.

Producing titanium and nickel

UA232 disk: The titanium used to manufacture the CF6-6 fan disk in the Sioux City event was produced in the early 1970s using the Kroll process. In this process, titanium dioxide, called rutile, is reacted with chlorine to produce titanium chloride. This is reacted with sodium to form titanium and salt. The mixture is mechanically broken down into small pieces, and the salt is leached out leaving pure titanium—which is often called titanium sponge due to its appearance. The titanium sponge is mixed with alloying elements and compacted into bricks. The bricks are welded together into sticks in an argon atmosphere to prevent the titanium from reacting with oxygen. The sticks are then melted into an ingot in a vacuum oven in a process called vacuum arc remelt (VAR). At the time that the UA232 disk was made, the VAR procedure was then repeated in what is commonly referred to as a double VAR process.

If the argon atmosphere present during the welding process described above is not pure and there is any oxygen present, the oxygen may react with the titanium forming hard-alpha. A hard-alpha inclusion in titanium can be a source for the initiation of a fatigue crack in a highly stressed part such as a fan disk. Hard-alpha can be formed during other parts of the manufacturing process, but in this instance it was believed to have been formed during the welding of the bricks.



Recovered fragments of the Stage 1 Fan Disk from UA232

Recovered fragments of the High Pressure Turbine Stage 2 Disk from AA383

Figure 2. Disk side-by-side comparison.

Failure Surface of the Stage 1 Fan Disk from UA232

Failure Surface of the High Pressure Turbine Stage 2 Disk from AA383

Figure 3. Failure surface comparison.

The ingot formed after the double VAR process is then extruded into a billet. The extrusion process works the material and may cause any hard-alpha inclusions to crack or void. Subsurface cracks and voids are detectable during ultrasonic inspection (UTI). The billet was subjected to contact UTI during which a UTI probe was moved along the surface of the billet. The billet passed this inspection.

The billet was then cut into mults, which is short for multiples. The mult for the UA232 disk was then forged and rough machined into a sonic shape that was ready for UTI. The part was then subjected to immersion UTI. In this process, the part is immersed in water and the UTI probe is moved around the part but does not contact the surface of the part. Immersion UTI is more sensitive than contact UTI. The UA232 disk passed the immersion UTI.

A macroetch (ME) inspection was also performed on the UA232 disk in the sonic shape as opposed to the final machined shape. This inspection highlights micro-structural changes or anomalies on the surface. The UA232 disk passed the ME inspection. The hard-alpha inclusion located on the bore surface would have had a greater chance of being detected if the part was macroetched in the final machined shape.

The part then went through final machining and was inspected using FPI. In this inspection, the part is immersed in or wetted with FPI fluid. The fluid is then gently rinsed from the surface of the part. The part is then inspected with ultraviolet light. If there are any surface cracks, the fluid should remain in the cracks and glow under the ultraviolet light. No crack indications were found on the UA232 disk.

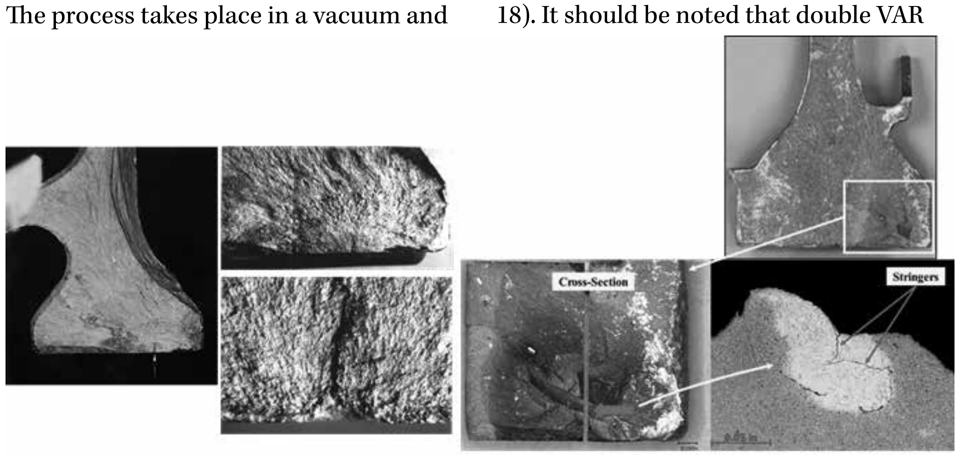
AA383 Disk: The Inconel 718 alloy used for the CF6-80C2 HPT Stage 2 disk in the Chicago event was produced in 1997. The Inconel material was made using a triple-melt process consisting of vacuum induction melt (VIM), electroslag remelt (ESM), and VAR. In the VIM step of the process, the raw material, consisting of the elemental nickel material, master alloy, revert (scrap or chips from previous melts and processes), and reactive material is melted in a vacuum furnace and is poured into ingots. The purpose of this step is to produce the desired chemistry and remove impurities. These VIM ingots are then remelted in the ESR process. In this step of the process, the VIM ingot is lowered into a layer of active/reactive slag. As the VIM ingot melts, the molten droplets sink through the slag removing impurities. The droplets collect into another ingot, the ESR ingot. The purpose of this step is cleanliness of the material. The ESR ingot is remelted again. The process takes place in a vacuum and results in another ingot—the VAR ingot. The purpose of this step is to establish the desired microstructure and serves to further refine the cleanliness.

The ingot then undergoes a billet conversion process, including homogenization and forging. The billet produced from these processes is subjected to immersion UTI. The Chicago event billet passed this inspection.

The billet was then cut into mults. The mult for the Chicago HPT disk was then forged, heat treated, and machined into a sonic shape. The part then underwent immersion UTI, which it passed. After that, the HPT disk went through final machining and processing. It was then inspected using an FPI process, which it passed.

Manufacturing processes

Both the titanium and Inconel processes were considered state-of-the-art at the time the parts were manufactured. The titanium alloy was manufactured using a double VAR process. The industry had since determined that the triple VAR process produced parts that were much less likely to have inclusions such as hard-alpha than the those produced using the double VAR process. As shown in Figure 5 (see page 18), the rates of hard-alpha inclusions and high-density inclusions improved dramatically from the early 1990s to the early 2000s "driven by incorporating prior lessons learned and continuing to pay great attention to detail in the manufacture of premium quality Ti used in critical rotating aircraft engine applications." Since then, the industry has moved to a cold hearth melt + VAR process that has proven to be much better than even triple VAR as shown in Figure 6 (see page 18). It should be noted that double VAR



Anomaly area of the Stage 1 Fan Disk from UA232

Anomaly area of the High Pressure Turbine Stage 2 Disk from AA383

Figure 4. "Anomaly" comparison.

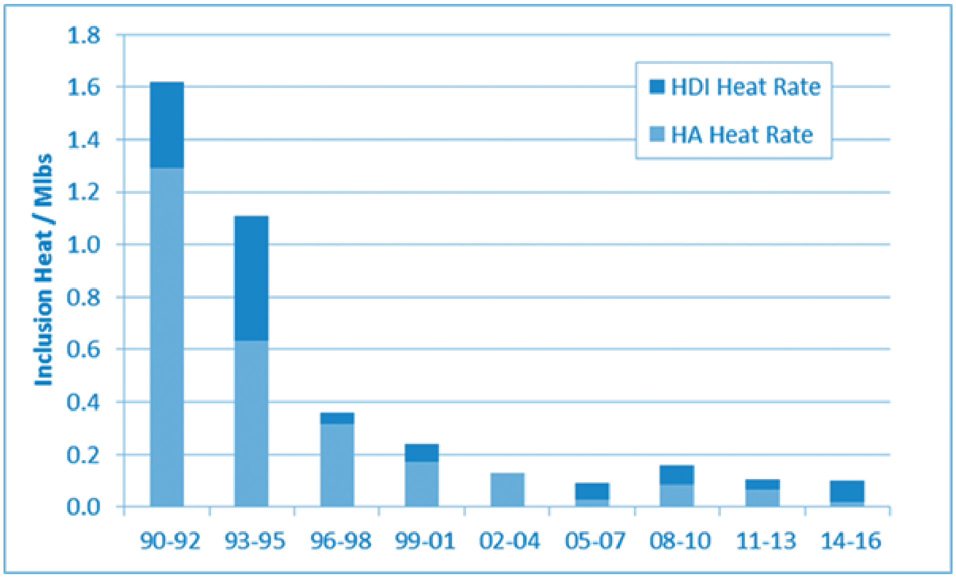


Figure 5. Hard-alpha and high-density inclusion rates from 1990 through 2016 in premium quality titanium.

is still in use by some manufacturers in relatively low-stress applications.

