FORUM

ISASI

Air Safety Through Investigation

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AIR SAFETY INVESTIGATORS
INCORPORATED AUGUST 31, 1964

YOUR NEW PRESIDENT

Greetings from Canada. I'm thrilled to be the first woman and first flight attendant to hold the position of ISASI international president. It's an honor and a privilege that I won't take lightly. Your Executive officers are now truly international in nature, with representation from the European, U.S., and Canadian Societies. We'll do our best to ensure that all national societies are represented equally in everything ISASI does.

I have big shoes to fill. Frank Del Gandio led ISASI through many years of growth, and we were fortunate to have him in the position of president. Frank will continue to be a member of the International Executive officials as executive advisor and Dick Stone as communications advisor. I'm grateful for their continuing support. Others like Ron Schleede and Bob MacIntosh have given tirelessly of their time and have always been there to keep the Society on the right track. They deserve our thanks for their many years of service. It's important to remember that all of your Executive Officers are volunteers, working for ISASI with no financial remuneration. I look forward to working with Rob Carter, Chad Balentine, and Eric Prince along with society presidents and committee and working group chairs to ensure that ISASI remains at the forefront of the aviation investigation community.

I haven't had the opportunity to meet all of you, so I thought it would be appropriate to provide you with bit of my background. I joined Air Canada in 1971 as a cabin crewmember and very quickly became interested in cabin safety. The flight attendant union persuaded me to take on the role of Cabin Safety Committee chair, and the rest, as they say, is history. I soon realized that cabin safety wasn't receiving the attention it deserved from the regulatory and investigation community, so I made it my mission to bring about change.

I joined ISASI in 1990, and in 2003 I was appointed Seminar Committee chair, a role I held until now. It was also my privilege to hold the position of Canadian SASI president from 1994 until I stepped down in 2021. I've been a member of several industry groups, including representing ISASI on the International Civil Aviation Organization's Cabin Safety Group and have taught accident investigation courses for the University of Southern California and the Southern California Safety Institute.

Fatal accidents are becoming fewer in number, due in large part to the work of ISASI members worldwide. Improvements in cabin crew training, design features such as floor-level lighting, fire-retardant cabin materials, and increased seat strength, to name just a few, have all gone a long way toward increasing survivability.

While I looked for someone to take over as seminar chair, I've been reviewing some of the information on past seminars. ISASI's first annual seminar was held in Washington, D.C., in 1970. Since then, we've been to Canada (Toronto, Ottawa x 2, Montréal, Vancouver x 2, Victoria, Halifax), the U.S. (Washington, D.C. x 6, Los Angeles, Seattle x 2, San Francisco x 2, Dallas x 2, Chicago, Scottsdale, Atlanta, Anchorage, Boston, Orlando, Salt Lake City, Baltimore, San Diego), the UK (London, Shannon), Germany (Munich, Augsburg), France (Paris), Spain (Barcelona), Iceland (Reykjavík), the Netherlands (The Hague), Israel (Tel Aviv), United Arab Emirates (Dubai) Australia (Canberra, Adelaide, Brisbane), New Zealand (Rotorua, Auckland), Venezuela (Caracas), Mexico (Cancun), Taiwan (Taipei), Singapore, and Japan (Sapporo). An impressive list by anyone's count. We've covered such topics as lessons learned, accident prevention, incidents to accidents, cultural differences, future challenges, and safety management systems, to name just a few. It's my firm belief that we've made a difference and have been part of the reduction in worldwide aviation accidents.

It's my hope that ISASI will continue to grow over the next few years. The aviation industry has changed a great deal during the past years, and ISASI must keep up.

COVID has taken its toll, and we must think of new ways to keep the organization current while meeting the needs of our members. I hope that more of you will want to become involved. With this in mind, an e-mail has gone out to all members asking them to consider being part of our Reachout program. We need new and current instructors to keep the program viable. We also need states and organizations that would benefit from our specialized training to make their needs known so that we can tailor a program to meet their requirements.

ISASI 2022 in Brisbane was a huge success with more than 350 delegates in attendance both in person and virtually. Unfortunately, I wasn't there in person but joined virtually for all the presentations. I was pleased to note the international makeup of both attendees and speakers with representation from 29 countries. My thanks to all those involved in putting the program together.

While it's obvious that many of you are still exercising caution when it comes to travel, it's my sincere hope that we'll be able to meet in person in Nashville, Tenn., at ISASI 2023, Until then, stay safe and healthy. ◆

Barbara Dunn
ISASI President

ISASI 2022

The International Society of Air Safety Investigators held its 52nd annual International Accident Investigation Conference at the Pullman Hotel in Brisbane, Queensland, Australia, August 30–September 1. It was organized principally by the Australian Society (ASASI).

The organizers adopted a "hybrid" format, allowing for both remote and in-person attendance. There were no pre-seminar tutorial sessions, formal Society and working group meetings, military workshops, or companion program. In-person attendance was gratifyingly respectable at 220, with an additional 116 attending online. Participants represented 29 countries.

Tuesday, August 30

ISASI President Frank Del Gandio was not able to attend in person. The seminar was opened by John Guselli, president of ASASI, and Robert Carter, vice president of ISASI. Guselli welcomed the attendees and outlined the program, and Carter gave a brief update on ISASI elections, with Barbara Dunn as the president-elect, Rob Carter as vice president, Chad Ballentine as secretary, and Eric Prince as the new treasurer. Guselli then introduced the first keynote speaker, Angus Campbell, chief commissioner of the Australian Transport Safety Bureau (ATSB).

ASASI President John Guselli and ISASI Vice President Robert Carter open ISASI 2022 in Brisbane, Australia.

Some 220 in-person participants gather in Brisbane, Australia, for ISASI 2022, and 116 participate online.

ISASI 2022 Technical Program

Keynote: Prioritizing Emerging Safety Trends in the Face of Reactive Accident and Incident Investigations:
The ATSB's Next Safety Watch Priorities—Angus Mitchell, Chief Commissioner, Australian Transport Safety Bureau.

Sharing Experiences of Investigating a Boeing 737-500 Accident—Capt. "Ray" Nurcahyo Utomo, National Transportation Safety Committee, Indonesia

Capt. Utomo was deeply involved in the investigation of this accident that occurred on Sept. 1, 2021. The recovery of important items of wreckage, including the flight recorders, was severely hampered by the extensive breakup of the aircraft structure and the conditions on the sea bottom.

The National Transportation Safety Committee (NTSC) received valuable assistance from the Singapore Transportation Safety Investigation Bureau, and the initial search for the recorders was based on the last radar positions, followed by search by hydrophone for the recorder beacons. The flight data recorder was recovered quite quickly as was the beacon for the cockpit voice recorder, but it took a month more to find the CVR memory unit, requiring extensive dredging of the muddy seabed. The investigation was also hindered by travel restrictions resulting from the COVID-19 pandemic. For instance, some investigation interviews were conducted using videocalls, and most group discussions were held online—not as effective as meeting physically.

At the time of presentation, some 18 months after the accident, the NTSC was assessing comments on the draft report.

Brisbane, Queensland, Australia—Review

By Robert Carter, ISASI Vice President

The report indicates that the aircraft initially experienced thrust lever position differences—the cruise thrust split monitor did not disengage the autothrottle—and the crew did not immediately notice the change in aircraft attitude.

Digital Transformation in Air Safety Investigation—Javier Casanova, Sikorsky, USA (Virtual)
Casanova reviewed the development of drone-based viewing and analysis of accident sites involving Sikorsky helicopters. This originated with a particular accident in which the investigation team was initially prevented from accessing the site because of radioactive material emanating from the postcrash fire from the blade inspection system. The team innovated using locally sourced drones. This was successful, and the team developed the drone techniques for subsequent investigations. This included Sikorsky investigators acquiring FAA Part 107 licenses and buying two FAA-registered commercial drones.

In particular, the team developed its capabilities in 3-D imaging of accident sites using the commercially available Pix4D software, which can generate an orthomosaic image. As a "proof-of-concept" trial, a physical site simulation was arranged, taking items of Sikorsky S-61 wreckage and distributing them in a field in Georgia. The trial worked well, and Casanova demonstrated a "walk through" of this site, labelling items within the scene.

He concluded with the results of a field test of the drone technique, involving a UH-60A accident in Florida. Wreckage from the helicopter was spread over a 2-square-mile area, including a runway and nearby swamp. With approval of the U.S. National Transportation Safety Board (NTSB), the Sikorsky team launched its drone and the aerial imagery of the scene leading to the recovery of "missing" wreckage, critical to establishing the sequence of events. Development continues.

The Role of Cabin Crew in a Reduced Flight Crew Complement World—Capt. Trevor Jensen, Australia
Jensen reviewed the history of flight crews in commercial transports, with the disappearance of radio operators, followed by navigators and then flight engineers. He could envisage further reduction in the flight crew and a point where, with modern aircraft with high-autonomous function, at least part of the piloting function would become ground-based.

Jensen also envisaged the possibilities of other crewmembers supplementing the flight crew role where there might be a reduced flight crew complement. He cited, for instance, the European Union Aviation Safety Agency (EASA) NPA (2022-06) proposals for regulatory framework for the operation of drones and posed several challenging questions about training, recency, and qualifications.

From See and Avoid to Detect and Avoid: Learnings from a Mid-Air Collision Investigation—Nathalie Boston and Michael Dawes, ATSB, Australia
The background of this presentation was a mid-air collision on Feb. 19, 2020, with four fatalities. The accident was in noncontrolled airspace in the proximity of a noncontrolled airfield. It is likely that both twin-piston aircraft were in IMC, and flight data did not indicate any evasive maneuvers or direct radio communications.

In the investigation, the ATSB implemented some of the investigation techniques presented at ISASI 2021 by John O'Callaghan of the NTSB (see page 18) and showed a simulation of the views from the two aircraft. The investigation showed that mid-air collisions in Australia are rare, particularly involving IFR aircraft and that the see-and-avoid principle remains the last defense against collisions in all conditions. This has been long recognized as an ineffective defense, with the four pilots involved having very limited opportunity to sight the other aircraft in time to maneuver and avoid.

The investigators consider the future is for the industry to move to tools that assist pilots to detect and avoid such as ADS-B IN technologies, and the Australian government is encouraging ADS-B fitment for VFR pilots through a $30 million rebate scheme.


Capt. Trevor Jenson, left, and ATSB's Nathalie Boston and Michael Dawes answer questions about their presentations.

Keynote: Aviation Safety in the Australian Defense Force: An Update—Wing Commander Clare Fry, Defence Flight Safety Bureau
Wing Commander Fry described the role of the Defence Flight Safety Bureau (DFSB) and particularly its role in relation to the Defence Aviation Safety Authority, emphasizing the functional independence of the DFSB with its independent "forward leaning" investigative capability within its four sections, dealing with research, education, investigation, and publishing.

DFSB handles some 4,500 safety reports each year—from minor incidents (Class B) to full accidents (Class A). There has been a dramatic reduction in fatalities and hull losses over the last years, but there still are some "close calls." Factors in the improvement seem to include the capability of aircraft in service, the maturing of programs, and an improved cultural environment. But some factors do not seem to have improved: supervision, fatigue, stress, and complexity.

Fry concluded with a description of the SALUS aviation safety intelligence portal as the emphasis moves "from counting accidents to monitoring risk."

Group Wing Commander Clare Fry, acting director, DFSB, opens the afternoon session with a keynote address.

Challenges in Managing Corporate Response in a Crisis—Sam Farmiga (and Dave Chapel), General Electric, USA

The presentation described the crisis-response process GE Aviation uses to respond to product-related business crises, including aviation accidents. This is an evolutionary and adaptive process that constantly learns, aiming to improve. A major incentive was GE's response to the 2009 US Airways "Miracle on The Hudson" event, resulting from bird strikes to the engines. This led GE to reevaluate and evolve its accident response system when the need to "stay ahead of the news cycle" required that it join internal and external responses. This has gone well beyond GE's aviation events, such as in GE's response to Hurricane Florence.

Today the safety team assesses an accident and investigates while equipping the communications team with relevant and timely information to stay ahead of the news cycle by embedding them in the investigation team. This changed how GE's 24-hour Aviation Response Center deals with aviation events and led to the development of a "standard work process," with a crisis management handbook for every employee. The handbook covers guidance for several types of events, including aviation events, facility issues such as fires or natural disasters, and personnel issues such as violence in the workplace. This is supported in the GE engine lines crisis-management training program through the year, which includes a role-play simulation of an accident response.

Overall, the presenters consider that, by driving ambiguity out of an accident investigation, GE can deal with the expectations that arise during highly charged events.

Challenge in Investigating a Cabin Fire on Ground—Denis Cadoux, Airbus, France

Cadoux opened with the comment that serious cabin fires not related to aircraft impacts are rare events. However, where the fire is not contained by crew actions or fire-protection systems, the key evidence of the root causes of the ignition and the initial spread may well be destroyed by the fire's development. Further, onboard flight recorder systems generally provide only limited data concerning a cabin fire, challenging an evidence-based investigation.

The presentation highlighted two recent cabin-fire-on-ground events and how Airbus has developed a strategy and the practical technical means and expertise to identify the lessons learned from this kind of highly complex investigation. It included details of the "investigation pillars" that Airbus has developed, including the need to inspect "sister aircraft" to map smoke damage within the fuselage and identify potential heat sources and sources of fuel.

Cadoux finished with potential enhancements for future cabin fire safety investigation. These include more refined analysis of combustion residues and the use of computational fire dynamic simulation in investigations.

Can COVID-19 Rust Pilots' Operational Skills? Investigating the Impacts of the Pandemic on Pilots' Proficiency Using Flight Data Monitoring—Arthur Nichanian, Cranfield University, UK, and Horizon Swiss Flight Academy, and Wen-Chin Li, Cranfield University

This presentation by Nichanian was based on a rigorous statistical analysis of flight data monitoring and associated air safety reports of a major European legacy airline from June 2019 to May 2021. The data featured a "severity index" scale for each event, based on an algorithm, and was divided into three stages of eight months each: "Before pandemic" (June 2019–January 2020), "Pandemic beginning" (February 2020–September 2020), and "During pandemic" (October 2020–May 2021) with decreasing traffic volumes through the stages. The study looked at flight phases, short haul vs. long haul, and event categories.

Nichanian's results included particular illustrative examples. Broadly, COVID-19 did have an impact on pilot proficiency, with different impact on short-haul vs. long-haul pilots, correlated to recent flying experience. "Manual flying skills fade" was overcome fairly rapidly, whereas the loss of operational knowledge and soft skills decay were more difficult to recover, requiring learning and practice. Airlines faced challenges in adequately maintaining crew recency, but pilots and airline showed resilience. After a "phase of surprise," risks could be managed and kept under control, and enhanced training sessions for pilots were effective.

Wednesday, August 31

Keynote: From Nonnormal to New Normal: Building Resilience Through SMS—James Redgrove, General Manager, Safety Systems, Dreamworld

This keynote was an innovation for an aviation-based seminar, bringing the perspective of a leisure-park operator of a large site in Queensland that includes several adventure rides.

The park had been the site of a prominent accident on a "'river rapids" ride in 2016, with three fatalities, when one of the vessels became stranded at the top of a lifting mechanism. This resulted in the following vessel being upended, tipping the occupants toward the lifting mechanism. The tragic event, with multiple causal factors, had massive effects for the operator, financial and legal.

The park operator undertook to adopt an aviation-type safety approach and now has a full safety management system in place, with elements familiar to an aviation safety program. These include a commitment to a just culture and resilience based on the interaction among policy planning, risk and change management, safety assurance, and safety training and promotion.

