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ABOUT THE COVER

The Transport Safety Investigation Bureau of Singapore co-organized the 5th International Accident Investigation Forum with the Singapore Aviation Academy from May 18–20. Approximately 90 delegates attended, with most of them posing for a group photo.

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AIR SAFETY INVESTIGATORS
INCORPORATED AUGUST 31, 1964

IT'S BEEN AN HONOR

This is my last message as your president, a position I've held since 1998. I helped to steer the Society's helm for 24 years with assistance from many other elected officers, our office manager, and dedicated volunteers. It truly has been a team effort. As president, I wrote more than 90 "President's View" for *ISASI Forum*. And I had a lot of help from Marty Martinez and Gary DiNunno, who both have been editor of *Forum*. Now is the time to give someone else an opportunity to be your president.

ISASI has seen many positive changes since 1998. We purchased an office in 2000 to use as our international headquarters. We paid $101,000 for the facility and it's now valued at more than $200,000. Thanks to the hard work of Tom McCarthy, ISASI obtained U.S. and Virginia tax-exempt status in 2000, which has resulted in tremendous savings. The mortgage was paid off in 2008, and the purchase saves ISASI over $20,000 a year.

During the past two decades, we've added five new societies:

- Latin America in 2000,
- Asia in 2009,
- Pakistan in 2012,
- Korea in 2013, and
- Middle East North Africa in 2013.

There've been many new working groups formed:

- Airports,
- Corporate Affairs,
- Critical Incident Stress Management,
- Flight Recorder,
- General Aviation,
- Government Air Safety Facilitator,
- Human Factors,
- International Civil Aviation Organization (ICAO) (ISASI is an official observer),
- Investigators Training & Education,
- Military Aviation Safety and Accident Investigation,
- Position of ISASI,
- Promotion of ISASI, and
- Unmanned Aerial Systems.

There've been several new committees formed, including:

- Scholarship—which was formed after the death of National Transportation Safety Board senior accident investigator Rudy Kapustin in 2002. Thus far, 58 students have been the recipient of the Rudolph Kapustin Scholarship Award, and 10 have gained employment in the aviation industry because of receiving the award. This program is totally funded by donations in memory of all ISASI members who've died.
- Reachout—The first Reachout seminar was held in 2001. To date, we've held 54 Reachout seminars that have trained approximately 2,500 individuals. The seminars have been conducted in 27 countries.
- Strategic Planning—which was recently formed to develop a strategic plan to ensure that ISASI continues to promote the development and improvement of aviation incidents and accidents investigations.
- Mentoring—formed to link college students interested in aviation safety to ISASI members who can offer experience and expertise that will assist the students during their studies and perhaps even finding careers.

Over the years, we steadily built and updated online capabilities. In 2013, we began publishing an electronic newsletter, *ISASI Update*, that's sent to members via e-mail. That same year, we created a website with both public and member-only pages. We recently began offering the ability to join ISASI or pay your dues online. The *Forum* is better than ever, and now more than 40 percent of *Forum* recipients receive the magazine electronically. Also in 2013, we became an official observer at ICAO and continue to participate on committees and working groups to recommend international air safety improvements.

Our annual seminars have grown and are well attended. They're technically and financially a success for all the right reasons. I attribute a major part of their success to the hard work of Barbara Dunn, the Seminar Committee chair. We now give a "Best Paper" award at each seminar, which includes a plaque and a monetary stipend—thanks to an anonymous donor.

All these changes and improvements are a result of the dedicated efforts of the executive staff, Society officers, and other counselors both present and former. Their hard work, enthusiasm, and can-do attitude have directly attributed to ISASI's growth and success.

We now have about 1,400 members representing 88 countries. There are 106 corporate members, whose membership and support of ISASI indicate the value they place on belonging to the Society. The contributions that ISASI has made to aviation safety are numerous and monumental. However, we can't attach a number to this statement. We can rest assured that the roles of ISASI and our members have been highly influential in preventing accidents around the world.