Prior to the 1980s, Inconel was produced using the double-melt VIM + VAR process. The industry developed the ESR process, which greatly improved cleanliness of the material. Around the time of the Sioux City event, GE Aviation converted to the triple-melt VIM + ESR + VAR process for all Inconel critical rotating parts. This process produced high-quality parts. In fact, the AA383 event was the first time that a critical rotating nickel part had failed across the industry. The triple-melt nickel process was refined, and lessons learned were incorporated so that the inclusion rate improved even though the basic triple-melt process did not change. It should be noted that the inclusion rate for Inconel is much higher than for titanium; however, Inconel is also more inspectable and more tolerant to anomalies than titanium. This is in part due to differences in crack initiation and growth rates.

Inspection processes

Both the UA232 disk and the AA383 disk were subjected to UTI and FPI during the manufacturing process. Both were also subjected to FPI and/or ECI after entering service. The UTI process can detect cracks and voids that are subsurface. FPI can detect cracks on the surface, and ECI can detect surface and near-surface cracks and voids. The probability of detection (POD) for each process is less than 100 percent. UTI depends on the orientation of the crack or void relative to the ultrasonic wave. Contact UTI is affected by part geometry, cleanliness, and the couplant used. Following the UA232 event, multizone UTI was introduced, which allowed inspections of much higher sensitivity. Phased array and circ-shear UTI are later methods that also improve the POD.

For FPI, there are many factors that can affect the POD, including the length and tightness of the crack at the surface (which affects the amount of FPI fluid retained), the aggressiveness of the rinsing process, surface cleanliness, and the ability of the inspector to get a clear view of the surface due to factors such as part geometry, lighting, and inspector fatigue (human factors). Also, ME is often used following some manufacturing processes. ME is a chemical treatment of a metal surface to accentuate structural details and anomalies for visual observation. For titanium, GE Aviation uses a process called blue etch anodize (BEA), which, like ME, accentuates differences on the surface of the part for visual detection of anomalies. FPI, ECI, ME, and BEA inspections are effective at detecting surface or near-surface cracks and voids. UTI inspections are effective in detecting subsurface cracks and voids.

Table 2 (see page 19) summarizes the key parameters related to the event disks in terms of the forging and inspection processes used. Figure 7 (see page 19) is a schematic showing the various titanium and Inconel melt processes and high-level manufacturing and inspection steps and their rough timing of implementation.

NTSB recommendations

Table 3 (see page 19) shows a side by side of recommendations from the two NTSB accident investigation reports. Both events had many more recommendations than shown but the ones shown provide some interesting talking points.

1. Both events generate a recommendation that effectively request an evaluation of the state-of-the-art inspection techniques and whether they can be enhanced.
2. Both events spawn a recommendation to revise Advisory Circular 20-128(A) "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure."
3. The UA232 report recommends creating a historical database of rotary part failures that can be used in design assessments and safety analysis. This could be considered a precursor to the initiative to create AC39-8, "Continued Airworthiness Assessment Methodology," released in 2003. This guidance provides the historically based hazard potential for powerplant components and systems.

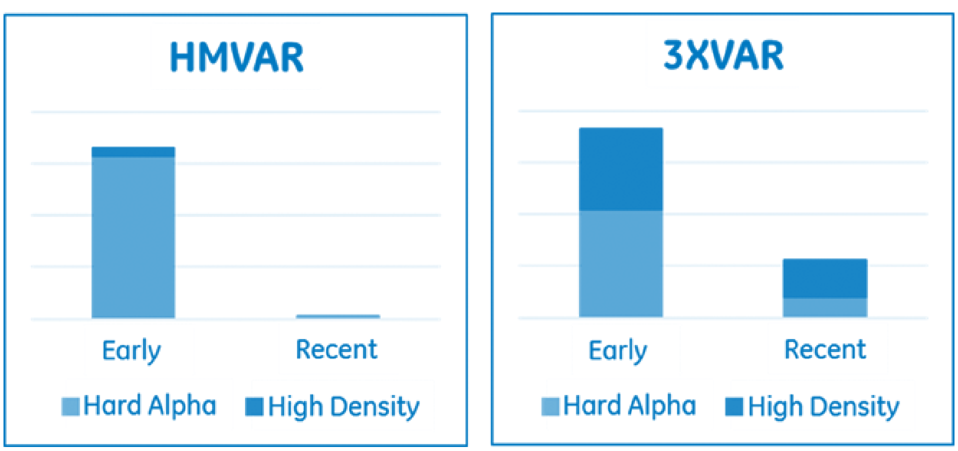


Figure 6. Premium quality titanium hard-alpha and high-density inclusion rates for hearth melt vacuum arc remelt (VAR) and triple VAR.

Discussion

At the time of UA232, capturing a video of a commercial aviation accident was

Item	UA232 Fan Disk	AA383 HPTS2 Disk	Comments
Alloy	Ti-6Al-4V	Inconel 718 (Wrought Nickel Base)	
Final Production Inspection Technique(s)	Immersive ultrasonic, Macro-etch, FPI	Immersive ultrasonic (prior to final machining), FPI	
Forging House	ALCOA / TIMET	ATI Specialty Materials	Histories of the UA232 disk forgings are not straightforward. Details can be found in the NTSB Accident Report.
Melt Date	2/23/1971	6/17/1997	
Melting Process	Double Melt (vacuum arc remelt x 2)	Triple Melt (vacuum induction melt, electroslag remelt, and vacuum arc remelt)	UA232 event disk was part of last heat that used Double melt, subsequent GE specs required Triple Melt
Billet Inspection(s)	Contact ultrasonic	Longitudinal wave water immersion, pulse-echo ultrasonic inspection	

Table 2: Comparison of Disk Forging/Inspection Parameters

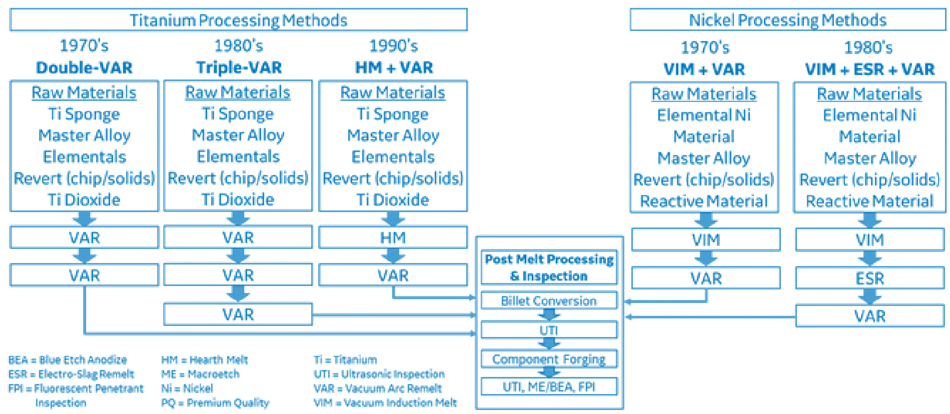


Figure 7. Side-by-side premium quality titanium and nickel processing.

UA232	AA383
Intensify research in the nondestructive inspection field to identify emerging technologies that can serve to simplify automate, or otherwise improve the reliability of the inspection process. Such research "should encourage the development and implementation of redundant ("second set of eyes") inspection oversight for critical part inspections such as for engine rotating components. (Class II, Priority Action) (A-90-167) *Note that this recommendation was sent to the FAA and a similar one was sent to AIA.*	**Establish and lead an industry group that evaluates current and enhanced inspection technologies** regarding their appropriateness and effectiveness for applications using nickel alloys, and use the results of this evaluation to issue guidance pertaining to the inspection process for nickel alloy rotating engine components. (A-18-3) Require subsurface in-service inspection techniques, such as ultrasonic inspections, for critical high-energy, life-limited rotating parts for all engines. (A-18-4)
Analyze the dispersion pattern, fragment size and energy level of released engine rotating parts from the July 19, 1989, Sioux City, Iowa, DC-10 accident and include the results of this analysis, and any other .peripheral data available, in a **revision of AC 20-128** for future aircraft certification. (Class II, Priority Action) (A-90-170)	**Revise Advisory Circular (AC) 20-128A**, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure," based on an analysis of uncontained engine failure data since the time that the AC was issued, to minimize hazards to an airplane and its occupants if an uncontained engine failure were to occur. The revised AC should include modifications to the accepted design precautions for fuel tanks given the fires that have occurred after uncontained engine failures. (A-18-5)
Create the mechanism to support a historical data base of worldwide engine rotary part failures to facilitate design assessments and comparative safety analysis during certification reviews and other FAA research. (Class II, Priority Action) (A-90-172) *Note that this recommendation can be considered a catalyst for AC39-8 Continued Airworthiness Assessment Methodology released in 2003*	

Table 3: Comparison of NTSB Recommendations (Abbreviated and Emphasis Added)

unprecedented. By the time of AA383, the airport tower had complete footage of the event, and passengers disembarking were taking videos of the aftermath. Newspapers told the story of UA232; the Internet captured the images of AA383.