Dreamworld's James Redgrove discusses the importance of a robust safety management system in a nonaviation environment.

Boeing USA V-22 Osprey Flight Test to Fleet: Lessons Learned—Jeffrey Hutchinson, Boeing

Hutchinson was employed in a number of roles during the development and deployment of this complex tilt-rotor aircraft. The design is a military development of Bell XV-3 and XV-15 experimental tilt-rotor aircraft, and the protracted and eventful development of the V-22 illustrated the practical difficulties in transitioning to an acceptably safe and deployable production aircraft.

In a richly illustrated presentation, Hutchinson detailed a number of the development mishaps that occurred during the separate phases of the aircraft development. He was an air safety investigator and was effective in bringing home to the audience the very human cost of accidents during aircraft development. Hutchinson finished with the resonant comment from his experience: "Thorough investigations result in effective system improvements."

"In It together": Maintaining Independence in Military Air Safety Investigations—Commander Dom Cooper, Deputy Director, Investigation; and Squadron Leader William Harwood, OPS-2 Investigator, DFSB, Australia

This joint presentation, by one Navy member and one Air Force member, gave both the advantages and efficiencies of a multiservice safety investigation unit. The presenters also showed the hurdles in demonstrating true functional (International Civil Aviation Organization style [ICAO]) investigative independence within the context of the military chain of command and the position of the DFSB within the Defence Aviation Safety Authority.

Cooper and Harewood gave examples; for example, a DFSB investigation of a "near miss" incident between two training PC-6 aircraft brought safety recommendations about ambient workplace recording devices. There were good results from the investigations of both a SH-60 Seahawk ditching in the Philippine Sea and the underlying issues concerning an F-18 ejection event on takeoff.

Overall, the DFSB remains committed to its independent accident and incident investigative capability and looks to increasing cooperation with the ATSB.

Collaboration of Cultures: Aviation and Health Care in Helicopter Air Ambulance Service—Shawn Pruchnicki and Jeffery Pearson, Ohio State University, USA (Virtual)

Pruchnicki and Pearson started from the premise that the safety cultures and priorities of health-care providers and health-care helicopter operators are distinct and that the separate organizational structures, standards and procedures, and professional cultures can drastically affect the effectiveness and safety of aviation operations. This can mean that aviation professionals and medical clinicians are left to function together as a team in a high-stress and unpredictable environment. This study seeks to identify deficiencies that may threaten aviation safety and find potential solutions from similar organization or industry models.

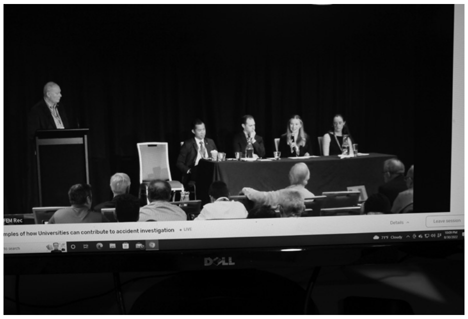
In looking at how to "bridge the culture gap," the presenters looked at different human factors investigative methods, avoiding "root cause analysis" as a research tool and looking at "Moray's model of error" to emphasize how particular actions "seemed appropriate" to an actor at the time. In looking at the NTSB's "health-care aviation" investigation reports, the presenters noted that medics were on board in 94% of the cases, but only one report included studies of all the personnel and that all the safety recommendations were directed at the aviation side. The presenters recommend further research.

Student Scholarship Presentations

Time was made for the 2022 ISASI Kapustin scholarship essay winner (see page 16) and the ASASI 2020 and 2021 Macarthur Job winners. They presented a summary of their work: Rudolf Kapustin Award 2022—Lt. Jun Kwan Chan, Aircraft Engineer, Malaysian Royal Navy, Cranfield University, 'Digital Crash Lab' Through the Applications of Augmented Reality (AR) and Virtual Reality (VR) Technology. Macarthur Job Award 2020—Matthew Harris, University of Southern Queensland, Australia, New Ideas on How to Implement Lessons Learned from Safety Investigations Back into Industry: The Supervisor's Role. Macarthur Job Award 2021—Madeline Higgins, University of Southern Queensland, Australia, The Impact of Pilot Currency and Recency on Aviation Safety During the COVID-19 Pandemic

Practical Examples of How Universities Can Contribute to Accident Investigation—Associate Professor Selina Fothergill, Ph.D., RMIT University, Australia

Brought into the program at short notice, Fothergill provided an insight into how universities can assist investigators on particular projects beyond, for instance, the personnel resource or capability of an investigative agency. This may be accomplished by using a "higher degree" researcher and therefore may serve the purposes of the investigative agency, the student's thesis, and the university department. This may be particularly appropriate in the case of an overall "safety study" covering several accident or incident cases with a particular common theme. Fothergill gave instances in which RMIT University has been involved.



ASASI Vice President Paul Mayes, at the podium, chairs a Q&A session with, from left, Kapustin Scholarship winner Lt. Chan Jun Kwan, Macarthur Job awardees Matthew Harris and Madeline Higgens, and RMIT Associate Professor Selina Fothergill.

Keynote: An Onsite Investigation in a Hostile Environment Australia on Fire 2020 (EC-130Q)—Greg Hood, Airservices Australia

Hood was the ATSB chief commissioner at the time of this accident and gave an effective illustrated presentation of the threats of the fire conditions that reached over an extended period over large parts of Australia.

Hood did not discuss the causal factors in this accident of a C-130 firefighting aircraft and its American crew but described the circumstances in which the accident occurred and the challenges this represented for the investigators. This included details of the deployment, initial meetings, and cooperation with the police and rural fire service agencies and working in the hostile environment, with substantial site hazards and dealing considerately with family visits.

Hood noted the ATSB interim reports into this accident and the final report were released on August 29. This includes safety actions already taken and safety recommendations.

Greg Hood of Airservices Australia presents a visual display and discussion of the dangers and adverse conditions that air accident investigators experienced during a recent period of widespread ground fires in Australia.

Professional Backgrounds Affecting the Collection and Interpretation of Data in Accident Investigation—Wesley Chan, Hong Kong ALPA, and Wen-Chin Li, Cranfield University

The presenters reviewed the increasingly wide data sources for investigators, especially audio and visual image sources such as smartphones, security and dashboard cameras, and drones providing images that can be used to create 3-D imagery of an accident site. However, current practices in the collection and interpretation of data may be subject to perceptive biases, as accident investigators come from different professional backgrounds such as manufacturing, regulating, human factors, piloting, engineering, and airline safety. This exposes the data collection process to the "relevance paradox" in which people tend only to acquire information that they perceive to be relevant to them. For example, when using drones for wreckage survey, investigators from different professional backgrounds may choose different "points of focus." Investigators' interpretation of data may also be influenced by the "observer effect" in which the understanding of an observation is dependent on the observer's expectation.

This study evaluates accident investigators' perception and interpretation of collected visual imagery and information on several criteria. The first assesses how a diverse group of investigators might agree on what data is considered relevant. The second and third criteria are of professional and national backgrounds, whether investigators from different occupations and national groups have varying interpretations of the same audio/visual data sources. Finally, understanding how different groups interpret causal factors helps with remedial strategies and benefits the "presentation phase," improving the viability of safety recommendations within an Annex 13 investigation.

Strength in Numbers: Integrating Data Science into Onsite Investigations—David Wilson, ATSB, Australia

Wilson opened with Carl Sagan's comment, "Extraordinary claims require extraordinary evidence" and then demonstrated a practical example of how data investigation techniques, with a thorough onsite investigation, may allow earlier detection of safety issues.

The practical example was a pair of fatal accident investigations conducted by the ATSB in 2011 and 2017 into triple-fatal accidents with the same community service flight provider (CSFP)—private, voluntary flights for public benefit. There were common accident mechanisms, with VFR flight into IMC or dark night conditions, spatial disorientation, and loss of control.

Preliminary assessment showed that these fatal accidents were very likely to be occurring at a higher rate than the average of other private operations. Although this was statistically significant, there was insufficient indication for conclusions of the relative safety of CSFP flights but enough information to further investigate the safety record of these flights.

Overall, the analysis showed that the likelihood of a CSFP safety occurrence was almost certainly higher than for other private operations, and combined with an assessment of organizational controls led to the identification that additional risk controls were required. Further analysis indicated, for instance, opportunities to conduct safer flights using regular public transport at comparable cost in at least one-third of these flights.

Unlocking Capability: Has the UK Rotary Industry Finally Come of Age?—Douglas Barnes and Niall Robertson, Air Accidents Investigation Branch, UK

Barnes and Robertson have extensive background in flying transport helicopters around the UK in military and civil roles. With North Sea oil exploration came a prolonged development of safe operating conditions in this challenging environment, and the authors provided a range of "lessons learned" cases from the helicopter offshore commercial activity in the North Sea. Here the decreasing accident rate was assisted by the introduction of a new generation of helicopters that offered enhanced capabilities, such as digital four-axis automation, icing clearances, and increased range. They were also accompanied by the introduction of new systems such as TCAS II and HTAWS.

The presenters then proceeded to relate this experience to the development of onshore helicopter operations and its challenges. One is represented by the fact that UK offshore helicopter operations had coalesced into four substantial operators, whereas the onshore commercial helicopter fleet has a larger number of smaller operators. However, the introduction of helicopters onshore such as the Airbus H145 and Leonardo AW169, accompanied by the introduction of enhanced capabilities, may present the sector with similar challenges and asks the question, "What role can a state investigation authority play to prevent history from repeating itself?

Awards Dinner: Speech Analysis as an Investigative Technique—Guest Speaker Dr. Malcolm Brenner, Human Factors Specialist Investigator

This after-dinner speech was from a highly experienced human factors specialist investigator and detailed factors involved in the investigation of the Exxon Valdez tanker in Alaskan waters in March 1989.

Delegates, companions, and guests gather for the traditional seminar banquet.

In particular, it highlighted the use the NTSB made of speech-analysis techniques from the recorded transmissions over several hours. This was instrumental in confirming alcohol impairment as a causal factor.

Thursday, September 1

Keynote: BARS, Basic Aviation Risk Standard, in Support of Accident Investigations—David Anderson, Flight Safety Foundation

Anderson opened with a confession, "I'm an auditor," but proceeded into an effective presentation on the insights this can give into operators. For instance, analysis shows that, in general, fewer than 3% of unstable approaches are converted into go-arounds.

Anderson has been involved with the Flight Safety Foundation's (FSF) Basic Aviation Risk Standard (BARS) Audit Program since 2010 in several roles and described its development to provide industry with a set of known, risk-based standards; an independent audit and assurance program; and data gathering and analysis. These elements combine to support safety investigations, providing a benchmark for how operations look when properly executed. He described elements of the BARS Audit Program and the comparable International Air Transport Association's Operational Safety Audit, the International Business Aviation Council's International Standard for Business Aircraft Operations, and ICAO's Global Aviation Safety Plan.

Central to BARS is the risked-based "Bowtie" model for the range of standards, including passenger operations, helicopter external loads, low-level survey, aerial mustering, offshore helicopter, remotely piloted aircraft systems, and other activities. All of these, with the rigor of the audit process, can aid the safety investigator.


FSF's David Anderson discusses the foundation's Basic Aviation Risk Standards Audit Program in support of accident investigations.

Using Lean Six Sigma to Improve Aircraft Accident Investigations: Ensuring Timeliness and Quality in Accident Reports—Kristi Dunks, NTSB, USA

Dunks highlighted that the NTSB, with other investigative agencies around the world, has suffered from a mismatch between the agency's ability to produce high-quality and timely investigation reports and a historical expectation that this would extend to all cases. She noted that this led in 2019 to the formalized review process to attempt to generate a coherent and consistent system of prioritizing workflow and improving timeliness while maintaining quality.

The NTSB's evaluation process used the principles of Lean Six Sigma, a method to evaluate processes and reduce waste and variation. As a result, significant early changes included the implementation of an accident classification framework, use of work plans for investigations, and applying defined markers for the investigation process. Dunks discussed the process used to evaluate the underlying issues of timeliness and quality and showed how a looping method of continual process evaluation and improvement is key in the long-term success of the project.

The Unexpected Safety Impact of COVID-19—Toni Flint, Air Accidents Investigation Branch, UK

Flint presented the very complex pattern of COVID-19 restrictions, particularly over the period of March 2020 to March 2021. Within Europe, there was much attention paid to the potential safety impacts ("rusty pilots in rusty aircraft?"), both from EASA and the UK Civil Aviation Authority. Operators and regulators around the world recognized some of the potential safety impacts. However, some flying continued, and operators put in place adaptations to meet the requirements of social distancing. She explored some cases investigated by the Air Accidents Investigation Branch (AAIB) in which such "workarounds" had unexpected safety consequences.

The three cases were different: one to a light turbine twin (G-CGTC), one to a development hydrogen-powered aircraft (G-HYZA), and one to a large modern turbofan freighter (G-ZBJB). All three have been published and are available on the AAIB website. A common theme was a loss of resilience in the operation due to COVID-19 restrictions, tending to disrupt the connections between individuals within the operational structure.

Flint closed with a brief discussion of "resilience" and the role of a safety investigation in improving it.


From left, Toni Flint, UK AAIB; Kristi Dunks, U.S. NTSB; and David Anderson, FSF, respond to participants during a Q&A session.

How Could Investigators Use Safety Models to Inform Decisions on What to Focus On?—Associate Professor Nektarios Karanikas, Queensland University of Technology, Australia (Virtual)

Karanikas discussed some of the safety/accident analysis models (SAMs) available to safety investigators: sequential, epidemiological, and systemic. He looked at the analyses of two specific cases, one in the UK and one in Canada. This included "mapping" to look at areas possibly missed within the analyses, commenting that researchers typically use SAMs to analyze investigation reports retrospectively, distilling causal and contributory factors. This may mean presenting, for example, aggregated data from several reports.

The presenter's suggestion was that a similar conceptual mapping before and during investigations would be helpful. For example, investigators could start with consulting a "simple" SAM to identify system areas of interest they might have missed, and then, depending on constraining factors, extend this mapping by using more detailed SAMs.

Maintenance Check Flight Accidents: A New Approach to Air Safety Investigations—Jay Nagy, University of South Queensland, Australia

Nagy reviewed accidents and incidents that occurred during nonroutine operations, particularly "maintenance check flights" in which occurrences appeared at least an order of magnitude higher than in routine operations. In the past, the operating industry has responded, but the study indicates that this has had limited effect due to a narrow focus on airline operations and crew competency, disjointed regulatory development, chasing elusive root causes, and "hindsight bias."

A new approach includes five steps: text analysis from reports, causal groups arranged, maps of causal logic, a global map of overall knowledge, and a case study looking for common structure and patterns. One of Nagy's conclusions is that check flight accidents are not isolated in-service events but emerge from systemic interaction of design and operational causes.

Handling Partial Power Loss in General Aviation Fixed Wing—Graeme Gow and Alison Campbell, AAIB, UK

Building on analysis that "partial power" events are three times as hazardous as total power loss, Gow and Campbell gave two detailed cases of recent UK accidents to light aircraft with single-piston engines resulting from a partial loss of engine power, one at Goodwood Airport (G-CJZU, June 2021) and one at Teesside Airport (G-BBSA, September 2021). There had been several similar UK accidents, and the presenters gave credit to an earlier ATSB special study of 2010 on accidents resulting from "partial power loss" covering the period 2000–2010. These resulted in changes to the partial power loss syllabus in Australia.