What does ISASI do for you? You gain some peripheral benefit by simply joining and paying your dues. As with many things in life, the more you participate, the more you benefit. You may attend a seminar—internationally, nationally, or locally. You may present a technical paper at a seminar, participate in a working group or committee, sponsor a seminar or training session, run for office, mentor an air safety student, speak to high school or college classes, or support ISASI in numerous other ways. Your active participation enhances aviation safety and expands and increases your aviation knowledge, thereby making you a more productive employee and member of the aviation community.

I've been honored and blessed to be your president and thank you for all your support over the years. I wish each of you success and safety in all your endeavors. ◆

Frank Del Gandio
ISASI President

Lessons Learned

The Sikorsky S-76B Accident in Calabasas, Calif.

By Dujuan Sevillian, Ph.D., U.S. National Transportation Safety Board

Dujuan Sevillian

(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, from Aug. 31 to Sept. 2, 2021. The theme for the seminar was "Staying Safe, Moving Forward." The full technical paper, Moving Forward: Lessons Learned from the Sikorsky S-76B Accident in Calabasas, CA*, is available on the Society's website, www.isasi.org, in the library section under the Publications & Governance/Technical Papers tabs. The author's views in this presentation do not necessarily represent the official position of the National Transportation Safety Board.—Editor)*

On Jan. 26, 2020, about 9:46 Pacific standard time, a Sikorsky S-76B helicopter, N72EX, entered a rapidly descending left turn and crashed into terrain in Calabasas, Calif. The pilot and eight passengers died, and the helicopter was destroyed. The investigation found that the pilot continued visual flight rules (VFR) flight into instrument meteorological conditions (IMC), which resulted in spatial disorientation and loss of control of the helicopter.

This paper provides human factors lessons learned from this accident, which include the following:

1. The importance of a safety management system (SMS) and safety assurance at operators.
2. The benefit of flight data monitoring (FDM) to identify and mitigate human factors issues and methods that could be incorporated into a company's SMS to mitigate risks and hazards.
3. Mitigation strategies for self-induced pressure and plan continuation bias.

Managing Organizational Safety

Many operators have either developed an SMS within their organization or are familiar with the concept of SMS, which is an active approach to managing safety by monitoring safety performance, including reducing risks and hazards to an acceptable level. Full implementation and oversight of safety policy, safety risk management, safety assurance, and safety promotion are essential to an effective SMS. While SMS is mandated by the U.S. Federal Aviation Administration (FAA) in 14 code of federal regulations (CFR) Part 121 airline operations, it is not required for 14 CFR Part 135 operators.

The U.S. National Transportation Safety Board (NTSB) has long recommended SMS for Part 135 operators, but this recommendation is still on the NTSB's Most Wanted list. The FAA has developed an SMS voluntary program (SMSVP), which allows Part 135 operators to develop and implement their SMS in conjunction with FAA oversight, but there is low participation by Part 135 operators in the FAA's voluntary program.

A review of FAA data showed that of about 1,900 certificate holders authorized to conduct Part 135 operations, only 17 have an FAA-accepted SMS. And 158 others, whose SMSs are in various stages of development, have applied for FAA acceptance (NTSB 2021). By implementing an SMS, a company is in a stronger position to reduce risks and hazards and aid in fostering an open and just safety culture.

Regarding the S-76B accident, the NTSB found that the operator had a non-FAA-accepted voluntary SMS (through an SMS vendor), but the company did not fully implement it with respect to safety assurance. Safety assurance includes a systematic review of processes and procedures, continuous monitoring and measurement of risks and hazards, and feedback to personnel on system health. It is an essential component in SMS that truly allows it to be a system. Outputs of safety risk management are assessed with safety assurance, and outputs of safety assurance provide feedback to safety risk management.

Safety assurance addresses how effective mitigations are and if they need to be modified, or if new ones need to be implemented. In this case, the operator did not conduct evaluations to ensure that its pilots were consistently completing the flight risk-analysis form, which hindered the effectiveness of the form as a risk-management tool.