In an evolving aviation system, technological advances and product enhancements are always being made. The 17-year span of the UA232 engine has as its backdrop the worst U.S. aviation accident (AA Flight 191, crash of a DC-10 after takeoff from Chicago O'Hare on May 25, 1979) as well as a string of other major events in the U.S. throughout the 1970s and 1980s. Key improvements during this timeframe include ground proximity warning systems, the advent of crew resource management (a key success factor in the UA232 event), and wind shear systems and detection training. Contrast this to the AA383 engine, which throughout its 18 years in service only two major U.S. domestic airliner events occurred: in 2001, AA Flight 587, an Airbus A300, in Queens, N.Y.—the second worst U.S. aviation disaster; and in 2009, Colgan Air Flight 3407, a Bombardier Dash 8 that crashed on approach to Buffalo, N.Y. Aviation safety within the U.S. national airspace system has improved to a level that there has only been a single fatality on a U.S. domestic airliner since the Colgan Air event just more than 10 years ago.

The manufacturing processes for both Inconel and titanium have seen improvements, but the focus by industry on titanium after UA232 has resulted in a process that minimizes hard-alpha inclusions to a level unimagined in 1971 when the UA232 disk was first forged. This success was driven by a collaborative approach of industry and regulatory agencies. In the wake of UA232, nine U.S. Federal Aviation Administration (FAA)/industry teams focused on the recommendations that the NTSB made as part of the investigation. Of note are the Jet Engine Titanium Quality Committee (JETQC) and the Aerospace Industries of America (AIA) Rotor Integrity Subcommittee (RISC). Inconel has also improved, but its higher tolerance to inclusions, crack initiation, and growth rate made it a lower-risk priority than the titanium activities. On Nov. 7, 2018, the FAA sent a request to the AIA to consider addressing the NTSB recommendations by chartering the longstanding and ongoing JETQC and RISC teams to apply their lessons learned from titanium to nickel alloys. These teams indicated that they would support the effort.

Safety management system

In 2010, the International Civil Aviation Organization (ICAO) released Annex 19, which defines the safety management system (SMS) framework. As of March 2018, all U.S. domestic airlines were required to have an SMS (14 CFR Part 5). In December 2018, GE Aviation was the first original equipment manufacturer (OEM) in the U.S. to receive FAA acceptance of its SMS, an SMS that was in place since January 2013. Within GE's SMS, one of the key learnings as it evolves is to ensure that lessons learned on one program are communicated to other programs. A formal process driving this cross-program review was implemented in mid-2017. As more operators and OEMs move toward SMS implementation and have internal lessons learned, the question should be asked: What forum ensures sharing of these respective findings on an industry, regulatory, global stage?

Summary and conclusions

This paper has reviewed the UA232 and AA383 accidents from an engine perspec-

(Continued on page 30)

ISASI Kapustin Scholarship Essay

The following article is the first of four essays from the 2019 Kapustin scholarship winners that were presented during ISASI 2019. The number of scholars selected each year depends upon the amount of money ISASI members donate annually to the scholarship fund. Details about scholarship applications and additional information can be found on the ISASI website at www.isasi.org. Application and essay deadlines are mid-April of each year.—Editor

APPLYING HUMAN FACTORS TO COMMERCIAL SPACE OPERATIONS

By F/O Stacey Jackson (WestJet), Embry-Riddle Aeronautical University

Aircraft accident investigation is a well developed, yet dynamic, part of the aviation industry. It exists in a constant balance between reactive and proactive actions; reactive in the conclusions and recommendations that are derived from an investigation and proactive in the development and implementation of the various mitigation strategies aimed at preventing a reoccurrence.

The future of aviation is attaining new heights, as the commercial space industry continuously achieves unprecedented successes. Even with exceptional technological advancements, and an evolution in operational environment, spacecraft operators must remember that at least one element has remained constant: the human.

Human error mitigation strategies that have been previously developed for other industries, including aviation, have been established through decades of data gathering and analysis. Failure to implement these strategies will result in the genesis of latent and active errors that when combined with other operational oversights will develop an error chain (Reason, 1990; Wiegmann & Shappell 2003).

Commercial space operators must incorporate the lessons learned through past experiences in related fields to improve future operational safety.

F/O Stacey Jackson

Human factors and commercial space operations

The commercial space industry is one that demands exceptional precision, with little room for errors, and yet it must include the human element that remains fallible in nature. Failing to incorporate error mitigation strategies has severe and often fatal repercussions as evidenced during the in-flight breakup of the reusable suborbital rocket SpaceShipTwo on Oct. 31, 2014. As a result of the investigation, the U.S. National Transportation Safety Board (NTSB) identified seven safety issues that contributed to the accident, one of which was a "lack of human factors guidance for commercial space operators" (National Transportation Safety Board, 2015, p. vii).

The term human factors is often used to describe an exceptionally broad topic that incorporates a vast subject array, including ergonomics, human cognition, sensation and perception, aeronautical decision-making, crew resource management (CRM), human physiology, effective communication, and threat and error management, for example. All of these elements have been incorporated into commercial aviation operations, through the Code of Federal Regulations (CFR) Part 121 and 135, as preventative methods to reduce human errors and improve performance (pilots and flight engineers, 2019; crewmember training requirements, 2019).

Unfortunately, the CFR guidance on pilot licensing for commercial space operations does not mandate a commercial or airline transport license, which could result in a pilot commanding a spacecraft with substandard human factors training, if any at all (crew qualifications and training, 2019). The application of different human factors concepts has greatly improved aviation safety, while improving synergy and teamwork among crewmembers. These concepts will provide a similar benefit to commercial space operations if they are incorporated into regulatory provisions.

Oversight and accident prevention

Title 14 CFR §460 provides federally regulated guidance on training elements that must be incorporated to satisfy the licensing requirements for human space flight (aeronautics and space, 2019). Title 14 C.F.R. §460.15 identifies the necessity of human factors training to incorporate elements that could "affect a crew's ability to perform safety-critical roles" (human factors, 2019, para. 1). This four-item list primarily discusses ergonomics, in an effort to improve the flight crew's operational efficiency and decrease dissonance when liveware interfaces with the hardware and software of a spacecraft (International Civil Aviation Organization, 1993.)

Although important, ergonomics is only one small aspect of human factors. The lack of federally regulated guidance on the additional aforementioned components is a severe detriment to the future of spaceflight safety. Unfortunately, U.S. law has limitations on the authority of the Federal Aviation Administration (FAA) when it comes to regulating the commercial space industry. The U.S. Congress established a dedicated learning period that was extended from Oct. 1, 2015, to Sept. 30, 2023, resulting in the moratorium on the development and implementation of new safety regulations for commercial space operations (Ward, 2016; Reimold & Sloan, 2017).

It would be irresponsible to rely solely on perfect compliance with federal regulations to mitigate the industry from risk, and, as such, commercial space operators must identify the gaps in regulations and mitigate the associated risks. Risk identification and mitigation is a combined effort between several participants, including, but not limited to, the federal regulator and the operator. The creation and implementation of federally regulated requirements provides the necessary foundation upon which operators can build their own defences; however, when this foundation has not yet been developed, it behooves operators to build it themselves.

Operator involvement in accident avoidance

In the late 1970s, it was identified in the first generation of CRM that the aviation industry had an unrealistic expectation of human performance and incorrectly assumed that humans could be trained to execute their duties with zero human error (Helmreich, Merritt & Wilhelm, 1999; Maurino & Murray, 2010). Fortunately, this erroneous thought process was, for the most part, corrected in the subsequent generations of CRM, and appropriate provisions have been in place for the past several decades.