Gow and Campbell concurred with the ATSB view that partial power loss is often more difficult for light aircraft pilots to contend with than total power loss, with much more complex decision-making. They concluded with three AAIB safety recommendations to the UK Civil Aviation Authority on changes to the partial power loss training syllabus, detailed guidance for examiners and instructors for rating revalidation, and safety promotion regarding techniques for managing partial power loss.

Keynote: Preparing for the Next Aerospace Revolution—Professor Graham Braithwaite, Director of Transport Systems, Cranfield University, UK

Braithwaite's future-looking presentation was on point as his luggage took three days to arrive in Brisbane! He looked at current and future university-based aviation programs, including the newly commissioned SAAB 340 conversion in the UK's National Flying Laboratory, the opportunities and challenges of electric vertical takeoff and landing aircraft, next-generation air traffic management, and decarbonization programs. He closed with a plea, "Let's not forget what we've already learned." Adaptation targets for 2050 require fundamental, not just incremental, change.

Professor Graham Braithwaite, Cranfield University, UK, offers a look into the future for aviation school programs.

Flight Data Investigations and Analysis—Faisal Bashir, SereneAir, Pakistan (Virtual)

Bashir described Flight Operations Quality Assurance (FOQA) programs and how operational flight data provides valuable information to corporate safety managers in drawing a "bigger and better" picture. However, flight data investigation and analysis cannot be done without a reliable database of recorded events, and a flight data monitoring (FDM) program is therefore an essential part of FOQA. FDM has now matured with extended lists of recorded flight parameters and has proven to be a highly effective tool for safety managers. It works well for operators who run a dedicated FOQA program. However, small-fleet operators have a different perception and attitude toward FDM programs.

Bashir noted that runway excursions (and incursions) are one of the "significant five" high-consequence risk outcomes, computed at the global level. He then gave an example of this type of excursion event in which the root cause is typically in the occurrence of unstabilized approaches. If these are not monitored critically in the FDM program, they ultimately become the precursors for excursion events. This represents a continuing challenge for safety managers.

Scaling Embracement of "Fly-Fix-Fly" Design and Test Methodology—Jeffrey Kraus and Jim Buse, Boeing, USA

Kraus and Buse focused on embracement of the "fly-fix-fly" testing method, using a scaled application approach to "accelerate engineering learnings," optimizing design improvements. They demonstrated the "rapid prototyping" now possible in innovative UAS developments in which safe levels of development flight test may be achieved by the use of open and remote test sites.

Examples from recent programs included a 5.5% aerodynamic model of a proposed hypersonic aircraft. In reviewing some of the underlying causal factors, the presenters commented that some of these accidents derive from schedule pressures on relatively inexperienced test teams. Thus, a "lesson learned" within this manufacturer is that it is better for the separate small UAS developments to be tested under the same testing organization.

ISASI 2023 Briefing, Nashville, Tennessee—Robert Rendzio, ISASI Southeastern Regional Chapter, USA (Virtual)

ISASI Southeastern Regional Chapter President Robert Rendzio, leading the committee for the 2023 ISASI seminar in Nashville, Tennessee, presented a slide show of the venue and planned program, "Accidents: The Current Which Lies Beneath." The seminar dates are Aug. 21–25, 2023, with tutorials on August 21, banquet on August 24, and an optional half-day event on August 25.

Closing remarks

Guselli and Carter provided the closing announcements. The award for "Best Paper" was presented to Nathalie Boston and Michael Dawes of ATSB. Guselli thanked all who contributed to the event and wished everyone safe travels home. ◆

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Using Lean Six Sigma to Improve Aircraft Accident Investigations

By Kristi Dunks, Ph.D., Acting Deputy Director of Regional Operations, Office of Aviation Safety, U.S. National Transportation Safety Board

(This article was adapted with permission from the author's technical paper presented during ISASI 2022, a hybrid in-person and virtual seminar hosted from Brisbane, Australia, Aug. 30–Sept. 1, 2022. The theme for the seminar was "Current Challenges for Aviation Safety." The full technical paper, Using Lean Six Sigma to Improve Aircraft Accident Investigations: Ensuring Timeliness and Quality in Accident Reports*, is available on the Society's website, www.isasi.org, in the Library section under the Publications & Governance/Technical Papers tabs. The views expressed in this article are not those of the NTSB and are not necessarily endorsed by the NTSB.—Editor)*

Kristi Dunks

In 2021, the U.S. National Transportation Safety Board (NTSB) investigated more than 1,200 domestic aircraft accidents. Investigating this number of accidents requires that the investigative and report processes at the NTSB be streamlined and efficient. The NTSB's Office of Aviation Safety evaluated the timeliness and quality of its regional investigations using Lean Six Sigma, a method to improve processes by reducing waste and variation. As a result, significant changes were implemented to improve the timeliness and quality of the NTSB's regional accident investigation reports.

Timeliness refers to the amount of time that it takes to complete an investigation. Quality refers to the value of an investigation relative to its purpose. Aircraft accident investigations that are not completed in a timely manner can have a negative impact on aviation safety due to the delay in communicating lessons learned. If those investigations also lack quality, the investigations will likely provide minimal value.

In 2019, we formed a four-person team to analyze the NTSB's regional aviation accident reports and found that the timeliness and quality of the reports varied. To understand why this situation was occurring, we reviewed accident report timelines and complexity, docket information, travel information, report content, and historical event data to form a framework to build from.

Although we recognized a timely and quality report when we saw it, as we began our work, we realized that our office did not have clear standard definitions for timeliness and quality. We understood the need for such definitions given that some investigations were not completed until 4 years after the accident with no clear reason why and that investigations involving similar defining events did not always contain the same level of factual support and documentation.

From the beginning, we kept in mind the common Lean Six Sigma adage, "It is not a people problem, it is a process problem." It is easy to say that problems result from staff members not doing their work; but as an organization, we must take responsibility if the work is not meeting timeliness and quality expectations.

Define, Measure, Analyze, Improve, Control

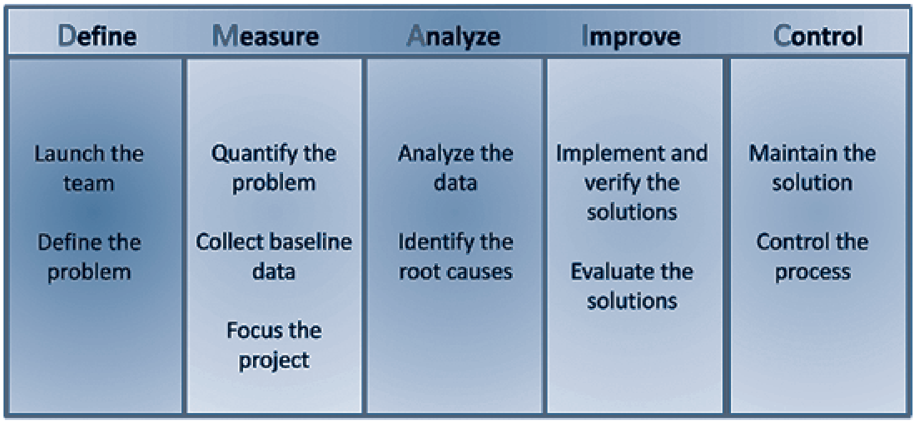
To focus our methodology and provide tools to work through the process for improving report timeliness and quality, we used the define, measure, analyze, improve, and control (DMAIC) quality strategy. Each letter of DMAIC represents a phase of the process (see Figure 1).

Define

The first step was to define the problem that we would evaluate. The focus for the team was to improve the quality and timeliness of investigations completed by the NTSB's regional offices. We mapped out the investigative process from the initial notification to the publication of the final report and probable cause.

Measure

With the outline of the investigative process in place, we then created timelines with detailed content for each phase of the investigation. One of our limitations was the lack of information pertaining to quality over time as well as the individual timelines and tasks that made up each phase of the investigation. Although we had ample data related to overall timelines, more granular data specific to each phase was unavailable.



Define	Measure	Analyze	Improve	Control
Launch the team Define the problem	Quantify the problem Collect baseline data Focus the project	Analyze the data Identify the root causes	Implement and verify the solutions Evaluate the solutions	Maintain the solution Control the process

Figure 1. DMAIC quality strategy.

Analyze

The purpose of the analyze phase of the DMAIC process is to understand the root cause of a problem. As we analyzed the data, we realized that there were many potential underlying issues and solutions. We were uncertain where to focus our efforts to have the greatest impact on our operations.

Improve

When we reached the improve phase, we sought support externally to help us determine the best path forward. We realized that conducting a kaizen—a Japanese concept of continuous improvement through work operations and personal actions—would provide the most benefit to our team and help us work through a vast amount of information.

A kaizen is a multiple-day event, usually 3 to 5 days, that aims to create goals to improve a process. Because we did not have the Lean Six Sigma expertise internally at that time, we completed an interagency agreement with the U.S. Federal Aviation Administration, and a Lean Six Sigma Master Black Belt facilitated the kaizen event and worked with the team to evaluate our data and complete our analysis.

To conduct the kaizen, we expanded our team to 10 people, including investigators and analysts. We met at an off-site location to help the team focus solely on the task at hand and completed our core work in 3.5 days. All the data gathering and analysis that we had done before that time supported our kaizen event.

During the kaizen, we used several tools to work our way through the improvement process and determine how to focus our efforts. Some of the primary Lean Six Sigma tools that we used were as follows:

- SIPOC (Suppliers, Inputs, Process, Outputs, Customers) Process Map—a SIPOC is a high-level process map that helps to define a business process using a table format. This format allows the team to easily understand the process as work begins.
- SWOT (Strengths, Weaknesses, Opportunities, Threats) Analysis—a SWOT analysis allows the team to understand those areas in which we excelled and those areas in which we did not. When looking at a SWOT analysis, strengths and weaknesses are internal to the organization, and opportunities and threats are typically external. This information then feeds into the process changes.

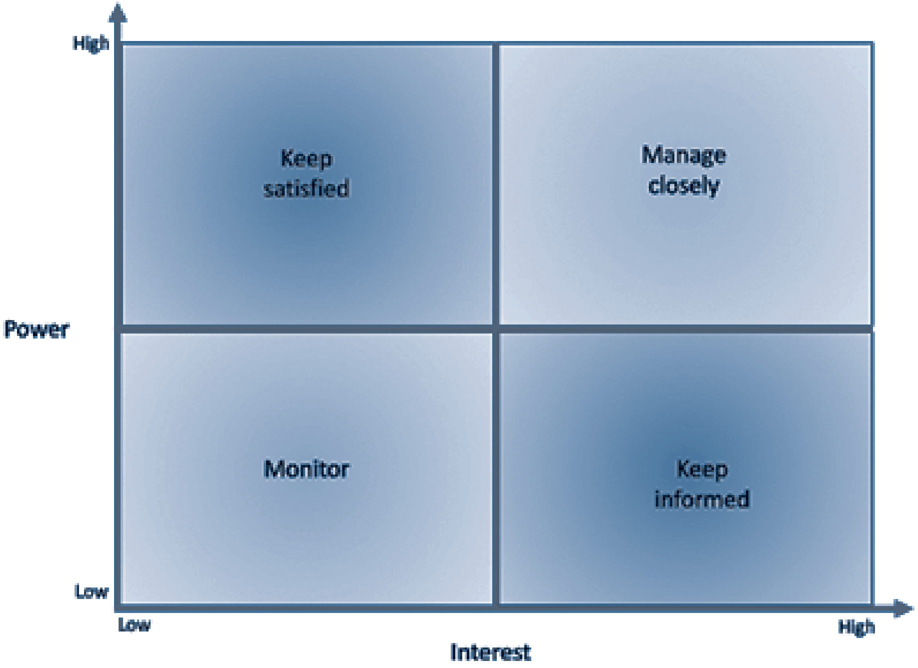


Figure 2. Stakeholder analysis.

Stakeholder Analysis—as a U.S. federal government agency, we have many stakeholders that have varying interest in our work. Through a stakeholder analysis, we were better able to understand how to focus our communication. The stakeholder analysis (see Figure 2) is based on a matrix that evaluates stakeholders' power and interests. Depending on where the stakeholders fall on the matrix, they would be managed closely, kept informed, kept satisfied, or monitored.

Process Map—The SIPOC provided a high-level diagram of our process; from there, we created a process map (also referred to as a workflow diagram) that showed each of the steps in the process and the workflow for each. For those sections of the process for which we had data available, we also included average overall timelines for step completion.

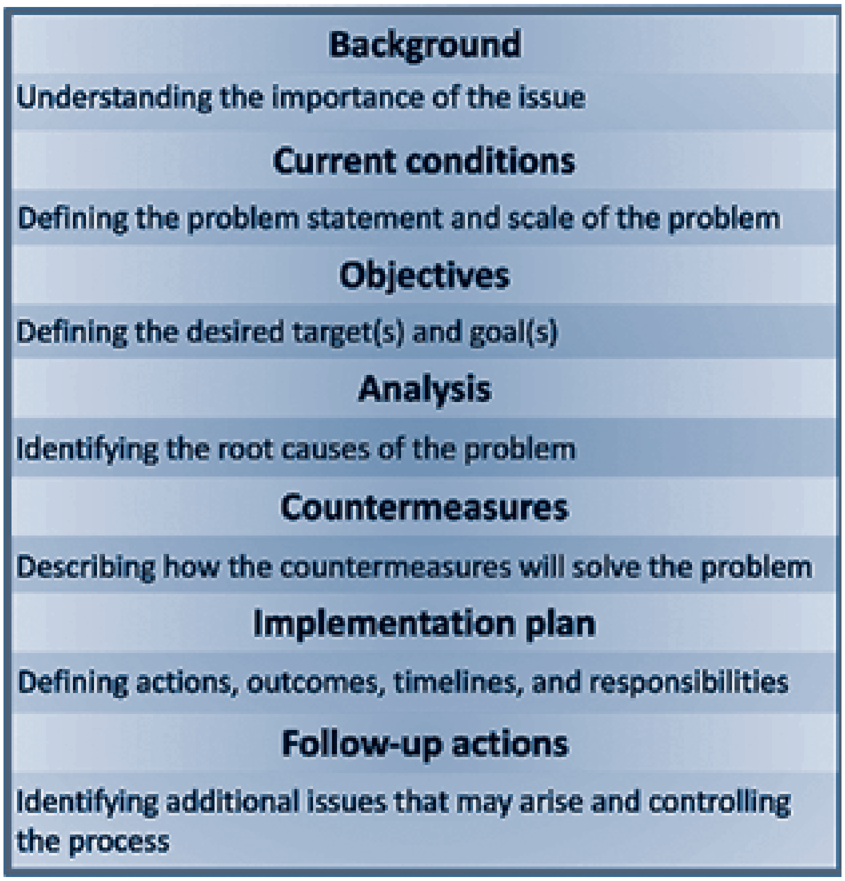
Fishbone Diagram—A fishbone diagram (also referred to as a cause-and-effect diagram) allows the problem to be identified and the potential causes to be brainstormed within the group. Each of the problems is categorized using topics such as methods, technology, and personnel, although any category can be used. Under the categories, the causes are identified. The team outlined the investigative phases, which included the initial notification, launch and return, preliminary report, fact gathering, report writing, analysis, and report publication. Due to the range of investigations and their associated timelines, for the kaizen we used timelines for regional investigations for which one or more of our regional investigators traveled to the accident site, and then we developed the average times for each phase using that information.

The most extensive time period was from the completion of the preliminary stage (notification, launch and return, and publication of the preliminary report) to the completion and submission of the draft accident report. Rather than focus on improving the entire process at once, we decided to keep our efforts focused on building quality early in the process.