For example, in 2019 several pilots forgot to fill out flight risk-assessment forms. When pilots do not fill out forms prior to flying, the company does not

Discuss safety assurance scalability with company management

Assist company management develop their SMS requirements for safety assurance

Management determines who will oversee safety assurance and who will have responsibility to ensure procedures and processes are followed

Management determines company resources to support safety assurance

Management sets expectations for personnel involvement in safety assurance

Management determines how continuous monitoring of processes and procedures will be handled

Assist company on best practices for safety assurance

Provide feedback to company on what is working and not working in terms of managing safety assurance

Figure 1. Safety assurance high-level process.

have an adequate understanding of risks associated with the flight, which can lead to the pilot and company not understanding possible hazards. And by not evaluating the forms, the company does not have an adequate understanding of how often forms are not being filled out and why they are not consistently filled out by pilots.

The NTSB also found that the operator did not measure the effectiveness of its safety risk controls and did not conduct internal audits. As the safety committee was responsible for trend analysis, it did not conduct any analysis on hazard trends. By not conducting these types of analyses, the company does not have an adequate understanding of the system health. Overall, the operator did not have a good understanding of how well its SMS was performing with respect to safety assurance and safety risk management.

So how can operators effectively implement and manage the safety-assurance component of SMS? Can an operator be too small to manage safety assurance? These are important questions to ask when managing this aspect of an SMS. The current FAA SMS strategy provides operators with tools that are needed to implement and manage safety assurance within their organization. It also helps an operator understand how to develop safety assurance with respect to scalability. The FAA process also notes its involvement with operators to ensure they follow requirements for effectively implementing and managing safety assurance.

Figure 1 illustrates a high-level process that the FAA and operator could use when having initial discussions on integrating the safety-assurance component within an operator's SMS.

The process starts with the FAA and operator's discussion on safety-assurance scope, which will help the operator brainstorm ideas regarding how to implement safety assurance within its organization. This also includes a review of the FAA's requirements for safety assurance and the operator's understanding of those requirements. Safety assurance requires an operator's understanding and implementation of safety risk management. With respect to safety risk management, the operator must identify hazards within its operational environment (e.g., workload/distraction) and undertake an analysis of potential consequences of the operation regarding identified hazards (e.g., risk analysis). When the operator meets the requirements for safety risk management, safety assurance provides the operator with strategies for monitoring and measuring performance, which helps the operator understand how well its system is performing, including areas that may need further review and analysis.

Next, the company must address role clarity. In other words, who has responsibility, accountability, and authority for safety assurance? Role clarity helps an organization understand who will handle specific areas of safety assurance (e.g., internal evaluation program, company risk profile). Who will take on the responsibility of measuring and monitoring safety performance? This is key to the effective management of safety.

The company should also identify which company resources would be compatible for managing safety assurance (e.g., developing metrics with respect to trend analysis) as a long-term effort and setting expectations for personnel involvement with safety-assurance processes and procedures. How are the mitigations that were put into place for safety risk management working, and do they need to be modified or do new ones need to be developed? What type of system will provide metrics on how well the operator is performing with respect to those mitigations? Does everyone have access to those metrics, and do personnel understand the output of the metrics and how it relates to the overall goal of safety assurance?

Company personnel at each level of the organization should have a stake in the company's safety performance metrics so that they can have input into safety best practices and areas of improvement. Finally, the FAA's oversight can facilitate the operator in maintaining compliance with requirements for safety assurance and can address questions the operator may have on safety assurance. Overall, having safety assurance adequately integrated and managed within the framework of SMS will provide the operator with an understanding of the overall system health and allow the operator to discuss areas that are working well and areas that need improvement.

Data Monitoring

FDM was highlighted as an NTSB recommendation in the S-76B accident, as the agency had previously recommended that the FAA mandate FDM for Part 135 helicopter operators. The NTSB also recommended FDM because the operator did not have a device on board the helicopter to record flight operational data and did not have an FDM, which can aid the operator in evaluating how the helicopter was flown by the pilot.

As previously noted, FDM can be utilized to understand pilot performance issues, including observation of recorded data that allows company personnel to address pilot adherence to regulations, company policies, and procedures and to develop corrective action based on observed data.

In this case, had the operator developed and implemented an FDM program, it may have assisted company management with addressing deviations from established company norms and procedures and potential safety issues. And by having an FDM, the company has the potential to reduce risks and hazards that could lead to an accident.