Unfortunately, the assumption that training could result in perfect human performance was one of the primary failures in the hazard analysis that was conducted by Scaled Composites LLC prior to the launch of SpaceShipTwo (National Transportation Safety Board, 2015). The Transportation Safety Board of Canada has identified that the majority of accidents, regardless of size, can be attributed to the failure of an organization to identify and mitigate hazards and manage risk (Fox, 2016).

The aviation industry has spent the better part of 50 years analyzing the limitations of both cognitive and physiological human performance and from this was able to develop and implement mitigation strategies. These conclusions were developed from previous accident investigations, incidents, voluntary reporting, and other forms of data gathering. Even though operations in space likely contain unique elements, the foundation of human performance and error prevention that have been established in the aviation industry is transferrable.

Data application

The purpose of aircraft accident investigation is to develop an understanding of the actions and decisions that led to the unfavorable outcome, and to apply that information to the development of mitigation strategies (Wiegmann & Shappell, 2003; Wood & Sweginnis, 2006). Approximately 80% of all aircraft accidents have some element of human-related error, and it is imperative to apply the lessons learned to future actions in an effort to prevent a reoccurrence (Campbell & Bagshaw, 2002). The aviation industry is well versed with data mining and has identified relationships, links, and trends that have already benefitted aviation safety; but this, too, has its shortcomings.

First, there is not a singular database that contains all of the related information, and as such not every relationship or trend can be identified. Second, the databases that do exist are built on a combination of quantitative and qualitative data, the latter being subject to bottom-up and top-down information processing errors (Gibb, Gray & Scharff, 2010). Information recalled through human memory is never perfect and, as such, cannot be considered a fact. But it is still valuable for the sake of data mining and accident prevention. Third, databases are incomplete as not every incident or accident is reported.

Furthermore, there are situations in which an intervening action caused the cessation of the accident sequence, leaving the crew unaware of the potential disaster that would have occurred. These scenarios are almost impossible to track, simply because it is exceptionally difficult to document an event that did not happen. Clearly, data collection and mining are not perfect but even so provide valuable predictors of future behavior.

How the past predicts the future

Using the central limit theorem, behavioral and social scientists specializing in inferential statistics often witness a normal distribution pattern in the majority of populations in nature (Aron, Coups & Aron, 2011). This results in 68% of the population falling within one standard deviation of the average and 96% within two standard deviations. The distance from the average for any value is derived from a variety of factors, including environmental and educational, as well as the physiological and cognitive abilities of the participant. Values that are found on the extreme of the population curve are referred to as outliers but are rare in populations that follow a normal distribution (Aron et al., 2011).

Understanding that human performance is likely to follow the normal curve, given that the fluctuation of influential variables remains relatively consistent, future human performance can be predicted with relative accuracy based on previously acquired behavioral data (Aron et al., 2011). With relative simplicity, the commercial space industry could implement mitigation strategies to improve human performance during operations in space.

Conclusion

Even though commercial spaceflight is a unique and attractive mode of transportation, there are exceptional risks involved. Human spacecraft operators are fallible, and their performance is comparable to highly trained aircraft pilots. As such, the lessons that have been previously learned in aviation-centered human factors should be evaluated and adapted for flight in space. Furthermore, federal regulations must eventually evolve to develop a satisfactory level of safety that protects the operating crew and passengers from avoidable risks.

In addition, research must be conducted to develop specialized oversight for the commercial space industry, as well as additional education for investigators of spacecraft accidents. Regulations and policies must be created to facilitate data gathering and mining, specific to operations in space, as well as a process for implementing risk mitigation strategies.

The development of safe and efficient commercial space operations is entirely dependent on the ability of industry leaders to remember the past and apply this wealth of knowledge to the creation of future safety measures. ◆

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Julian E.
Echeverri

Anthony T.
Brickhouse

Diego M.
Garcia

LAMIA FLIGHT 2933: WHO LIVED, WHO DIED, AND WHY

By Anthony T. Brickhouse, Embry-Riddle Aeronautical University, U.S.A.; Diego M. Garcia, Embry-Riddle Aeronautical University, U.S.A.; and Julian E. Echeverri, Aviation Accident Investigation Group, Colombian Civil Aviation Authority, Colombia

(Adapted with permission from the authors' technical paper LAMIA Flight 2933: Who Lived, Who Died, and Why *presented during ISASI 2019, September 3–5, in The Hague, the Netherlands. The theme for ISASI 2019 was "Future Safety: Has the Past Become Irrelevant?" The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Introduction

An Avro 146-RJ85, performing charter flight LAMIA LMI2933 for the Brazilian Chapecoense football team, was destroyed after impacting a wooded hillside south of José María Córdova International Airport in Colombia. The official accident investigation board included more than 20 experts from five states. At the end of the investigative process, the board determined that fuel exhaustion was the cause of the crash. Of the 77 occupants on board, only six survived. Five occupants suffered serious injuries, and one sustained minor injuries. Crashworthiness and survivability analyses were performed to assess the conditions that allowed these occupants to survive the crash.

Methodology

It is taught in academic circles around the world that for occupants to survive an accident, specific stipulations must be met. Occupants must have occupiable living volume during the dynamic portion of the crash. Decelerative (G-forces) must be within human tolerances. And occupants must survive all postcrash factors until rescue and medical treatment occur. Air safety investigators use the CREEP (container, restraint, environment, energy absorption, and postcrash factors) methodology to assess the different factors that influence survivability in a crash (see Table 1, page 25). Actual flight data, crash scene analysis, medical and forensic information, and personnel interviews from this accident were gathered to determine acceleration loads, magnitude and duration, aircraft structural collapse, and energy absorption. Injury causation, search and rescue, and health-care services for the aircraft occupants were also explored. All five CREEP factors were depicted and weighted for each one of the six survivors in order to evaluate what specific conditions contributed to survivability.

Results

CREEP elements played different roles for each of the surviving occupants of the accident aircraft. Energy absorption and restraints were decisive for all six survivors. The container was a protective factor for three of them, while environmental factors during the crash dynamics were also important as a protective element. In contrast, postcrash factors were detrimental for all of the six survivors.

Discussion

Occupant survival analyses derived from aviation accidents are crucial for crashworthiness design, but also for education, research, and safety enhancements of current aerospace systems. A comprehensive survival analysis, especially when occurrence circumstances diminish the odds of survival for occupants as in this case, becomes paramount. Research can contribute to enhanced aircraft design and restraint systems, improved emergency services, advanced accident investigation techniques, and in general an augmented awareness and understanding of safety promotion and accident/injury prevention for the general public, operators, and regulators.

Background

The aerospace industry nowadays is labeled as an ultrasafe industry given the safety performance indicators assessed by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA). According to recent research, accident rates were in between 12.2 fatalities per billion passengers in 2017 for the former and 1.35 per billion in 2018 for the latter. Even though these indicators are near their historical best, high-profile accidents involving commercial aviation operators bring high-impact consequences for the general public in terms of trust and willingness to use airline transportation services. Recent studies described a survival percentage of 81% for all aircraft occupants of commercial passenger aircraft accidents, and in 90% of accidents there was at least one survivor.

According to different aspects and elements unique for each one of the occurrences, the outcomes in terms of survivability of an accident are dichotomously categorized as survivable or nonsurvivable. It is not unusual that, in spite of the theoretically exceeded human tolerance capabilities in certain crash events, there are one or more surviving occupants in the aftermath of an accident. This is precisely the case regarding LAMIA Flight 2933 that crashed near Medellin, Colombia, in November 2016 (see Figure 1).

According to the Colombian Aviation Accident Investigation Authority (GRIAA), the accident aircraft, an AVRO 146-RJ85, registered with the tail number CP 2933, was conducting a chartered flight from Viru Viru International Airport in Santa Cruz de la Sierra, Bolivia, to José María Córdoba International Airport (SKRG) in Rionegro, Colombia. The aircraft was carrying the Brazilian football team Chapecoense and some journalist and administrative directives from the team. During a holding pattern waiting to be authorized to intercept the localizer for the approach to Runway 01 of José María Córdova International Airport, the aircraft suffered a sequential flameout of its four engines and impacted the southern slope of a mountain located 10 nautical miles south of the threshold of Runway 01 of SKRG at 02:59 Zulu time at night during rainy weather conditions.