By working methodically through the process, we were able to determine several areas of improvement that focused on the early investigative phases. These areas included the following:

- Creating standard work plans for common defining events,
- Updating case types and adding classifications,
- Requiring a work plan and progress meetings for investigations, and
- Developing guidance.

With these key improvement efforts identified, we prepared an A3 report and


Background

Understanding the importance of the issue

Current conditions

Defining the problem statement and scale of the problem

Objectives

Defining the desired target(s) and goal(s)

Analysis

Identifying the root causes of the problem

Countermeasures

Describing how the countermeasures will solve the problem

Implementation plan

Defining actions, outcomes, timelines, and responsibilities

Follow-up actions

Identifying additional issues that may arise and controlling the process

Figure 3. A3 report.

briefed the office directors. The A3 process is a way to use systematic problem solving to define the problem, identify the root causes, and implement the solutions. The A3 report includes background, current conditions, objectives, analysis, proposed countermeasures, the implementation plan, and any required follow-up (see Figure 3). The implementation plan can be updated as the team works through the process.

After the A3 report was approved by the directors, we began to communicate the upcoming changes to staff through in-person meetings, providing time to answer questions and address concerns. Throughout the process, we continuously communicated with staff about the current status of the project and the path ahead. During this time, we also created the standard operating procedures and standard work plans that would form the foundation of the upcoming process changes.

In early March 2020, we held in-person training for all investigative staff to review the standard operating procedures, work plans, and other guidance. We worked through many case study examples together before having staff use the guidance to work through other case study scenarios during the training.

On March 15, 2020, the process changes were implemented. These process changes required the following:

- Creating a work plan, in consultation with the regional chief, for all investigations within 15 business days of an accident.
- Using standard work plans, as applicable, based on the defining event of an accident.
- Publishing a preliminary report, when required, within 15 business days of the accident.
- Scheduling progress meetings to review and evaluate the work plan with the regional chief during the investigation.
- Using three primary accident types—MA, FA, and LA—based on the type of launch (NTSB board member launch, team launch, and no team launch, respectively).
- Categorizing accidents, using Classes 1 through 4 (most complex to least complex, respectively), based on the scope of the accident.
- Submitting Class 4 investigations for final review within 90 days after the determination that an accident occurred.

Control

As we implemented these changes, all chiefs in the Office of Aviation Safety met biweekly to review the metrics and discuss and resolve any issues. Through these initial meetings, we were able to identify procedural inconsistencies early on and receive feedback on the overall process.

Additionally, all Office of Aviation Safety staff initially met quarterly to discuss these same metrics as well as to review scenarios and receive further training on the new process. Staff provided feedback on the process changes and let us know what additional guidance would be helpful to clarify their understanding of the process. As these changes became part of our standard process, the length between meetings was increased from quarterly to three times per year. We also created an electronic form so that staff could submit feedback at any time.

In addition to increased communication, we periodically sample investigation reports to identify whether the timeliness and quality requirements are being met. As quality issues are identified, they are discussed with the chiefs, and training is provided as needed.

Conclusion

Building quality into the beginning of a process has helped us streamline how we conduct our investigations as well as reduce the number of early errors or omissions that need to be corrected downstream during the report review process. The timeliness of our reports has also improved: there are no longer any open cases more than 4 years old, and the number of open cases that are more than 2 years old continues to decrease.

Standard work defines how a process, including an investigation, is carried out. When there are no standard work requirements for investigations, each investigator will develop their own way of completing an investigation, and inconsistencies in both quality and time can result. Standard work does not restrict an investigator on the paths that they might pursue during an investigation. Instead, standard work ensures that the investigation is appropriately scaled based on the accident circumstances and that the tasks required for the investigation are clearly defined with a plan for their timely completion. ◆

The ISASI Awards Committee selected the following essay, which was presented during ISASI 2022, as the sole 2022 Rudolph Kapustin Scholarship winner. This annual scholarship is dependent upon voluntary donations from ISASI members and national and regional societies. Details about the scholarship, application, and deadlines can be found on the ISASI website at www.isasi.org.—Editor

Jun Kwan Chan

Kapustin Scholarship Essay:

The Role of Augmented Reality And Virtual Reality in Future Aircraft Accident Investigation Training

By Lt. Jun Kwan Chan, Aircraft Engineer, Malaysian Royal Navy; Cranfield University, School of Aerospace, Transport, and Manufacturing; 2022 Kapustin Scholarship Recipient

Introduction

Aircraft accident investigation (AAI) has long been a challenging and demanding task due to the complexity of accidents and the involvement of various institutional levels, sectors, and other stakeholders. Many articles and literature have placed a strong emphasis on the conduct of an investigation (e.g., techniques, framework, evidence gathering, application of technology, etc.), but the idea of leveraging the advantages of modern technology to train investigators is still underdeveloped. Roed-Larsen & Stoop (2012) identified training and competence of personnel as one of the four major challenges for investigating bodies.

To remain competitive, national investigating bodies must invest in effective and cost-efficient training for their workforce. In this highly specialized field, the training program must be constantly revised to adapt with the rapidly evolving aviation environment in order to produce a versatile and competent investigator. This paper is primarily focused on the future potential of augmented reality (AR) and virtual reality (VR) as well as the advantages they could bring to a classroom environment.

Challenges of AAI Training Today

The challenges to train accident investigators come in several ways. Oftentimes, budgetary allocation remains the cornerstone that limits other critical factors such as training aids, facilities, and logistics support. As a result, this will ultimately influence an investigator's learning experience, hands-on exposure, and the overall competency of the workforce within an organization. AAI learning can come from several entities such as tertiary education, a professional organization offering certified training courses, or a national body such as the U.S. National Transportation Safety Board (NTSB).

In order for trainees to put their theoretical and methodological knowledge into practice, a training program frequently involves a practical session at a crash lab that is usually equipped with an accident reconstruction site. However, these facilities are often very limited, or not available, in certain parts of the world. Thus, trainees are often sent to a specified location for days or weeks to attend a training course.

Considering the tuition and cost (e.g., accommodations, travel, meals, etc.), the opportunity for a small company to invest in their employees' upskill training may be very limited. With the volatile economic climate, it isn't surprising that continuing professional training and education is often the first item to be rejected in budget planning (Fabian, 2010). Putting the above into perspective, a roughly estimated total cost to attend an AAI course ranges from US$2,175 to US$6,335, taking into account tuition, lodging, an international flight, and general expenses. These figures were estimated from the AS101 AAI and AS301 AAI for Professionals Course offered by the NTSB (NTSB, 2022).

Furthermore, with the infinitesimally small number of accidents per million departures (see Figure 1) as aircrafts have become more reliable, the chances for investigators to get access to real crash sites are even smaller. Therefore, value-based training is essential in ensuring return on investment (Kearns, 2005) and a chain of impact for an organization (Phillips, 2003).

The COVID-19 pandemic has changed the usual ways in which the world conducts its daily business. People are forced to be conversant in handling technology as virtual meetings are now more frequent than in-person meetings. In today's increasingly interconnected world, we must adapt and reinnovate to maximize the usage of technology. Hence, this paper is recommending the use of AR and VR to digitalize a crash lab and use it as a supplemental tool to train future investigators.

Solution: "Digital Crash Lab" using AR or VR Technology

AR is defined as a real-time direct or indirect view of a physical real-world environment that has been enhanced or augmented by adding virtual computer-generated information to it (Carmigniani & Furht, 2011). An ultimate

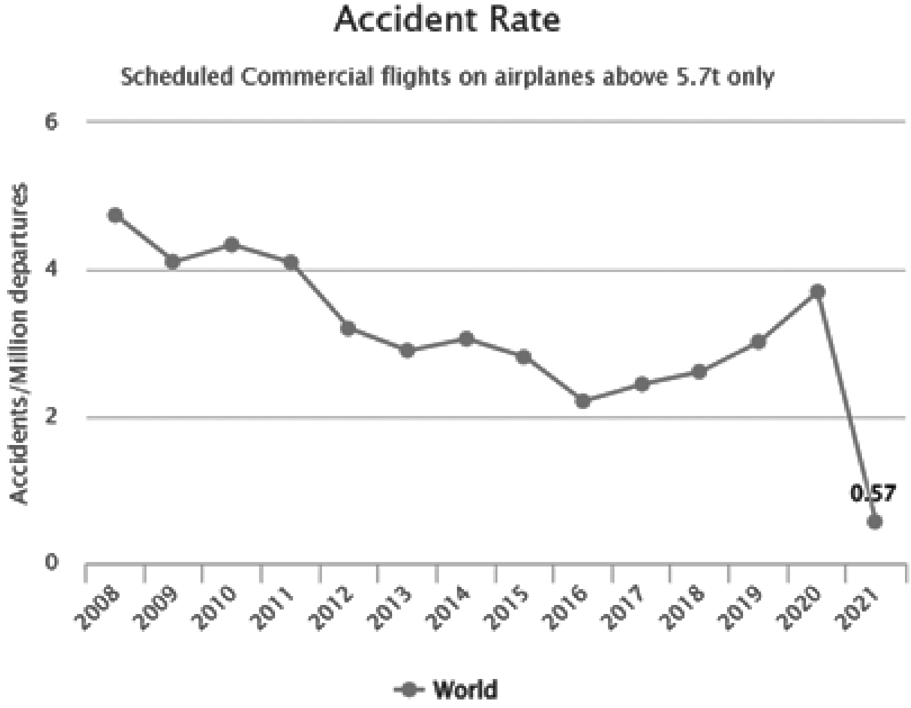


Figure 1. Accident rate from 2008 to 2021 (Interntional Civil Aviation Organization, 2022).

example would be the popular mobile game "Pokémon Go!" in which virtual 3-D Pokémon creatures appear in a real-world environment. The overlaying computer-generated information runs interactively in real time and aligns real and virtual objects together (Azuma et al., 2001).

There is currently no implementation of AR in AAI training and very limited literature exploring the capability that it offers to the aviation industry. D'Anniballe et al. (2020) explored the application of AR to recreate a real aircraft crash scene in a full-scale 3-D presentation without compromising the accuracy of the data acquired. In the study, the digitization of a crash site used both aerial photogrammetry and laser scanning techniques to recreate the crash scene before it is was transferred to an AR device for analysis.

However, this example only explores the usage of AR in an actual investigation setting but not in a training environment. In short, a similar application in the training domain can also be optimized with the introduction of AR.

Meanwhile, VR is an environment in which one is totally immersed and able to interact with a completely synthetic world (Milgram & Kishino, 1994). VR applications in aviation are currently used predominantly in engineering, maintenance, and the recently approved first VR flight simulation training device for rotorcraft pilots (EASA, 2021). The increasing trend of using VR as a training tool can be seen in other sectors such as the reconstruction of a mining operation incident (Schafrik et al., 2003; Kizil, 2003) and with digital forensic investigators (Karabiyik et al., 2019). In the field of AAI, a virtual lab environment (VLE) had already been created at Embry-Riddle Aeronautical University (Burgess & Moran, n.d.). Hiverlab also collaborated with Singapore Aviation Academy under the recognition of the Civil Aviation Authority of Singapore to pioneer and develop an AAI course with VR simulation experience for aircraft crash site investigation training (CAAS, n.d.; Hiverlab, n.d.).

Multiple crash scenarios such as Singapore Airlines Flight 006, Ethiopian Airlines Flight 302, and Malaysia Airlines Flight 17 can be converted into a 3-D model immediately after the crash, making the overall learning experience more engaging and interactive through a VLE. These examples prove that there is potential for the future generation AAI training developments in the realm of AR and VR.

The Advantages of AR or VR Leading-Edge Technology

The introduction of this modern technology into AAI training has tremendous potential. The following are some of the advantages of training in a digital crash lab using AR and VR compared to the conventional training method.

- Cost effective—While initial cost may be a setback, investing in AR or VR technology is more cost efficient in the long run than maintaining a physical lab. A virtual training course can be flexibly conducted anywhere around the world at the preference of the customer, reducing travel time and overall cost. It even allows the organizer to bring the digital crash lab (VR devices) as a "traveling classroom" to a specific location for this purpose. The latest VR Headset Oculus Quest 2 costs US$397–497 per unit, which is a huge cost difference compared to a physical course. To put numbers into perspective, investing in one trainer for a basic course is equivalent to the price of purchasing 15 to 17 Oculus Quest 2 units.
- Teach a Higher Number of Trainees—More trainees can be trained at a particular time for different level courses such as basic, recurring, or advanced.
- Modularization of High-Fidelity Models—Trainees are able to access different 3-D models modularized to a specific airframe and widen their exposure to a variety of crash-site scenarios. Wreckage components from a real crash site can easily be reproduced for classroom learning.
- Database for Team Learning—Encourages cooperation and collaboration within the AAI community. Knowledge sharing and idea exchange can take place with other experts from different organizations. A collection of crash scenes forming a large database can be stored and accessed for future reference regardless of the user's physical location.
- Connectivity and Networking—Worldwide trainees are able to connect through any online platform in a VLE that still allows for in-group learning or team projects.
- Health and Safety—Without

compromising the learning experience, a digitalized crash lab mitigates the exposure of trainees and instructors to hazards that may present at a physical crash site.

- Versatility—AR and VR can also be used in conducting an actual investigation. It can preserve important perishable evidence for future learning, providing a real-world experience for a large number of students. In addition, AR and VR devices can also be tailored to different non-AAI-related learning topics within an organization.
- Machine Learning (ML) and Artificial Intelligence (AI)—In the long term, ML and AI should be incorporated within the AR and VR environment to facilitate investigators in the future. These groundbreaking innovations are emerging as technology slowly takes over human routine work with more accuracy.

Conclusion and Future Consideration

AAI is a technically demanding role that should only be undertaken by well-trained personnel with exceptional qualities. In order to train an investigator to have sound knowledge and investigation skills, an organization should examine the training that prepares them for the job. It isn't sufficient to choose someone with aviation experience and knowledge when the occasion arises because AAI itself is considered a "specialist task" that requires specific training (Smart, 2004).

This paper stresses the importance of focusing on AAI training and addresses some challenges to train a well-qualified AAI. With budgets being an overarching concern, the objective to be cost efficient has led to the recommendation of using AR or VR technology as an alternative. Since training is a systematic process (Salas et al., 2012) and organization resources are limited, wise decisions must be made on allocation of funds without neglecting training requirements.

The virtual lab experience is an effective tool to supplement the existing training method as it provides a good perspective of a real-world accident. This state-of-the-art technology is still in the maturing stage, which presents some setbacks and limitations (Carmigniani et al., n.d.). With increasing research and rapidly improving technology (Buttussi & Chittaro, 2021), a digital crash lab should be well matured and more cost efficient in the years to come. ◆

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PART 1

THE ROLE OF FLIGHT SIMULATION IN ACCIDENT INVESTIGATIONS

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John O'Callaghan

(This article was adapted with permission from the author's technical paper presented during ISASI 2021, a virtual seminar hosted from Vancouver, B.C., Canada, Aug. 31–Sept. 2, 2021. The theme for the seminar was "Staying Safe, Moving Forward." The full technical paper, The Role of Flight Simulation in NTSB Accident Investigations, *is available on the Society's website, www.isasi.org, in the library section under the Publications & Governance/ Technical Papers tabs.—Editor)*

In today's aviation industry, computer-based flight simulation is ubiquitous. The world's airline pilots are trained in simulators; pilots of high-performance general aviation aircraft can also seek high-fidelity simulator training. And even novice pilots working on obtaining an instrument rating can log some of their training time using ground-based flight training devices. Moreover, it might well be that the largest group of people exercising flight simulation software today are not pilots at all, but thousands of individuals in love with aviation who have vicariously "slipped the surly bonds of Earth" through the spectacular scenery and cockpit realism offered by "games" such as X-Plane and Microsoft Flight Simulator. While flight simulation is perhaps used most commonly for both serious pilot training and leisurely entertainment, simulation is also a valuable engineering tool used by aircraft manufacturers in the development and testing of their products. As described in this paper, simulation is also useful for analyzing and communicating the circumstances and causes of aircraft accidents.

The U.S. National Transportation Safety Board (NTSB) has used simulation in the investigation of numerous aviation accidents. In several of these investigations, to recreate and evaluate the accident scenario, simulators were used in the usual way: pilots in a cockpit "cab" (a cockpit mockup) manipulated the flight controls, and the simulator computed the response of the airplane and updated the visual scene, sound and motion cues, and cockpit instruments accordingly.

In many NTSB cases, however, simulators have been used in unusual ways, including as a device for recreating the accident airplane's motion, flight control movements, and instrument displays—without any pilot involvement or solution of the equations of motion—using data recorded by or derived from flight data recorder (FDR) information. In addition, the aircraft aerodynamic and systems models underlying full-flight simulators have been exercised on a desktop computer (without a cockpit cab or pilot in the loop) to determine the set of flight control inputs required to produce a recorded aircraft trajectory or to analyze the effects of recorded pilot control inputs and external disturbances, such as wake encounters. The NTSB has even used Microsoft Flight Simulator X to visualize the motion of aircraft and the view out of the cockpit windows during mid-air collisions.

This paper describes these different uses of flight simulation for accident investigation and illustrates each through case studies of the 2009 US Airways Flight 1549 "Miracle on the Hudson" ditching on the Hudson River (US1549), the 2001 American Airlines Flight 587 accident (AA587), a 2017 spatial disorientation accident involving a Pilatus PC-12, and a 2015 mid-air collision between an F-16 fighter jet and a Cessna 150.

What is simulation?

For the purposes of this paper, simulation refers to the methods and devices used to compute an aircraft's response to thrust and control inputs and to recreate (as far as possible), in a ground-based facility, the experience of operating that aircraft. The aircraft's response is computed by using mathematical models of the forces and moments acting on the aircraft in the solution of the aircraft equations of motion. The corresponding "experience" of flight is recreated through a cab, which can include flight controls, flight instruments, a visual display (to depict the view through the aircraft windows), and a motion system. A given simulator's cab or other pilot interface might only include some of these components.

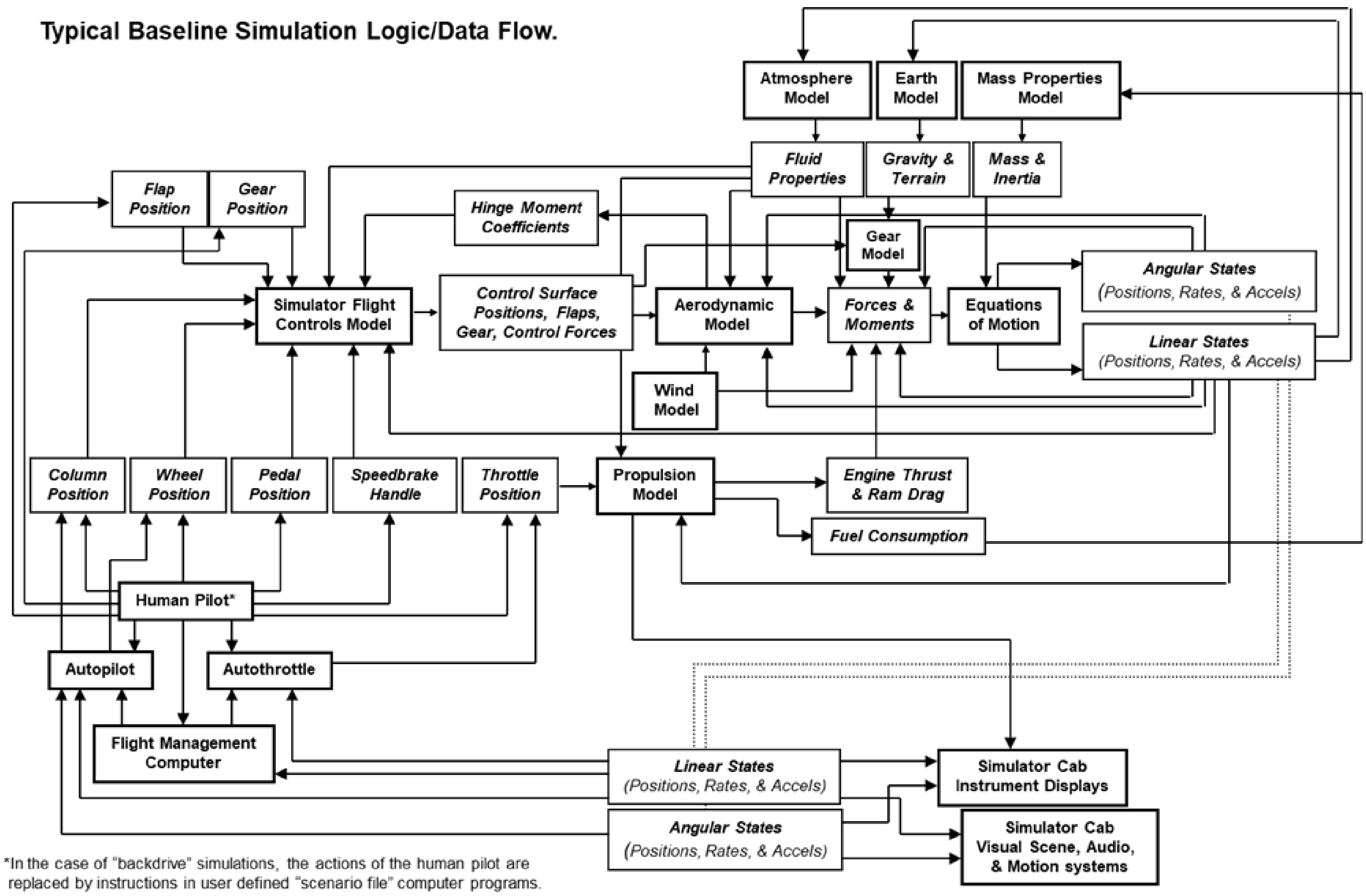

Figure 1.

Overview of the computational flow in a full-flight simulator

The different ways of using flight simulation for accident investigation introduced above can be better understood by reviewing how a full-flight simulator (FFS) works and by describing the different components and computational tasks involved. Figure 1 is a flow chart depicting the logic and data flow in a typical FFS incorporating a cockpit cab, visual display, and motion system. The boxes with thicker lines and nonitalicized text represent simulation models—units of computer code and data that describe the behavior of a part of the airplane or its systems mathematically. The boxes with thinner lines and italicized text represent physical quantities or values computed by the simulation models. The arrows indicate which simulator models compute the various physical quantities and how these quantities are used as inputs by other models.

Starting with the box labeled "Human Pilot," we see that by manipulating the simulator cab controls the pilot can generate inputs to the column, wheel, throttles, speedbrake handle, flaps, gear, and other cockpit controls duplicated in the cab. Pilots can also provide inputs to the flight management computer, autopilot, and other cockpit systems. In the case of "desktop" engineering simulations, which run on a computer without a cab (and are described below), these "pilot" inputs are accomplished by computer code. For both desktop and cab-based simulations, the pilot inputs are eventually processed by the simulator flight controls model that calculates the appropriate response of the airplane control surfaces, and by the propulsion model that computes the response of the airplane's engines and the resulting thrust forces and moments. The aerodynamic model then uses the control surface positions along with the motion state of the airplane (airspeed, altitude, etc.) to calculate aerodynamic forces and moments on the airplane. Ground reaction forces are computed by the gear model. The total forces and moments are used along with quantities calculated by the mass properties model in the solution of the equations of motion that determine the motion states, both angular and linear. Angular states are the airplane's yaw, pitch, and roll angles and their time derivatives (angular rates and accelerations). Linear states are the components of the 3-D position of the airplane in space and their time derivatives (velocities and accelerations). These states are also used as inputs in the various mathematical models that compute the quantities that eventually affect the forces and moments.

In the case of cab-based simulations, information about the airplane motion states and from the propulsion model are used to drive the visual displays and cockpit instruments in the cab. For simulator cabs on a motion base (such as Level-D training simulators), the motion information can be used to maneuver the base to duplicate, within limits, the acceleration cues (g forces) felt by the pilots. In the case of "animations" or "backdrive" simulations (described below), the aircraft states that drive the visual scene, cockpit instruments, and cab motion aren't computed by solving the equations of motion or by exercising the simulator aerodynamic and other models but are defined a priori from recorded or precomputed data.

Three "tiers" of simulation

Referring to Figure 1, we can define three "tiers" of simulation, differentiated by the elements of an FFS that each incorporates. From the most to the least complex, these simulation tiers are described as follows:

Tier 1: Full-flight simulations (physics, graphics, and pilot)
Tier 1 simulations incorporate all the simulator elements depicted in Figure 1. The equations of motion are solved based on forces and moments computed by the mathematical models of the aircraft's aerodynamics and systems (physics). The resulting visual scene, audio environment, and cab motion are presented to the pilot (graphics). The pilot interacts with the simulation in real-time through the cockpit controls and interfaces (pilot).

Tier 1 simulations are used when aircraft operational and human performance questions are of primary interest. These simulations help investigators to define and experience the circumstances faced by a flight crew during an accident and to understand and evaluate the decisions and actions the crew took in response to those circumstances. Investigators can experience the accident scenario (e.g., a flight control problem or a loss of thrust), evaluate the urgency of the situation and the effectiveness of existing emergency procedures, and explore different strategies for coping with the emergency. In addition, if the accident crew made an error (such as misconfiguring the autoflight or navigation systems), investigators can evaluate the context in which the error was made and gain insight into possible reasons for the error. To address these kinds of questions, the pilot interface elements shown in Figure 1 are fundamental, driving the need for an FFS.

Tier 1 simulations are generally only available at commercial training providers, large Part 121 operators' training departments, or at aircraft manufacturers' facilities. Consequently, investigators will need to partner with these organizations (usually through an organization's role as a party to the investigation or in the case of commercial providers through contracts) to access these devices.

Tier 2: Desktop simulations (physics only)
This tier of simulation solves the equations of motion based on forces and moments computed by the mathematical models of the aircraft's aerodynamics and systems but doesn't incorporate the elements used to present the state of the airplane to a pilot (visuals, audio, motion, cockpit instruments) or to receive inputs to the simulation from the pilot (cab controls and system interfaces). The flight control and other inputs required by the simulation to exercise the models and solve the equations of motion are generated by computer algorithms or read from data files. The aircraft state parameters computed by the simulation are saved to a data file and/or plotted on a computer screen. Since these operations can be performed using only a personal computer, Tier 2 simulations can be referred to as desktop simulations.

Tier 2 simulations are used when the physical performance of the aircraft is of primary interest and the interface between the pilot and the airplane is irrelevant or predefined (e.g., when the pilot's flight control inputs are recorded by an FDR). Tier 2 simulations can be used to evaluate the effect of different environmental conditions or flight control inputs on the performance of the aircraft or to compute a set of flight control and throttle inputs that reproduce the flight track recorded by surveillance systems (such as ADS-B or radar data).

Tier 2 simulations can also be limited in scope so as to evaluate the performance of individual aircraft systems, without having to simulate the entire aircraft. Similarly, depending on the problem, a Tier 2 simulation might not require the complete set of aerodynamic and systems models underlying an FFS but only those corresponding to the flight condition of interest. For example, simulations of the landing roll of an airplane (to determine the effect of different runway conditions and/or deceleration devices on the required stopping distance) can be done with a very small subset of the aerodynamic and thrust data underlying an FFS.

Because Tier 2 simulations can be run on a desktop computer without the pilot interface hardware required by an FFS, the NTSB has developed its own simulation software with which to perform Tier 2 simulations. However, obtaining the aircraft models and data needed to address a particular problem can be challenging, given aircraft manufacturers' concerns about divulging intellectual property. But suffice it to say that the NTSB has obtained partial to full aircraft models from different aircraft manufacturers during the course of investigations involving those manufacturers' products, and has obtained full aircraft models under licensing agreements with some simulator manufacturers and aircraft model developers, both for free and at cost.

Tier 3: Backdrive simulations and "animations" (graphics only)
Tier 3 "simulations" only incorporate the data output elements of the FFS illustrated in Figure 1: the generation of the visual scene and the simulator cab instrument displays and motion. The state of the aircraft that drives these elements isn't computed by exercising the simulator models and solving the equations of motion but is defined beforehand based on data obtained from an FDR or computed some other way. In essence, the simulator visuals and/or cab are used to "replay" preexisting data. The simulator becomes a "media player," and the "channels" this player exercises can include the visual scene, cab motion, cab instruments, and even the cab flight control and throttle positions. In an "animation," only the visual scene (from the interior and/or exterior of the aircraft) is generated. In a backdrive simulation, one or more elements of the cockpit cab are driven with prerecorded data.

Tier 3 simulations and animations are used to visualize preexisting data in the most intuitive context possible. An animation that presents a video of the aircraft position and attitude throughout an accident sequence is much easier for investigators, managers, and the public to understand than engineering plots of performance parameters vs. time. Even for engineers, the presentation of the aircraft's motion in real time can help to impress the pace of events in a way that data plots can't.

Backdrive simulations

allow investigators to "relive" an accident scenario from the pilots' seats. Like Tier 1 FFS simulations, backdrive simulations help investigators to define and experience the circumstances faced by a flight crew during an accident. But unlike Tier 1 simulations, in which the investigators are in control of the simulation, backdrive simulations allow investigators to witness the exact flight control inputs employed by the accident crew, and the exact aircraft response that resulted. In special cases, cockpit voice recorder (CVR) audio from the accident can by synchronized with the backdrive so that the accident crew's recorded conversation can be monitored while their actions on the flight controls are visualized. In essence, investigators become spectators in the cockpit at a high-fidelity reenactment of the accident.

Like Tier 1 simulations, backdrive simulations require a cockpit cab and the other pilot interface elements shown in Figure 1. Consequently, full backdrive simulations can only be performed using an FFS. In addition, the FFS must have the ability to be programmed to accept input data from a file to drive the cockpit cab controls, visual display, motion system, and other elements, as opposed to the normal way of operating in which the simulation computes these data in response to inputs made by pilots using the cab controls. Training simulators operated by commercial pilot training providers aren't likely to be easily programmed in this way, and investigators will likely have to rely on aircraft manufacturers' "engineering" simulators that are designed to accommodate programing changes as part of aircraft development and testing cycles. On occasion, engineers in an airline's training department may be able to reprogram their training simulators to support a backdrive scenario. For the AA587 investigation, the NTSB used the NASA Ames vertical motion simulator (VMS) to accommodate a backdrive simulation that could reproduce a larger range of load factors than that possible with a training simulator. A trade-off in this case was that the VMS cockpit cab didn't represent an Airbus A300 (the accident model) as well as an A300 training simulator would have.