The investigation process identified the following causal factors:

- Inappropriate planning and execution of the flight by the operator in regard to the amount of fuel required for the safe completion of the intended flight.
- Sequential flameout of the four engines as a consequence of fuel exhaustion.
- Inadequate decision-making on the part of the aircraft operator in terms of the implementation of operational safety in its processes.
- Loss of situational awareness and wrongful decision-making by the flight crew because of the fixation of continuing the intended flight with an extremely limited amount of fuel.

There was no postimpact fire, and the aircraft was destroyed as a result of the crash. Of the 77 occupants, 71 perished and six survived with serious and/or minor injuries. Despite the high-energy impact, the almost complete destruction of the airframe, the rough environmental conditions after the crash, and the limited first responders' assistance secondary to the geographic conditions of the accident site and the accessibility from there to health-care services, eight survivors were found among the wreckage at the accident site. Unfortunately, one of these survivors was lost at the crash site before the evacuation, and another died from his injuries at the regional hospital shortly after arrival.

After taking into account these different factors, accident investigators can point to one or more of these elements as the potential source(s) of injuries to occupants and the different levels of injury severity generated by their interaction.

After an accident investigation, fatalities and both severe and minor injuries are explained in terms of CREEP elements for the specific occurrence and the specific conditions that each accident presented to occupants. This depends on their position in the airframe, the energy amount and dynamics of the crash, the correct and effective use of different types of restraining systems, their opportunity to egress the scene, and the support received after the event, among other factors. When the investigation process determines that all these elements were against occupant survival, yet one or more occupants survived, other analysis and factors should be considered. This is the case with LAMIA Flight 2933. The objective of the present study is to analyze the different elements of CREEP methodology for the six survivors of the flight.

Kinematics

For the survival factors analysis specific to the crash of LAMIA Flight 2933, the authors of this study referred to the official final report published by the Colombian Civil Aviation Authority (CAA) and GRIAA, where crucial data are depicted and analyzed. Data included weight and balance, speed, distances, accelerations that were mainly retrieved from the flight data recorder (FDR), cockpit voice recorder (CVR), and operational records and forms. The final report included photos, diagrams, formulas, and calculations for relevant information related to injury causation to occupants. Other publicly available resources such as interviews, expert analysis, documentaries, press releases, and reports were also taken into account.

Following the procedure for CREEP analysis, the authors weighted and modeled all the available information in order to build a general, unified model for the entire airframe and for all occupants. Afterward, a detailed analysis for each one of the surviving occupants was conducted in terms of energy absorption, container preservation, restraint elements, and environmental and postcrash factors. This was done to explain the potential conditions and factors that determined the survivability of six of the 77 occupants of the ill-fated flight.

The first approach for the analysis was energy calculations. This was accomplished using the FDR data, crash scene distances, wreckage distribution, and forensic analysis for specific injuries evidenced in both fatal and nonfatal victims of the crash. This was done to determine

Figure 1. An Avro 146-RJ85.
Source: GRIAA. Final Report. Accident. COL-16-37-GIA Fuel Exhaustion AVRO 146-RJ85, Reg. CP 2933 Nov. 29, 2016, La Unión, Antioquia, Colombia.

Acronym	Factor	Explanation
C	Container	The available living space for occupants resulting during and after the accident dynamics.
R	Restraint	Seats, seat belts, and other restraint systems protecting occupants from being injured by other structures and elements, and preventing them from being projected inside and outside of their living space.
E	Energy	The deceleration forces experienced by occupants during the crash; since occupants are not a fixed part of the airframe, energy can be either attenuated or amplified.
E	Environment	All the surrounding factors created by the crash that can injury occupants, like fumes, extreme heat or cold, toxic materials, or fast-moving objects within their living space.
P	Postcrash Factors	All the different situations and elements that can affect occupant survival after the dynamic portion of the accident. Postcrash fire and smoke, wreckage evacuation, and search-and-rescue systems are the most relevant elements under this domain.

Table 1. CREEP survivability methodology

the acceleration pulse shape and duration and the onset rate and the magnitude for energy vectors (horizontal and vertical acceleration) using the following equations:

Horizontal G calculation for triangular pulse:

$$G_H = \frac{V_{H1}^2 - V_{H2}^2}{gS_H}$$

Vertical G calculation for triangular pulse:

$$G_v = \frac{V_v^2}{gS_V}$$

Pulse duration:

$$t = \frac{2(V_{v1} - V_{v2})}{gG_v}$$

Where the following:
GH = Horizontal G loading
VH1 = Initial impact velocity
VH2 = Secondary impact velocity
g = Acceleration of gravity
SH = Horizontal deceleration distance
Gv = Vertical G loading
SV = Vertical deceleration distance

The second approach for the analysis was the CREEP study for estimating the resulting living space during and after the dynamic portion of the crash, the restraining systems' characteristics, usability and effectiveness for the surviving occupants, and factoring environmental and postcrash aspects affecting the occupants' possibilities of receiving timely medical assistance, treatment, and recovery.

Finally, a resulting model based on an analog scale comparing the estimated contribution of each one of the CREEP elements was consolidated for each one of the surviving occupants.

Results of kinematics

For energy calculations, estimated weights, distance, and speeds were derived from dispatch records and FDR-related elements. This was done in order to replace available terms of the energy magnitude and duration equations. Based on the data and scene and impact dynamics reconstruction, it was determined that after the initial impact at the top of the hill, a descending energy dissipation trajectory (approximated 55-degree slope) was generated along a magnetic course of 296 degrees, continuing for around 140 meters (462 feet) downhill on the northern slope of the ridge. This is where the majority of the aircraft wreckage came to rest almost completely destroyed. The only recognizable sections of the airframe were the tail and empennage section (which was preserved and found at the top of the hill slightly behind the initial impact site) and the right wing with a small fuselage section attached directly below it (see Figure 2). Final distribution and destruction level of the debris also suggested that the main wreckage dissipated the remaining postimpact energy in a snowball-like pattern, with its center in the front portion of the fuselage, which was also the most badly destroyed. This final distribution pattern also explains the

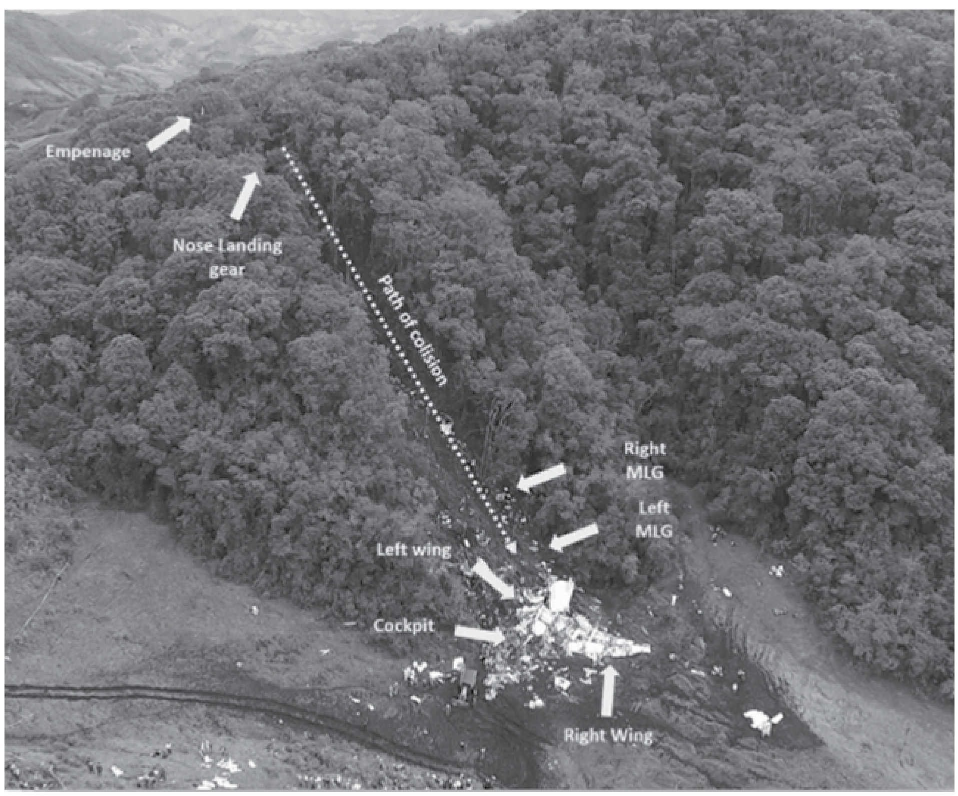


Figure 2. Postimpact path and main wreckage location.
Source: GRIAA. Final Report. Accident. COL-16-37-GIA Fuel Exhaustion AVRO 146-RJ85, Reg. CP 2933 Nov. 29, 2016, La Unión, Antioquia, Colombia.