As previously noted, Tier 3 simulations also include animations, consisting of video images of the airplane's motion from different points of view, such as from the pilot's seat (depicting the view out the window and the instrument panel) and/or an external view from a "chase plane." Animations aren't really simulations at all, only graphic representations of preexisting data. Many NTSB animations (for aviation accidents and accidents in other transportation modes) have been created using general 3-D modeling software unrelated to simulation. However, animations are included here as Tier 3 simulations because, once the underlying aircraft position and orientation data is defined, an animation of an aviation accident can be created in a matter of minutes with flight simulation software such as X-Plane or Microsoft Flight Simulator compared to the many hours required using general-purpose 3-D modeling software.

The NTSB has used all three tiers of simulation in the investigation of different aircraft accidents; sometimes a single investigation itself requires the use of all three tiers. In many cases (in aviation and other transportation modes), an animation depicting an exterior view of the aircraft (or other vehicle) driven by data generated during the investigation will be used to present the circumstances of an accident most intuitively to NTSB board members and to the public.

Examples of the use of the three simulation tiers in several NTSB accident investigations are presented below. Before describing the details of these simulations, however, it's helpful to provide brief descriptions of the accidents themselves.

Aircraft accidents discussed in this paper

The simulation case studies concern the following aviation accidents investigated by the NTSB:

- American Airlines Flight 587 (Belle Harbor, New York, 2001),
- US Airways Flight 1549 (Weehawken, New Jersey, 2009),
- Mid-air collision between an F-16 and a Cessna 150 (Moncks Corner, South Carolina, 2015), and
- PC-12 (N933DC) crash after takeoff (Amarillo, Texas, 2017).

These accidents and the resulting investigations are further described in the full presentation text posted in the library section of ISASI's website.

Examples of Tier 1 FFS simulations used in accident investigations

Tier 1 FFS were used in the investigations of both the AA587 and the US1549 accidents.

American Airlines Flight 587

The Human Performance Study Report: American Airlines Simulator Exercise describes the purpose of an exercise conducted in an American Airlines Airbus A310/300 FFS:

"On Dec. 4, 2002, the Human Performance Group conducted a study in the A-310/300 training simulator as part of its meeting at the American Airlines Training Academy, DFW Airport, Texas. The purpose of the study was to examine the Advanced Aircraft Maneuvering Program (AAMP) excessive bank angle recovery exercise, a simulator scenario in which the instructor induced an excessive bank angle in a wake turbulence context. Following initial ground training and simulator briefings, six pilots from the Human Performance Group performed the scenario multiple times using different pilot rudder input strategies to evaluate whether the scenario encouraged particular pilot inputs."

The report goes on to describe the procedures used to experience the AAMP "excessive bank angle" upset training in the simulator:

"For purposes of the study, the instructor was asked to initiate the roll event at about 240 knots airspeed but, otherwise, to introduce the scenario as a normal AAMP simulator exercise. The instructor set up the exercise as a departure behind a Boeing 747 airplane, in this case having each pilot execute a normal takeoff on Runway 31L at JFK Airport in day, visual conditions. During a climb to 5,000 feet, the instructor cautioned that the airplane was following behind a large aircraft, directed the pilot to turn, and initiated the roll event while the airplane was banked at an altitude between 2,000 to 2,500 feet. The simulated airplane exhibited an uncommanded roll in one direction (either left or right determined arbitrarily by the computer) followed immediately by a substantial uncommanded roll in the opposite direction. The simulator scenario was programmed to momentarily inhibit the aircraft response to pilot inputs in roll and yaw during the event to allow the simulated airplane to reach a substantial bank angle before recovery began. Each pilot was instructed to recover the airplane according to the AAMP training they received from the training tape and simulator instructors. After recovery, the simulator trial ended and the pilot provided verbal evaluations on structured interview questions."

This procedure was repeated for five additional trials that were identical to the first except that the roll maneuver was initiated during level flight after the pilot indicated his readiness. During the successive trials, the pilot was instructed to respond using one of five specific recovery strategies:

- Partial wheel, no rudder (Strategy A)
- Full wheel, no rudder (Strategy B)
- Full wheel, partial rudder (Strategy C)
- Full wheel, full rudder (Strategy D)
- Pilot's own preference

The report then presents the results of the study in terms of pilot responses to interview questions and a record of the maximum bank angle achieved during the exercises. Among other results, the report notes:

"Strategies A to D provided a range of potential recovery strategies, and pilots reported definite preferences. Three pilots selected Strategy A as the worst strategy, and all six pilots questioned whether Strategy A provided sufficient control authority to achieve recovery. Two pilots selected Strategy D as the worst one, with several pilots indicating there was a possibility of overcontrol. Based on pilot evaluations and pilot actions on the first and last trial, pilots appeared to prefer a strategy of full wheel and limited rudder in response to the scenario.

"Contrary to pilot evaluations, the four recovery strategies showed little difference in terms of maximum bank angle reached. Each recovery strategy showed an average maximum bank angle between 104 and 107 degrees and none, of the individual recoveries by any subject was achieved at less than 100 degrees despite the widely varying nature of the inputs provided under the four strategies."

US Airways Flight 1549

The simulation test report for US Airways Flight 1549 describes exercises conducted in the Airbus "S31" A320 FFS (with a motion base) and "S22" engineering simulator (with a fixed base). As stated in the report, the objectives of the exercises were to

- allow the NTSB Operations/Human Performance Group to familiarize themselves with the A320 cockpit, instrument displays, controls, systems, and normal takeoff/landing and emergency procedures.
- identify and evaluate the operational and airplane performance implications of the various options available to a flight crew following the loss of thrust on both engines. This will apply to the context of US Airways Flight 1549 and other relevant options.
- evaluate the A320 ENG DUAL FAILURE checklists/procedures.
- evaluate the operational feasibility of achieving minimum vertical speed at touchdown.

The report goes on to describe the simulation participants and procedures as follows:

"Four airline transport pilot members of the Operations/Human Performance Group, three of whom [were] type rated on the A320, and one of whom was an A320-rated Airbus test pilot, participated in an observational study at the Airbus Training Center in Toulouse, France, on April 14–16, 2009. The simulators used for the observations were an S22 engineering test simulator and a S31 motion-based training simulator….

"The purpose of the simulations [was] to identify and evaluate the various options available to the flight crew of US Airways Flight 1549 following the bird strike (e.g., land at an airport or land on the Hudson River) and to determine the implications of each of those options. Additionally, the group expanded beyond the context of Flight 1549 in order to understand the implications of a dual-engine failure in which the aircraft is in the EMER ELEC mode (no green or yellow hydraulics). Finally, the group evaluated the checklists and procedures made available to flight crews, as well as the operational feasibility of achieving minimum vertical speed at touchdown.

"Each pilot was fully briefed on the maneuver before it was attempted. The autopilot was off for all tests. Flight scenarios were flown from zero groundspeed on the takeoff Runway 4 at LGA, from a preprogrammed point shortly before the bird strike and loss of thrust, and from 1,500 feet above the river on approach to landing.

"Initial conditions duplicated as closely as possible those of the accident flight. They were programmed into the simulator (winds, temp, altimeter, weight, and balance). The profile flown duplicated as closely as possible the accident profile (airplane position, thrust setting, altitude at beginning of turns, thrust reduction and cleanup altitudes, speeds, and altitude/speed combination) up until the time of bird ingestion and dual-engine failure. Following the failure, pilots followed the US Airways QRH ENG DUAL FAILURE checklist and relied on their training and experience to complete the test conditions. An observer was present to document observations, times, etc. Data from the S22 engineering simulator was recorded electronically for later review and analysis. In addition, the runs flown in the S31 motion-based simulator were recorded with a video camera mounted so as to approximate the point of view of an observer in the jumpseat.

"At the completion of each condition, the pilot flying was asked to rate the difficulty of the landing on a scale of 1 to 7 (1 being very easy, 7 being very difficult) and to provide any comments about observations made during the scenario. In addition, one A320 test pilot and one A320 type-rated pilot completed the Cooper Harper Rating Scale at the end of each condition they performed.

"The purpose of the evaluation of the flight crew's options following the loss of engine thrust wasn't to 'second-guess' or call into question the crew's (wise) decision to ditch the airplane in the Hudson River, rather than to attempt to glide to a runway. Instead, the purpose was to 'evaluate the operational and airplane performance implications of the various options' and to determine whether a return to LGA was even possible (a question that would certainly be asked both within and outside of the investigation). The test conditions for the attempted glides back to a runway included both immediate turns toward a runway following the loss of thrust, and a 35-second delay before initiating any turns to

Condition #	Airport	Runway	Timing	Turn	Flaps	Simulator
2.1	LGA	22	Immediate	Right	Available/Pilot's discretion	S31/Motion
2.1a	LGA	22	Immediate	Right	Available/Pilot's discretion	S22/Fixed
2.1b*	LGA	22	Immediate	Right	Flaps 3/Slats only^	S22/Fixed
2.2	LGA	13	Immediate	Left	Available/Pilot's discretion	S31/Motion
2.2a	LGA	13	Immediate	Left	Available/Pilot's discretion	S22/Fixed
2.2b†	LGA	13	Immediate	Left	Flaps 3/Slats only^	S22/Fixed
2.2c†	LGA	13	35 seconds	Left	Available/Pilot's discretion	S22/Fixed
2.3	TEB	19/24	Immediate	Left	Available/Pilot's discretion	S31/Motion
2.3a	TEB	19/24	Immediate	Left	Available/Pilot's discretion	S22/Fixed
2.3b§	TEB	19/24	Immediate	Left	Flaps3/Slats only^	S22/Fixed
2.3c§	TEB	19/24	35 seconds	Right	Available/Pilot's discretion	S22/Fixed

*Table 1. Conditions tested during the attempts to glide back to a runway following the loss of engine thrust. Notes: Conditions 2.1, 2.2 and 2.3 performed only once with a different pilot in each condition to provide them with the physical/motion-based cues associated with an immediate turn to an airport; * Condition performed only if Condition 2.1a is successful; † Condition performed only if Condition 2.2a is successful; § Condition performed only if Condition 2.3a is successful; ^ Condition assumes EMER ELEC with APU started.*

account for the time required for the crew to assess the situation and decide upon a course of action."

The conditions tested during the attempts to glide back to a runway are listed in Table 1 of the simulation report.

The results of the attempts to glide back to a runway are reported as follows:

"A total of 20 runs were performed in the S22 simulator in which pilots attempted to return to LGA Runways 13 or 22 or attempted to land at TEB Runway 19. Five of 20 runs (25%) were discarded due to poor data or simulator malfunctions, leaving 15 runs for analysis (six runs to LGA Runway 22, seven runs to LGA Runway 13, and two runs to TEB Runway 19). Eight of 15 runs (53%) made successful landings. The eight successful runs were made following an immediate turn to an airport after the bird strike. See Table 1 for details of each run.

"Specifically, six runs were made to return to LGA Runway 22 immediately following the bird strike. Of those six, two (33%) resulted in a successful runway landing—one using flaps at the pilot's discretion (Condition 2.1a; one additional attempt was unsuccessful) and one using slats only (Condition 2.1b; four additional attempts were unsuccessful). Due to inadequate successful landing attempts following an immediate turn after the bird strike, attempts to land at LGA Runway 22 after a 35-second delay (Condition 2.1c) weren't performed.

"Additionally, pilots attempted to land at LGA on Runway 13. All four pilots successfully landed (100%) on LGA Runway 13 following an immediate left turn to the airport following the bird strike (Condition 2.2a). Two runs were attempted in which the pilot was required to use slats only on landing on Runway 13 (Condition 2.2b). One landing (50%) was successful, and one landing wasn't successful, requiring the pilot to ditch in the waters adjacent to LGA. The one attempt to return to LGA Runway 13 following a 35-second delay (Condition 2.2c) wasn't successful. No additional attempts were made to return to LGA Runway 13.

"Finally, two runs were attempted to determine the ability of the airplane to land at TEB Runway 19 immediately after the bird strike. In both runs, pilots were able to use flaps at their discretion (Condition 2.3a). One attempt (50%) was successful, and one attempt was unsuccessful. Due to inadequate successful landing attempts following an immediate turn, Conditions 2.3b and 2.3c weren't attempted."

These results vindicate the flight crew's decision to ditch the airplane in the Hudson River instead of attempting to glide the airplane back to LGA over a densely populated city.

The Airbus simulators were also used to "to evaluate the operational feasibility of achieving minimum vertical speed at touchdown." The investigation determined that in order to prevent a rupture of the aft fuselage upon contact with the water (as occurred in the Flight 1549 accident), a flightpath angle of -0.5 degrees or shallower had to be achieved. On Flight 1549, the touchdown flightpath angle was -3.4 degrees, which resulted in a vertical speed at touchdown of about -750 feet per minute, beyond what the skin of the fuselage could withstand. The resulting fuselage breach and water penetration into the cargo hold and aft cabin submerged the aft door sills below the level of the river, rendering the life rafts attached to the aft doors unusable. As a result, there was insufficient raft space available for all the passengers, and some passengers had to stand on the wings of the airplane to await rescue.

The Airbus simulators were used to evaluate the pilots' abilities to touch down within the -0.5 degree flightpath angle constraint. The simulation test report describes this task as follows:

"All conditions started at a predetermined location of 1,500 feet above the Hudson

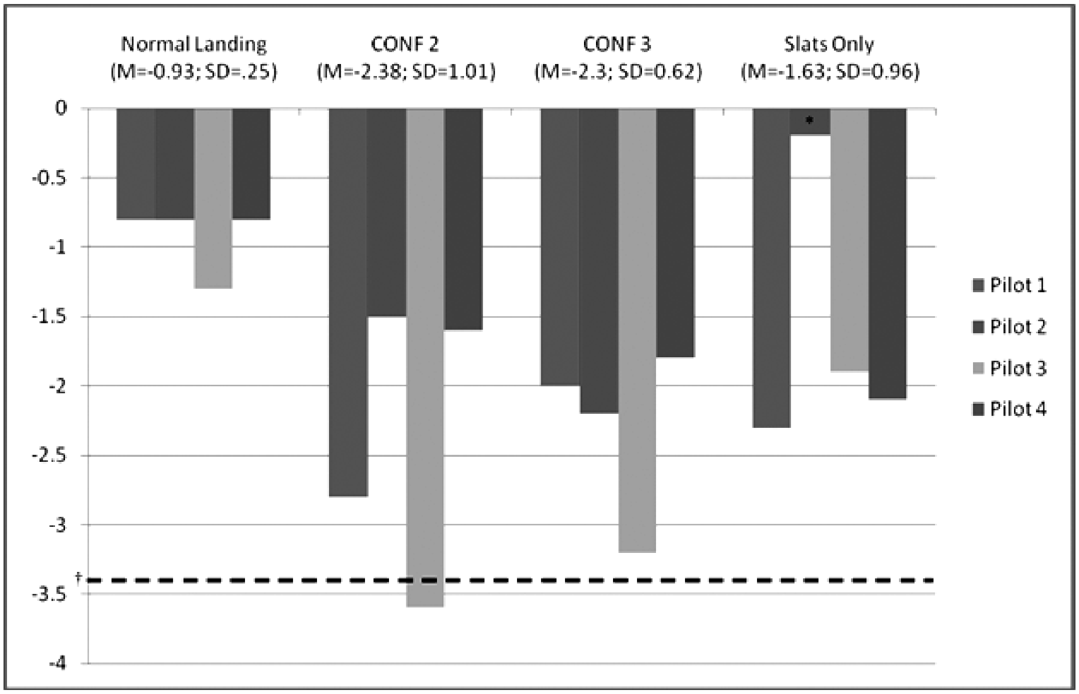

Figure 2.

Condition #	Heading	Speed±	Flaps	Simulator
3.1*	Left to 220	Green Dot	Flaps 2	S31/Motion
3.2	Left to 220	Green Dot	Flaps 2	S22/Fixed
3.3	Left to 220	Green Dot	Flaps 3	S22/Fixed
3.4	Left to 220	Green Dot	Flaps 3/Slats only^	S22/Fixed

*Table 2. Conditions for the US1549 simulated ditching tests. Notes: *Condition 3.1 will "recreate" the accident flight; ± Per the QRH, pilots will maintain green dot speed until configuring for landing at which time they will assume F speed on the speed tape; ^Condition assumes EMER ELEC with APU started.*

River and 200 knots, which closely replicates the location and airspeed of the accident flight. The left-seat pilot was at control when the simulator was 'released' and the right-seat pilot performed the US Airways QRH ENG DUAL FAILURE checklist and other duties as assigned by the pilot flying. The left-seat pilot attempted to land on the river following guidance in the QRH ('touchdown with approximately 11 degrees of pitch and minimum vertical speed')."

Ditching tests were conducted using Flaps 2, Flaps 3, and Flaps 3 with slats only. The results of the tests are reported as follows:

"A total of 16 runs were performed in the S22 simulator in which pilots attempted to ditch the airplane, of which two were discarded due to poor data. Each of the four pilots attempted a landing under each of the three conditions—using CONF 2 (Condition 3.2), using CONF 3 (Condition 3.3), and using CONF 3/Slats only (Condition 3.4). The flightpath angles of each of these runs are presented in Figure 2. See Table 2 for details of each run.

"In addition, two runs were attempted in which the pilot flying was instructed to fly within the flight envelope protection range (i.e., alpha protection) to understand the impact of such conditions on the flightpath angle. The flightpath angles at touchdown for the landings were -6.5 and -6.3 degrees."

The test results plotted in Figure 2 indicate that only one of the 12 landings on the water achieved a flightpath angle within the -0.5 degrees target at touchdown and that all but one landing achieved a flightpath angle shallower than the -3.4 degrees of US1549. In addition, Figure 2 indicates that the -0.5 degree target is shallower than that achieved by the four simulator pilots during their normal landings on a runway.

Examples of Tier 2 (desktop) simulations used in accident investigations

Not counting Tier 3 animations, Tier 2 (desktop) simulations are those most frequently used by the NTSB, since all that they require is a desktop computer, a simulation program (or "engine"), and a mathematical model of the aircraft of the scope and fidelity required for the problem at hand. Some problems can be addressed with very simple, low-fidelity models—e.g., when the simulator is used to create a physically realistic, smooth flightpath through noisy radar data, and only the motion of the aircraft's center of gravity is of interest. Such simulations can produce aircraft speeds and accelerations that are more realistic than those obtained by filtering or otherwise mathematically smoothing the radar data. Other problems, however, require more complex and higher-fidelity models because the handling qualities and other physical characteristics of the aircraft are of primary concern.

For the AA587 accident, a Tier 2 desktop simulation was used to determine the relative significance of the encounter with the B-747 wake, and of the first officer's control inputs in response to that encounter, on the subsequent motion of the airplane. For the Amarillo PC-12 accident, a desktop simulation was used to determine a set of flight control inputs, and the associated control forces, that would result in a match of the airplane's flight track as recorded by radar. Both of these simulations required high-fidelity mathematical models of the airplanes involved.

American Airlines Flight 587

Airbus and the NTSB both conducted Tier 2 desktop simulations of the final seconds of flight of AA587. The Airbus simulation computed the expected response of the A300 to the flight control inputs recorded on the FDR without any external forces or moments associated with the encounter with the B-747 wake applied; only vertical and horizontal wind gusts were used in the simulation to account for wake effects. The resulting simulator output matches the aircraft motion recorded on FDR well, but not perfectly; as stated in the NTSB Aircraft Performance Study:

"The simulator match of the accident event…is good, but not perfect. Factors that can cause the simulator to calculate motion that differs from that measured in flight include

1. Errors in the flight sensors or other measuring/recording equipment.
2. Inaccuracies in the simulator aerodynamic and/or other mathematical models.
3. Improper simulator initialization or matching technique.
4. External forces or moments not modeled in the simulator.

"While a better match of the FDR data could probably be obtained by trial and error with external winds or other effects attributable to a wake encounter, the match in hand does provide important information about the accident sequence. The simulator results indicate that the motion of the airplane, and most importantly, the buildup of the sideslip angle, is consistent with and principally the result of the movements of the airplane's control surfaces, especially the rudder."

The NTSB desktop simulation used mathematically applied "external" rolling, pitching, and yawing moments (in addition to horizontal and vertical wind gusts) to force a better match between the simulator response and the motion recorded on the FDR.

As discussed in the Aircraft Performance Study, crew comments recorded on the CVR, a NASA analysis of the wake of the B-747 that departed JFK ahead of AAL587, and the AAL587 FDR data all indicate that AAL587 encountered the B-747 wake twice shortly before the accident. The Airbus and NTSB simulations of the accident start just before the second wake encounter, at about 09:15:47 EST.

As described in Appendix B to the Aircraft Performance Study, the trailing vortices in the wake of the B-747 produce significant disturbances in the direction and velocity of the surrounding air. In fact, the vortices may induce updrafts of 20 knots in one place, and downdrafts of 20 knots only 30 feet away. Similar differences in horizontal gusts are also possible. Depending on the geometry of how the airplane encounters the wake, these changes in wind speed and direction can cause the angle of attack to increase on one wing and decrease on the other, creating a rolling moment. Changes in the local flow angles over the horizontal stabilizer can produce pitching moments, and changes in flow over the vertical stabilizer can produce yawing moments. These "vortex-induced" rolling, pitching, and yawing moments aren't modeled in the baseline A300 simulator, and so if they're not accounted for in some way, the simulator will not be able to duplicate all the forces and moments acting on the actual airplane, and the simulator motion will not match that recorded on the FDR.

The load factor and engine N1 data fluctuations recorded on the FDR between about 09:15:50 and 09:15:54 suggest that the second wake encounter occurred during this time and that the motion of the airplane was affected by the wind gusts induced by the wake. To account for these effects, during this 4-second period the NTSB simulation incorporates external rolling, pitching, and yawing moments that make the simulator motion more closely match the motion recorded on the FDR. After the 4-second period, the airplane is assumed to be free of the wake, and the external moments are removed.

In addition to external moments, the wake can induce forces on the airplane that can be accounted for by changes in the velocity of the airmass surrounding the airplane (as opposed to differential changes in the flow at various points). These gross effects are modeled in the simulator as vertical wind gusts and changes in the horizontal wind speed and direction.

Throughout the simulation, the simulator cockpit control positions and aerodynamic surface positions are driven to match the positions recorded on the FDR as closely as possible without sacrificing the match of the motion recorded by the FDR. Because of the effects of the SDAC filter, the filtered simulator control surface positions are matched to the FDR positions.

To get a sense of the magnitude of the effects of the vortex-induced external moments and vertical and horizontal wind gusts, the simulator match is repeated, but without any cockpit control or control surface movements. The simulator then computes the response of the airplane solely to the forces and moments induced by the wake encounter.

The NTSB simulator match of the Euler angles (heading, pitch, and roll) recorded on the AA587 FDR is shown in Figure 3 for the case in which the simulation is driven with both the flight control inputs recorded on the FDR and with the wind gusts and external moments required to force a better match. The NTSB simulator match of the Euler angles for the case in which the simulation is driven only with the wind gusts and external moments (and the flight controls are left in their trim positions) is shown in Figure 4. The Aircraft Performance Study Addendum #1 concludes that:

"The simulator match of the accident maneuver… indicates that while external winds and moments, assumed to be attributable to the wake encounter, are required to match the motion recorded on the FDR, the large roll and yaw oscillations, lateral load factors, and sideslip angles achieved during the maneuver are the result of wheel and rudder inputs. By themselves, the external winds and moments only produce an initial 10 degree deviation in bank angle and only subtle changes in heading, resulting in sideslip angles of less than 2.5 degrees."

PC-12 (N933DC), Amarillo, Texas

The Aircraft Performance Radar & Simulation Study for the Amarillo PC-12 accident describes the simulation used during the investigation as follows:

"[A] computer simulation of the accident flight was performed in order to generate a trajectory that is consistent with both the recorded radar data and crash site location and the performance capabilities of the airplane. The simulation also yields a set of control and throttle inputs that are consistent with the simulated trajectory (though it should be noted that other inputs, which produce similar but slightly different trajectories, could also be generally consistent with the recorded radar data)."

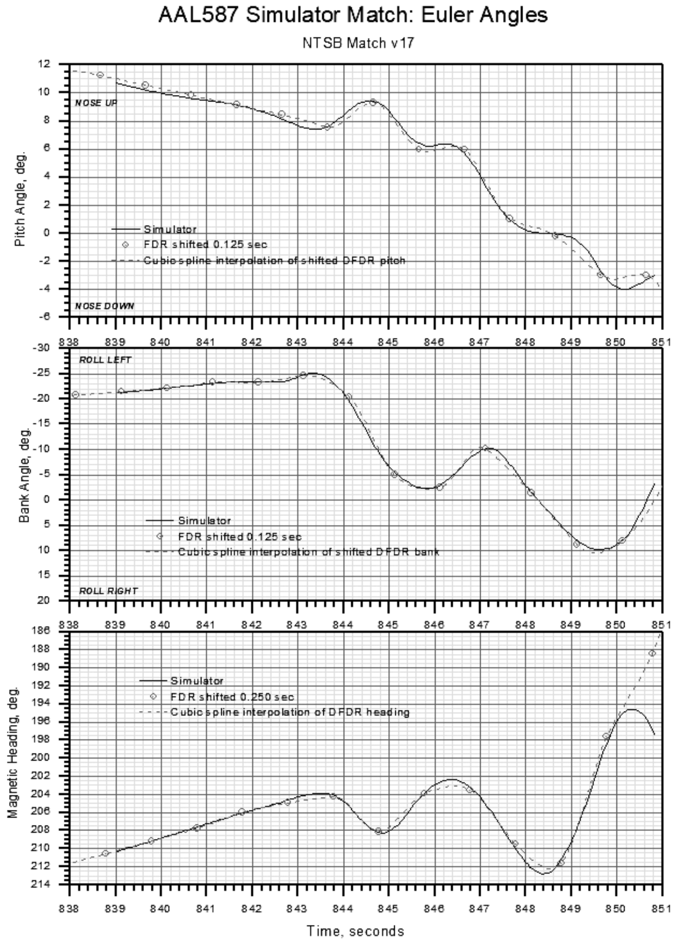

Figure 3.

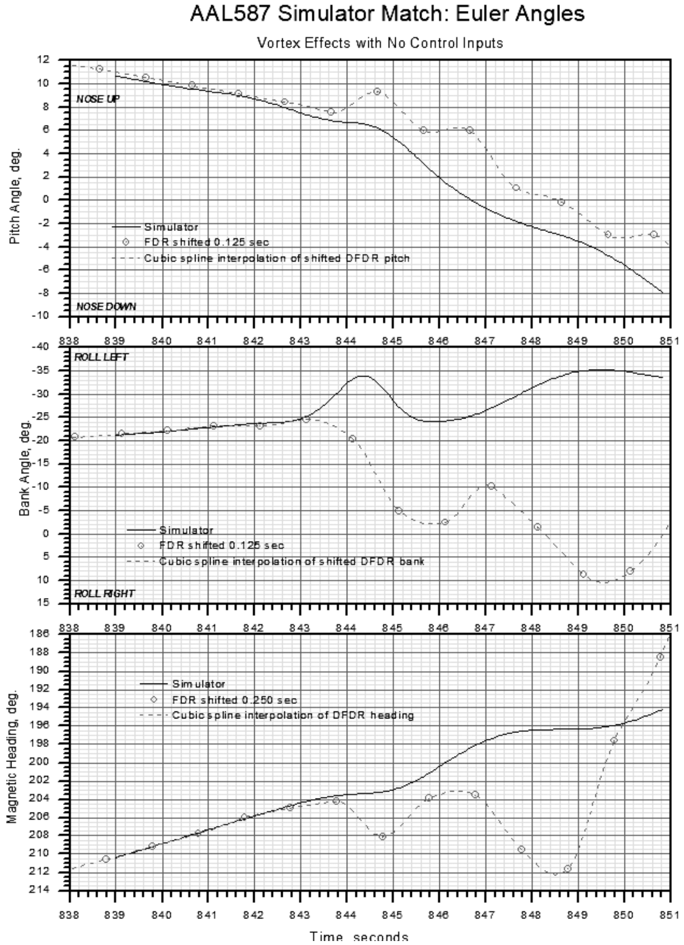

Figure 4.

The following information sources define the "target" trajectory and airplane model used in the simulation, and provide criteria by which to measure the quality of the simulation match:

1. Radar data: For the simulation to "match" the radar data, the position of the airplane in the simulation solution should lie within the uncertainty boxes of the radar returns at the times corresponding to those returns, and the altitude should fall between the ± 50 feet uncertainty band of the corrected Mode C data at those times.
2. Crash site data: The simulation and actual crash sites should coincide.
3. Performance data: The simulation should be representative of the Pilatus PC-12 aerody-

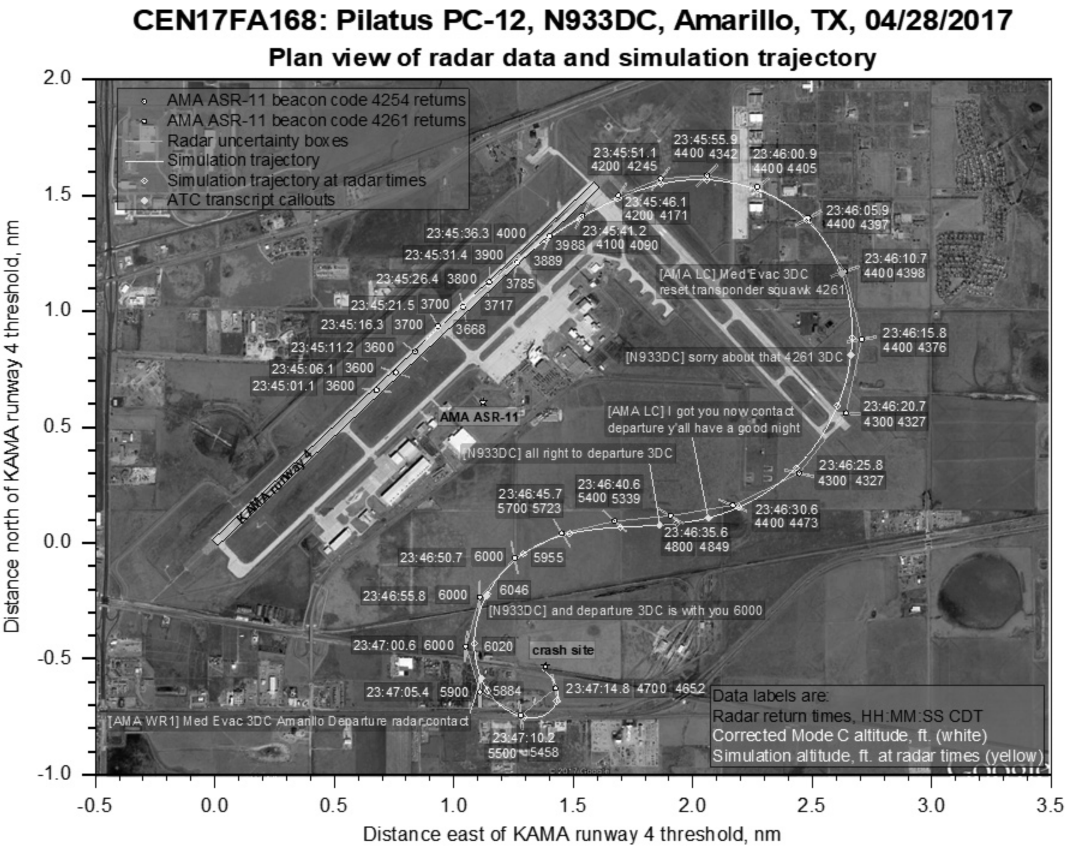

Figure 5.