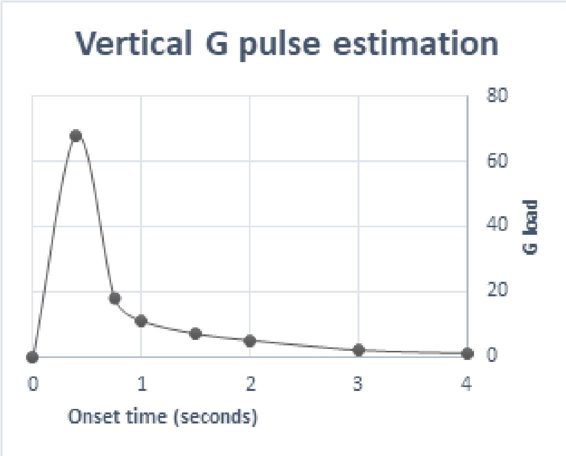


Figure 3. G loads and onset time modeling.

final location of most of the deceased passengers, especially those who probably were not using any restraint system at the moment of the initial impact.

The resulting energy calculations for a triangular pulse showed a peak around 70 Gs in the vertical axis at approximately 0.6 seconds, with an initial rapid deaccelerating force until around 0.8 seconds and then a more steady deceleration until around 4 seconds after the initial impact (see Figure 3).

Moving forward into the model, the approximate location of the six surviving occupants in the aircraft at the moment of the initial impact was assessed to determine the container's integrity, the restraint conditions, and environmental aspects such as potential blunt and penetrating trauma produced by fast-moving and high-energy elements surrounding them during the dynamic portion of the crash. To perform this assessment, the approximate occupant distribution within the aircraft cabin and type of injuries were taken into account (see Figure 4).

For occupants 1 and 2, the initial impact was estimated to have occurred right below and behind their seats. The energy affectation and dynamics experienced by these two occupants was different from the other four occupants since their seats were rear facing and supported by a structural wall dividing the galley from the rest of the passenger cabin. The container element for these two occupants was protective at least for the initial sequence of events, after which they were likely ejected from the airframe and were recovered near the empennage section according to rescuer statements and their own narratives.

Occupant 3 was recovered outside of the main wreckage on higher ground compared to the rest of occupants and main wreckage. For this occupant, there was not enough evidence to determine if the container played a protective role, but the probability is low given the injuries received by the close and immediate passengers around him and the condition of the container at the section where he was estimated to be seated.

For occupants 4, 5, and 6, it is highly probable that the container aspect was the most protective element, since evidence from the final wreckage revealed that the upper section of the fuselage, below the attachment to the right wing, was the only fuselage section that was almost intact after the crash impact.

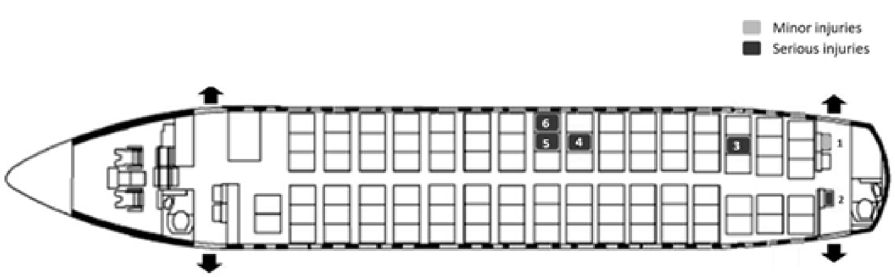
Restraint

The restraint element, along with energy absorption, was factored into the type and relatively low severity of the injuries of occupants 1 and 2. As previously mentioned, these two occupants were rear facing, wearing four-point restraint systems. These restraints offered extra protection and prevented further injuries from decelerating forces and during the dynamic part of the accident. For occupant 3, rescue personnel stated that he was attached by his two-point seat belt to the middle seat of a row of three, where the occupants to his left and right side were found fatally injured and also attached to their respective seats. These findings indicate that the restraint systems might have played a crucial role in the survival of this occupant.

Occupants 4, 5, and 6 were using two-point restraint systems like the rest of the passengers. According to their statements, they were using the seat belts at the time of the initial impact. This most definitely contributed to their final survival. For all the seats on the ill-fated aircraft, the G loads encountered by the airframe and the attaching structures were well beyond the threshold that they can support by design (usually 16 Gs for passenger seats). Most of the recovered bodies from the crash site were found restrained to their respective seats, but a significant number of bodies were recovered outside the main wreckage, along the path of postimpact energy dissipation. This is a good indicator that those occupants might not have been wearing their respective restraint systems at the moment of the accident.

Energy absorption

The energy absorption and dynamics for the six surviving occupants represent special difficulty for a general modeled assessment. It is highly probable that all six of them received high decelerating G forces at the moment of the first impact (around 70 Gs on the vertical axis). Because of the direction of the higher G peak, the seat design, and according to Eiband curves, this energy load might have been survivable for most of the occupants. Unfortunately, energy dissipation and injury prevention that would have allowed them to survive the dynamics of the crash were decidedly influenced by the other four elements of the CREEP model.



Person	Aprox. Location (According to survivors statements)	Injuries
1	Right AFT section	Lacerations, Contutions
2	Left AFT section	Polytrauma
3	Near to Right Wing	Polytrauma
4	Near to Right Wing	Polytrauma
5	Near to Right Wing	Polytrauma
6	Rear fuselage section	Polytrauma

Figure 4. Approximate distribution and injuries of surviving occupants.
Adapted from GRIAA. Final Report. Accident. COL-16-37-GIA Fuel Exhaustion AVRO 146-RJ85, Reg. CP 2933 Nov. 29, 2016, La Unión, Antioquia, Colombia.

Environment

Environmental aspects during the dynamic portion of the crash behaved differently for the six surviving occupants. For occupants 1 and 2, due to their facing toward the rear of the aircraft, the container and restraint factors, and ejection outside of the main wreckage, the other elements moving with very high energy did not represent any injury risk for them. This was also true for occupant 3. A different scenario existed for the other three surviving passengers, since they were seated in the middle section of the fuselage, where most of the occupants received fatal blunt injuries from the heavy and fast-moving elements inside their occupiable space. These elements were seats, luggage, interior cabin structures, and other passenger bodies. For occupants 4, 5, and 6, this element was most likely attenuated by the fact that during the crash dynamics, the fuselage broke into three main sections: one containing the front part of the fuselage, including the flight deck, which was destroyed and mostly disintegrated; the middle section, which included their location and which was fairly preserved around the right wing, precisely where they were seated; and a third section right behind the seats of passengers 4, 5, and 6, which was also completely destroyed.

Postcrash factors

Postcrash factors were determined to be detrimental for all six surviving occupants. Eight occupants survived the dynamic portion of the crash, but unfortunately two perished either during the evacuation or shortly after arriving at an appropriate medical facility. This was the result of persistent rain and cold temperatures, the high altitude, and the long response times for rescue teams because of the relative remoteness of the crash site. The rescue efforts were complicated by the nonexistent access roads to the site and the unavailability of air rescue services. Despite those adverse factors, rescue teams evacuated all survivors on stretchers by foot for at least one kilometer (0.6 miles) to a narrow unpaved road where ambulances and rescue vehicles could pick them up for an approximately hour-long drive to the nearest health-care facility. Also noteworthy was that occupant 4 was rescued from the wreckage with serious injuries approximately four hours after the crash.

Figure 5 shows the summary model for all CREEP-related elements for all six surviving occupants.