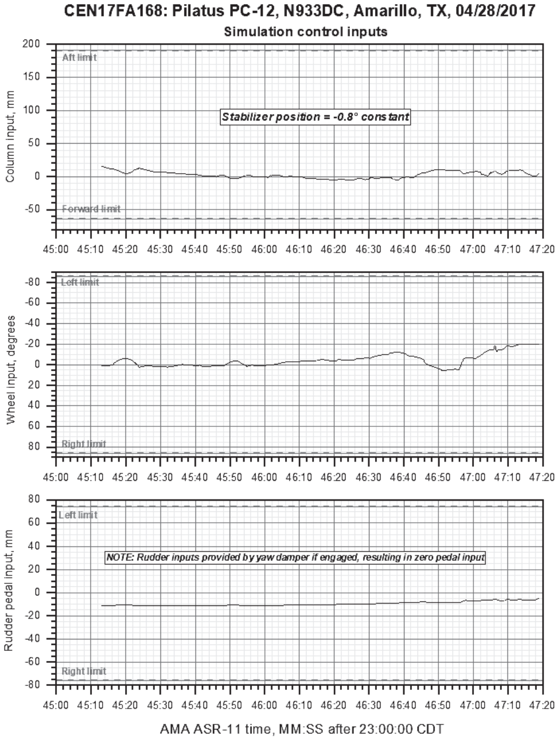

Figure 6.

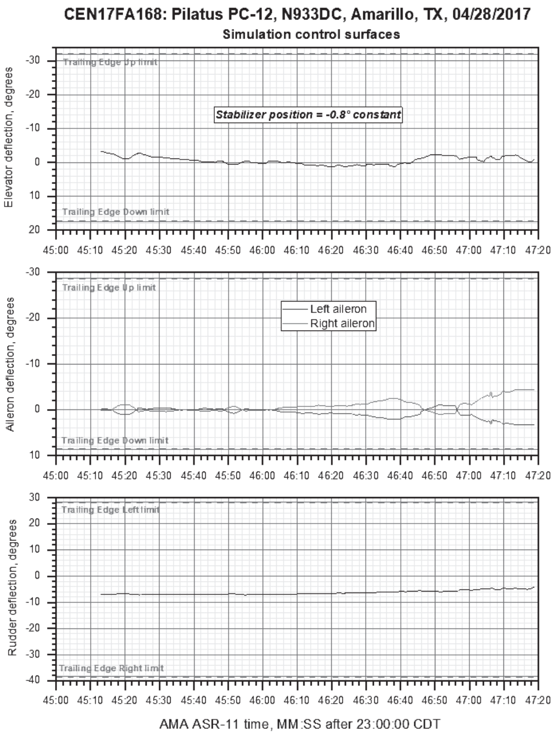

Figure 7.

namics and engine thrust capabilities. Airplane aerodynamics and engine simulation models provided by Pilatus were used for this study. These models were developed by Pilatus for SimCom (a flight simulator manufacturer) and were largely complete, except for the flight control system. For this system, Pilatus provided system description reports (including control gearing ratios and aerodynamic surface hinge moments) from which a flight control system model could be constructed. As described further below, the resulting model yielded reasonable control forces in the pitch and yaw axes but didn't yield reasonable control forces in the roll axis. For the roll control forces, a simpler, linearized model provided to the NTSB for a previous PC-12 accident investigation was used, and this model did yield reasonable roll control forces.

4. Wind data: The winds and temperatures aloft as a function of altitude, based on the…FDR data [from a B-737 that preceded N933DC out of KAMA], were used in the simulation.

The simulation uses a "math pilot" to generate control system and throttle inputs to produce pitch and roll angles and engine thrust that result in an approximate match of the "target" trajectory defined by the radar data and the impact point. Since the aerodynamic characteristics of the simulation are representative of the airplane, the engine power, angle of attack, Euler angles (pitch, roll, and heading), and control inputs and forces computed by the simulation to match the target track are relevant and of interest.

The flaps and gear-up configuration is used throughout the simulation, which starts at 23:45:13 with the airplane climbing at about 600 feet per minute through 3,640 feet MSL (about 40 feet AGL) and accelerating through 100 knots. This configuration is consistent with the normal takeoff procedure outlined in the AFM, which states that the gear should be raised after liftoff and positive rate of climb is established, and the flaps should be raised to 0 degrees above 100 knots. The flaps and gear-up configuration at the start of the simulation may be a little early (i.e., occur earlier than in the actual flight), which could account for the less than full thrust required at the start of the simulation.... The simulation thrust increases to maximum power at 23:45:20, so it's likely that the clean configuration was achieved by that time.

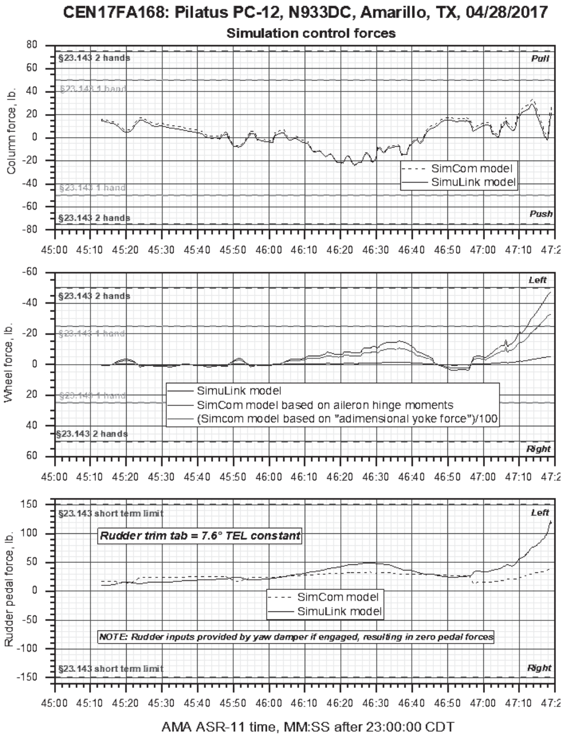

Figure 8.

The simulation results…satisfy the match criteria outlined above well, though not perfectly. As shown in Figure 5, the position of the airplane is within or close to the edge the uncertainty boxes of the radar data at the radar return times, and the impact is close to (about 130 feet from) the crash site. In general, the airplane positions are within about 200 feet of the corresponding radar returns. The attitude of the airplane at impact is heading 301 degrees true, pitch 42 degrees down, roll 76 degrees left. In this attitude, the projection of the leading edge of the wing along the ground is a line oriented southeast to northwest from 141 degrees to 321 degrees, which matches the general orientation of the ground scar of the left wing leading edge in the wreckage. The left-wing-low impact attitude is also consistent with the deeper impact crater created by the left wing than the right wing....

The study states the following concerning

(Continued on page 30)

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ISASI 2023 Call for Papers

ISASI 2023 will be held in the Nashville, Tennessee, at the Renaissance Nashville Hotel, Aug. 21–25, 2023. The seminar theme is "Accidents: The Current Which Lies Beneath." This will be an in-person event with tutorials on Monday, August 21, seminar presentations from Tuesday, August 22, through Thursday, August 24, and various gatherings throughout the week. Please find the official Call for Papers on the ISASI website at www.isasi.org. Please submit expressions of interest to isasi2023@isasi.org. ◆

PNRC Holds Regional Meeting

The Pacific Northwest Regional Chapter (PNRC) held a meeting on November 1 in Des Moines, Washington, reported Chapter President Gary Morphew. Guest speakers included U.S. Society President Steve Demko and ISASI President Barbara Dunn. ◆

USC Thanks Del Gandio

In a recent letter, Tom Anthony, ISASI corporate member representative, expressed thanks from the University of Southern California's (USC) Aviation Safety and Security Program to ISASI President Emeritus Frank Del Gandio for decades of service and stewardship to ISASI. He wrote that ISASI is the global leader in aviation accident investigation. "We are fortunate," he added, "that such an organization exists and has a tradition of professionalism and responsibility to the discipline.

"Many are the times that I attended the ISASI international conference and came away with the realization that I have something new and important." Noting that the USC program goes back to Jerry Lederer, Anthony said, "We are, in a sense, fruit of the same vine. You have served all of us involved in aircraft accident investigation well. We owe you a dept of gratitude." ◆

Pakistan Society Announces Aviation Safety Conference

"Pakistan Aviation Safety Challenges" is the theme of an international conference to be held at the Air College Institute PAF Base, Faisal, Karachi, Pakistan, on Jan. 10, 2023, reported Pakistan Society President Naseem Syed Ahmed. For more information and registration, contact Tassadaq Abbass at tasaddaqabbass@gmail.com or Nayyar Faruqui at nayyarfaruqui18@gmail.com. ◆

Susan Rice Presented Award During ISASI 2022

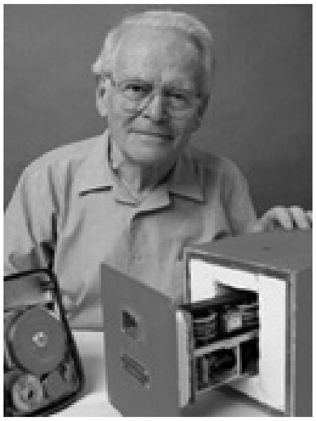
Australian Society executive officers President John Guselli, Vice President Alf Jonas, and Secretary Paul Mayes presented the David Warren Award to Susan Rice during the ISASI 2022 banquet. The Australian Society established the award to honor David Warren's contributions to transport safety. Rice was recognized for

- promoting transport safety through the formation of the Asia Pacific Cabin Safety Working Group and professional education through lectures, displays, and presentations;
- broadening professional relationships among ASASI members; and
- enhancing the prestige, standing, and influence of air safety investigators and transport safety professionals in matters of transport safety.

In 1934, Warren's father was killed in one of Australia's earliest air disasters, the loss of the Miss Hobart in Bass Strait. His schoolboy knowledge of electronics stood him in good stead when, many years later, he decided to design and build the world's first flight data recorder, now widely known as the "black box." Warren was involved in the accident investigations related to the mysterious crash of the world's first jet-powered aircraft, the Comet, in 1953. He argued that a cockpit voice recorder would be a useful means of solving otherwise unexplainable aircraft accidents.

The idea initially raised little interest so Warren decided to design and build an experimental unit to demonstrate the concept. It could continually store up to 4 hours of speech, prior to any accident, as well as flight instrument readings. It took 5 years before the value and practicality of the idea was finally accepted. It was another 5 years before it became mandatory to fit cockpit recorders in Australian aircraft. The modern-day equivalent of Warren's device is now installed in passenger airliners around the world. ◆

2022 David Warren Award recipient Susan Rice displays the plaque that the Australian Society presented during ISASI 2022.



David Warren (1925–2010)

This little-known inventor has probably saved your life!

The Role of Flight Simulation in Accident Investigations, Part 1

(Continued from page 27)

the flight control positions computed by the simulation's "math pilot":

Figures 6, 7, and 8 present the simulation flight control inputs, aerodynamic control surface positions, and flight control forces, respectively. The travel limits of the flight controls and aerodynamic surfaces are also shown in the plots, to provide a sense of the scale of the movements. To provide a scale for the control forces, the short-term force application limits specified in the certification standards for Part 23 airplanes (§23.143) are also shown in Figure 8. §23.143 specifies both one- and two-handed force limits for the pitch and roll

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(Editor's note: We have recently made many changes and corrections to the ISASI Information pages to add new corporate member organizations, remove corporate member organizations that aren't continuing to participate in ISASI, update corporate member organization name changes, and update committee and working group chairs. If a corporate member organization was incorrectly removed from this listing, the primary representative should contact Ann Schull at ISASI headquarters to remedy the problem and be restored to the listing. If an elected or appointed ISASI official has an incorrect e-mail address listed, please contact Ann Schull.)

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WHO'S WHO: ERAU LAUNCHES CENTER FOR AVIATION AND AEROSPACE SAFETY

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

Robert Sumwalt retired as the U.S. National Transportation Safety Board (NTSB) chair in June 2021. Shortly thereafter, Embry-Riddle Aeronautical University (ERAU) asked if he'd be interested in coming to the university to set up the Center for Aviation and Aerospace Safety (CAAS). As someone who'd devoted most of his adult life to safety, he jumped at the opportunity and joined ERAU as executive director of the center. In addition to her role as the university's presidential fellow, Dr. Barbara Holder accepted the position as the center's chief scientist and associate director.

The center's vision is simple: To be a trusted global leader for enhancing aviation and aerospace safety. Although ERAU is just building the foundation, figuratively speaking, it's pursuing that vision by promoting, leading, and fostering collaboration among government, academic, and industry leaders by focusing on the center's four pillars: research, education, training, and safety consulting.

The university is uniquely qualified to carry out this mission. With the Daytona Beach, Fla., Prescott, Ariz., and Worldwide campuses, ERAU has more than 1,300 aviation and aerospace full-time and part-time instructors—subject-matter experts in areas including airline operations and training, aerospace engineering, accident and incident investigation, human factors, safety management systems, meteorology, commercial space, aviation business administration, and many other related disciplines. This allows CAAS to reach across campuses to select faculty for projects such as research and consulting.

Research—One of ERAU's strategic goals is to grow the university's research portfolio, which ties in with one of the pillars of CAAS. Holder has already brought in two research grants, with two others in the preapproval stages. Potential sources of funding are likely to include government and industry.

Education—While ERAU already offers an extensive array of safety-related academic courses and degree programs, including a recently added master of science in aviation safety (offered online through the Worldwide campus), one task of the center is to seek areas in which the university's safety curriculum can be enhanced.

Training—ERAU already has a robust professional education program, with periodic short courses and certificate programs in safety-related areas such accident investigation, aircraft crash survival analysis, and human factors analysis and classification. The Robertson Safety Institute located at the Prescott campus has a crash lab featuring more than 12 wrecked aircraft, all laid out in a naturalistic setting. The Daytona Beach campus has eight wrecks. ERAU Worldwide has a virtual crash lab. CAAS is assisting with the development of new classes. For example, in September the university offered a new three-day course in disaster assistance and response. Taught by former NTSB disaster assistance experts Sharon Bryson and Paul Sledzik, the course had 16 participants from airlines, railroads, and other transportation sectors. In October, ERAU started a virtual data science course for a major airline and in December will offer an aircraft certification course. CAAS isn't replacing or absorbing the highly successful Robertson Safety Institute. Rather, the two are working closely together to complement each other's capabilities.

Safety Consulting—As with the other CAAS pillars, ERAU can leverage its unique capabilities to meet an organization's needs. The university was recently approached by a large airline to respond to a request for proposals to conduct a safety assessment of the airline. Another organization asked ERAU to evaluate its emergency response plan.

"We'll move into a newly remodeled building in late spring 2023," Sumwalt noted. "Located on the Daytona Beach campus, this building will incorporate office, classroom, and lab space. We hope you'll come see us. But if you can't visit in person, visit erau.edu/safety." ◆