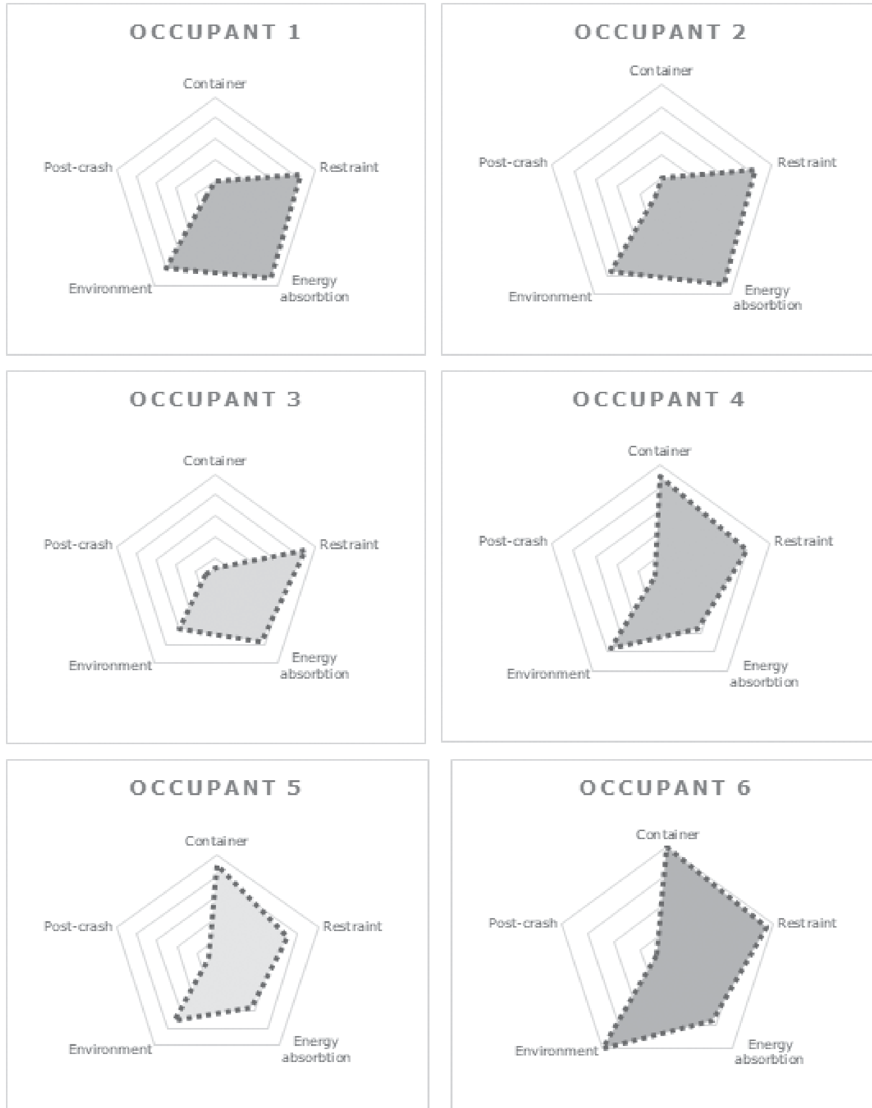


Figure 5. Surface graphs for CREEP element analysis for each surviving occupant.

Survivability and future safety

Future safety is the aim of any aircraft accident investigation. For survival factors, investigators must ask: If the same accident occurs again, will the outcome for occupant survivability be improved? If a similar accident to LAMIA Flight 2933 occurs again, will more than six passengers survive? Hopefully the answer to each of these questions will be a resounding yes, but this will not happen automatically. Occupant survival analysis derived from aviation accidents is crucial for crashworthiness design, but also for education, research, and safety enhancements to current aerospace systems—not to mention search-and-rescue teams and first responders for events of such magnitude.

The safety performance of the aerospace industry is currently at its best, but when accidents occur, survivability of occupants is still a topic with significant opportunities for improvement. A comprehensive survival analysis, especially when occurrence circumstances diminish the odds of survival for occupants like those in this particular case, can contribute to the enhancement of aircraft design and restraint systems, the improvement of emergency services, and the advancement of accident investigation techniques. In general, an augmented awareness and understanding of safety promotion and accident/injury prevention for the general public, operators, and regulators can also occur.

CREEP analysis presents a comprehensive inventory of factors to take into account when evaluating the different circumstances that contribute to occupant injury causation and severity in an aircraft accident. Yet more research is needed regarding possible redesign or reevaluation of the CREEP model to assess new and developing factors. Some of the factors that could influence the future of the current CREEP model include newer aircraft seats and pitches, composite materials, and supersonic air transport. A redesigned CREEP model should also account for personnel variability and individual conditions such as age, fitness, physical condition, and gender. ◆

SERC Meeting Held in Atlanta

The Southeast Regional Chapter (SERC) of ISASI recently held its annual meeting with Delta Air Lines as a cosponsor, reported SERC Secretary Alicia Storey. This meeting, which marked SERC's 10th anniversary of holding annual meetings, included a half day of hands-on enrichment education and a full day of presentations given by world-class speakers. The 2019 event was held August 2–3 in Atlanta, Georgia, U.S.A., at the Delta Air Lines training center. Forty-six SERC members attended, representing about a third of the SERC membership.

The Flight Safety Division of Delta Air Lines orchestrated Friday afternoon activities that included various tours of the Delta Air Lines training complex. SERC attendees were divided into three groups and were given comprehensive tours of Delta's in-flight training school, Delta's Simulation Division (where SERC attendees were able to command an MD-88), and received an overview and tour of Delta's operations customer center where all worldwide operations and movements are tracked 24/7.

Delta Air Lines dedicated no less than nine professionals to ensure SERC attendees were given a comprehensive experience that spanned from 1:00 p.m. to past 5:00 p.m. The National Air Disaster Foundation (NADF) hosted a Friday evening dinner for all attendees at Lickety Split near the hotel. The restaurant closed exclusively for the group.

On August 3, SERC meeting attendees participated in a full day of presentations at the Delta training center. These presentations included

- "The Importance of High Load Event Reporting" by Arben Dika, Aeronautical Accident and Incident Investigation Commission, Republic of Kosovo.
- "An Overview of the NADF" by Matt Ziemkiewicz, NADF president, and Gail Dunham, NADF executive director.
- "Fire and Explosion Investigations" by Anthony Brickhouse, Embry-Riddle Aeronautical University.
- "Daylight Black Hole Approaches" by Glenn Grubb, deputy director, international aviation safety, JAARS, Inc.
- "Accident Investigation/Engine Examination" by Bryan Larimore, accident investigator, Safran Helicopter Engines.
- "Investigation Discoveries: The Party System Effectively Unraveling Causality" by Tom Huff, senior aviation safety officer, Gulfstream Aerospace.
- "Taxonomy of Language as a Factor in Aviation Safety" by Elizabeth Mathews, Embry-Riddle Aeronautical University.

Speakers came from near and far for this 10th anniversary event. The day ended with a dinner at Malone's Steak and Seafood.

SERC will be evaluating a 2020 location for its annual meeting, including Memphis, Tenn.; Charleston, S.C.; or Mobile, Ala. ◆

PNRC's Fall Meeting Featured Barry Latter

ISASI's Pacific Northwest Regional Chapter (PNRC) held its fall meeting October 16 at the Museum of Flight in Seattle, Washington, U.S.A., reported Jeanne M. Elliot, PNRC secretary-treasurer. The featured speaker was Barry Latter, a well-known aeronautical engineer, aviation historian, and museum docent. Latter, born and educated in Britain, worked for the Hawker Siddeley Group prior to immigrating to the U.S. in the mid-1960s. He joined Boeing Commercial Airplane Company and made his mark as Boeing's chief engineer for the B-747/-767/-757/-737 Airplane Performance & Airworthiness Group.

Barry Latter gives a presentation during the Pacific Northwest Regional Chapter's fall meeting.

Latter's presentation, "Design and Operation for Flight Safety," provided a review of the historic origin of Boeing's "lessons learned" philosophy drawn from early accidents to establish a design process that gives an assurance of built-in safety from the outset. Guidance from FAA regulations and their significance were discussed, along with changes brought about by composite airplane structure and the introduction of digital electronics. Latter pointed out that one major change in safety design philosophy occurred in the 1970s with the advent of digital electronics, a subject he was personally involved with through B-747, -767, and -757 propulsion system design, test, and certification.

A highlight of Latter's remarks involved his personal experience in investigating several specific accidents and the lessons learned as a result. These remarks brought forth a healthy exchange of Q&As at the conclusion of his remarks.

The meeting also included a secretary-treasurer's report that summarized the chapter's financial status, along with an update on membership. PNRC President John Purvis provided further remarks relating to membership retention and recruitment. Participants agreed that the chapter's goal for 2020 should focus on stronger partnerships in the aviation community represented in Seattle and the promotion of ISASI to increase membership numbers and involvement. The chapter's program schedule for 2020 is currently under review. ◆

The Museum of Flight near Seattle, Washington, U.S.A.

ESASI Seminar Set for June 2020 in Budapest

Steve Hull, European SASI (ESASI) secretary, announced that the 10th ESASI seminar will take place in Budapest, Hungary, on June 3–4, 2020. The seminar will be held in conjunction with the European Civil Aviation Conference Air Accidents and Incidents Investigations that will be scheduled on June 2, 2020.

The aim of the seminar is to keep the European air safety investigation community abreast of current developments and evolving best practice in aircraft safety investigation. As in previous years, the seminar will include presentations on case studies, the European environment, challenges of modern air

Annual Dues Notice

Please note that ISASI annual dues payments are due by Jan. 31, 2020. Payments to the ISASI office can be made by check or credit card. Members in Austraila, Canada, and New Zealand should direct annual dues payments to their respective national society offices. Members who are not current are no longer eligible to participate in Society elections, meetings, and nominations for special recognition. In addition, they will not receive Society publications and other communications.

On October 23–24, ISASI International Councilor Caj Frostell, left, met with Dr. Abdallah Falah Alsamarat, director of the Aircraft Accident Investigation Department, Jordan Civil Aviation Regulatory Commission in Amman, Jordan. The trip also included a visit to Mount Nebo and the city of Madaba. ISASI and Middle East North Africa SASI seminars were discussed and promoted as inexpensive additional training activities.

safety investigations, and human factors in aircraft accidents and incidents. ◆

Scholarship Applications Due Mid-April 2020

The deadline for applications and essays for ISASI's 2020 Rudolph Kapustin Memorial Scholarship comes in mid-April of each year. Scholarship recipients are eligible for

- funded attendance at ISASI's annual seminar. A award of $2,000 will be made to each student who wins the competitive writing requirement, meets the application requirements, and registers for the ISASI 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 borne by the recipient. ISASI will assist with coordination and control the expenditure of funds.
- a one-year membership to ISASI.
- tuition-free attendance to ANY regularly scheduled Southern California Safety Institute course. This includes the two-week Aircraft Accident Investigator Course or any other investigation courses. Travel to/from the course and accommodations are not included. More information is available at www.scsi-inc.com.
- a tuition-free course from the Transportation Safety Institute. Travel to/from the course and accommodations are not included. More information is available at www.tsi.dot.gov.
- tuition-free attendance at Cranfield University Safety and Accident Investigation Center's five-day Accident Investigation Course, which runs as part of the university's master's degree program at the Cranfield campus, 50 miles north of London, UK. Travel to/from the course and accommodation are not included. Further information is available at www.csaic.net.

For details, application forms, and additional information, go to the Awards tab at www.isasi.org. ◆

Lederer Awards Applications Due Mid-April 2020

The Jerome F. Lederer Award is ISASI's highest recognition for air safety. Any member of ISASI in good standing may submit a Lederer Award nomination to the 12-person selection committee, which considers such traits as persistence, standing among peers, manner and techniques of operating, and achievements. Nominations for the Lederer Award are limited to a single-page submission. Nominees not receiving the award are reconsidered for three years and may be nominated again after an intervening year.

Nomination statements should emphasis an original and remarkable contribution and personal effort beyond normal duty requirements. The award may be given to an individual, group, or organization and may recognize a single event, series of events, or lifetime achievement. The nominee does not have to be an ISASI member.

Nomination forms and additional information can be found on the Awards tab at www.isasi.org. ◆

In Memoriam
DFRC Member Bryan Roberts Passes Away

ISASI recently received notice that member Bryan Roberts passed away on Sept. 14, 2019, in Fort Worth, Texas, U.S.A. He will be remembered as a loving husband, father, friend, and colleague to all who knew and loved him.

Bryan was a professional air traffic controller and a proud member of the National Air Traffic Controllers Association at the time of his death. His interest in aviation began in high school when he received his private pilot's license. Shortly after high school, Bryan entered the U.S. Army, proudly serving his country in the states and in Korea as an air traffic controller. It was in Korea that he met his wife, Hannah. After they were married and Bryan had separated from the Army, he was hired by the U.S. Federal Aviation Administration. He then completed his bachelor's degree at Embry-Riddle Aeronautical University and became one of the most respected and admired air traffic controllers. He also represented NATCA as a member of the U.S. National Transportation Safety Board accident investigation team. He always had a ready smile for those he worked with and everyone he encountered in his professional life.

COMPARING UA232 AND AA383 UNCONTAINED EVENTS

(Continued from page 19)

tive. Key similarities include

- Initiation of both events was the crack propagation of a disk defect to the point of disk fracture.
- The disk failures subsequently impacted aircraft systems. For UA232, the hydraulics system and for AA383 a puncture of the right-wing fuel tank.
- Both disks fractured before their designated life limit.
- Production and operational inspections did not find the defects/cracks.
- The introduction of the anomalies in the disks was during the forging process.
- Recommendations from both accidents are similar regarding engine rotating part processing and inspection—they need to be improved/enhanced.

Several differences are worth noting

- UA232 was a fatal accident with 111 fatalities, AA383 had 21 injuries (1 serious, 20 minor).
- The AA383 event was the first time that a critical rotating nickel part had failed across the industry. Hard-alpha issues with titanium disks had occurred multiple times prior to UA232.
- Post UA232, the industry/regulatory collaboration in activities related to understanding, improving, and enhancing titanium forging and inspection processes is the model for addressing complex issues. However, the comparison here does show that it is critical that lessons learned in one part of our industry need a forum to communicate learnings in support of SMS activities. ◆

Southern California, Thomas Anthony (thomasa@usc.edu)

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Military Air Safety Investigator, James W. Roberts (james.w.roberts3@boeing.com)
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Unmanned Aerial Systems, Tom Farrier (farrierT@earthlink.net)

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ISASI
107 E. Holly Ave., Suite 11
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ISASI 2020 SET FOR MONTRÉAL, CANADA

Barbara Dunn, ISASI 2020 Host Committee chair, reports that the Society's annual international accident investigation and prevention conference will be held Sept. 1-3, 2020, in Montréal, Qué., Canada, with optional tutorials on August 31 and an optional tour on September 4. The Canadian Society of Air Safety Investigators is the host organization. The committee selected Le Centre Sheraton Montréal, a nonsmoking facility, as the site of the conference. The theme for the meeting is "2020 Vision for the Future." Technical presentations will address the theme as well as relevant air safety investigation processes, case studies, and techniques.

A preliminary program includes:

- Monday—Tutorials on winter operations and military investigations and a welcome reception.
- Tuesday—Technical program, companions tours of Montréal, national and society meetings, and an off-site dinner.
- Wednesday—Technical program, companion tours of Montréal; working group meetings, and a free night.
- Thursday—Technical program and awards banquet.
- Friday—Optional tour of Montréal.

Hotel registration and site facility information will soon be posted on ISASI's website, www.isasi.org, as well as a call for papers with procedures and submission deadlines.

Travel information includes:

- Currency—Most Canadian businesses accept major credit cards and U.S. and Canadian dollars, although the exchange rate will be better at a bank or ATM.
- Taxes and tipping—For all purposes, purchases show prices without local taxes. Goods and services tax and provincial sales tax will be added to the final bill. Tipping restaurant service providers is expected and can range from 15 to 20 percent depending on the level of service.
- Visa information—For Canadian visa requirements, go to https://www.canada.ca/en/immigration-refugees-citizenship/services/visit-canada/entry-requirements-country.html.
- Climate—August and September in Montréal can be warm and humid with temperatures at 20°C/68°F during the day and cooler during the evening.
- Language—English and French are the two official languages of Canada. Montréal is a cosmopolitan city and both languages are available, but signs and conversation are predominately in French.
- Voltage—120V with a frequency of 60 Hz; power plugs and sockets are Type A, mainly used in North and Central America, China, and Japan; and B, similar to A but with a ground prong.

About Montréal

Montréal is the second-most populous city in Canada and the largest in the province of Québec. The city occupies about 75 percent of Montréal Island, the largest of 234 islands of the Hochelaga Archipelago. The city began as a French missionary settlement in the 16th century and became a fur-trading center that grew in size and commerce after the British conquest of New France in 1763. Its advantageous location on the St. Lawrence River allowed the city to become a transportation, manufacturing, and financial center. At the time of the confederation of Canada (1867), Montréal was Canada's largest city until Toronto claimed that title in 1970. ◆

ISASI 2020
"20/20 VISION FOR THE FUTURE"