A flight data recorder could have recorded data related to the accident helicopter's altitude and airspeed at various times while the pilot was flying enroute. For example, while the pilot was flying enroute, he noted that he was "going above the layers" and increased the helicopter's airspeed and altitude. An FDM program could have aided the company in determining why the pilot increased his airspeed and altitude and to determine if his actions were appropriate. In the case of the accident, the NTSB found that "the pilot's poor decision to fly at an excessive airspeed for the weather conditions was inconsistent with his adverse-weather–avoidance training and reduced the time available for him to choose an alternative course of action to avoid entering IMC. The company could use this data, in conjunction with other data (e.g., weather minimums enroute), to determine if the pilot complied with FAA and/or company standards.

An FDM program can be implemented into a company's SMS and can provide information for the safety risk-management component to identify and mitigate flight-related risks and hazards. Whether the risks are low, medium, or high, it is essential to monitor pilot performance and to form a safety net against potential hazards that could have a negative impact on the operator. Information gained from an FDM program can also serve as a method to improve pilot performance by identifying case studies for company pilots to review so they can learn from previous issues and reduce the potential of similar occurrences.

Self-Induced Pressure and Plan Continuation Bias

The NTSB's probable causes of the S-76B accident noted that the pilot's self-induced pressure and plan continuation bias were likely contributors that negatively impacted his decision-making while enroute to Camarillo, Calif. Self-induced pressure is a psychological phenomenon that can occur when a pilot's relationship (e.g., friendship) with a person or personal affiliation with an event influences a pilot's decision-making process. Self-induced pressure was first cited in a New Mexico State Police 2009 NTSB accident report, which noted that the accident pilot would take personal risks to save others (NTSB, 2009). The FAA (2016) published research on effective pilot decision-making and eliminating the negative impact that self-induced pressure has on pilot performance by employing effective single-pilot resource management. By doing this, the pilot has a better awareness of the risks and hazards and can make a more-informed decision.

Plan continuation bias is an unconscious bias in which a pilot will continue with the current plan despite changing conditions. Plan continuation bias is not a new phenomenon. Historically, plan continuation bias has been cited as a contributory factor in many aircraft accidents. Research conducted by NASA noted that 38 out of 51 (approximately 75%) accidents regarding pilot decision errors were related to plan continuation bias.

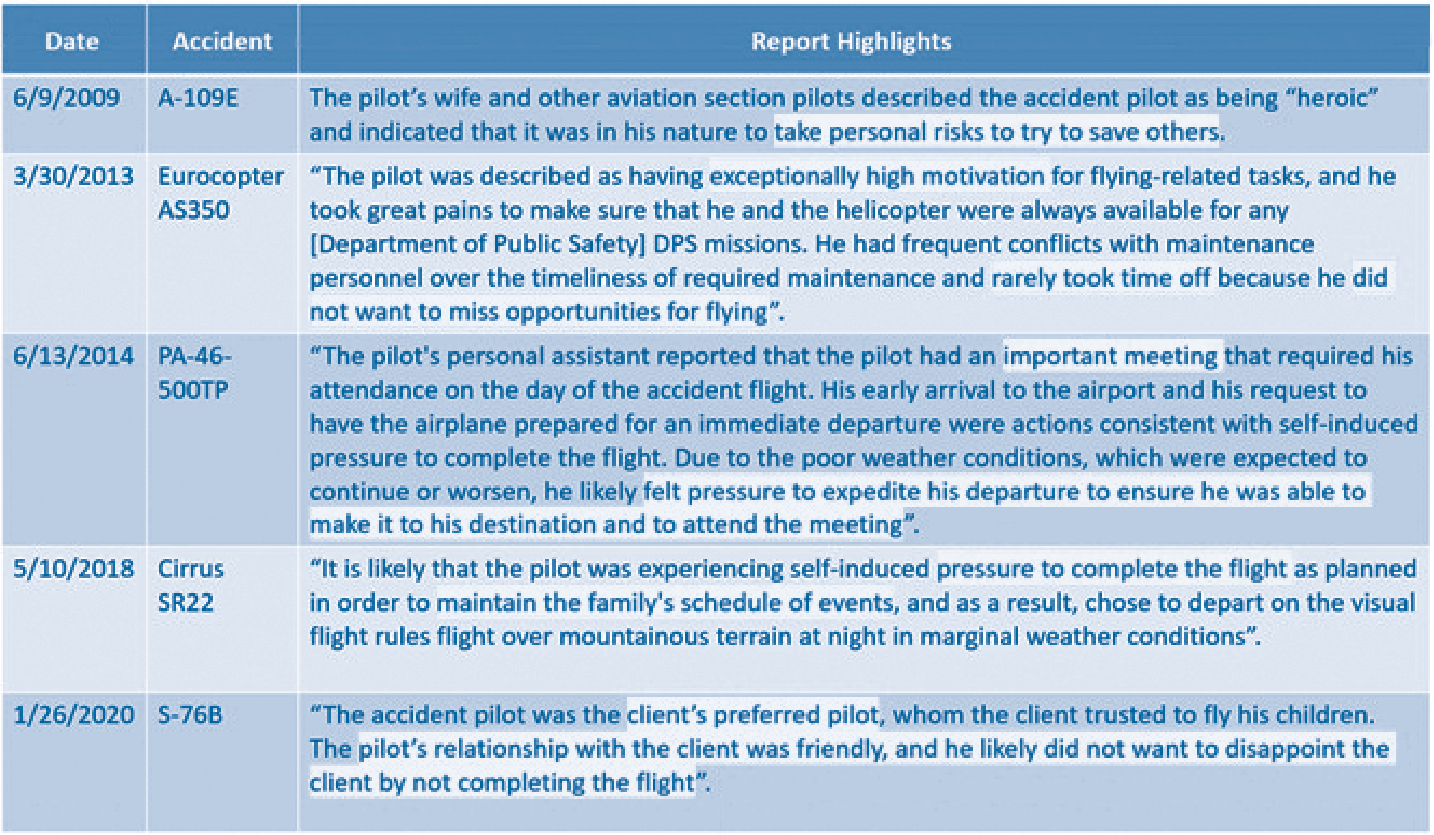
Research suggests there are two factors that influence plan continuation bias:

- early and sustained cues that suggest the plan is safe are compelling and unambiguous,
- later cues that suggest the situation is changing are much weaker, difficult to process, ambiguous, or contradictory.

The research also suggests that based on information available to the pilot at the time, they may think it is a great plan, but subsequent cues indicate otherwise, which may not be viewed in an equal light in terms of decision-making.

The Transportation Safety Board (TSB) of Canada noted that in a single-pilot scenario, "as workload increases, less mental capacity is available to process changes related to cues, and to consider the potential impact that they may have on the original plan."

So what are the effects of these two psychological phenomena on pilot performance? Within the context of self-induced pressure, a pilot may take shortcuts, skip company procedures, or not follow FAA regulations so that they ensure their friend is present at an event. These factors have the potential to negatively impact a pilot's decision to continue a flight despite changing conditions (e.g., changes in weather, flying from visual meteorological conditions into IMC). The consequence of a pilot's decision to continue can lead to imminent danger enroute, which has the potential to reduce the margin of error and the pilot's ability to correct the situation, potentially leading to an accident. Pilot



Date	Accident	Report Highlights
6/9/2009	A-109E	The pilot's wife and other aviation section pilots described the accident pilot as being "heroic" and indicated that it was in his nature to take personal risks to try to save others.
3/30/2013	Eurocopter AS350	"The pilot was described as having exceptionally high motivation for flying-related tasks, and he took great pains to make sure that he and the helicopter were always available for any [Department of Public Safety] DPS missions. He had frequent conflicts with maintenance personnel over the timeliness of required maintenance and rarely took time off because he did not want to miss opportunities for flying".
6/13/2014	PA-46-500TP	"The pilot's personal assistant reported that the pilot had an important meeting that required his attendance on the day of the accident flight. His early arrival to the airport and his request to have the airplane prepared for an immediate departure were actions consistent with self-induced pressure to complete the flight. Due to the poor weather conditions, which were expected to continue or worsen, he likely felt pressure to expedite his departure to ensure he was able to make it to his destination and to attend the meeting".
5/10/2018	Cirrus SR22	"It is likely that the pilot was experiencing self-induced pressure to complete the flight as planned in order to maintain the family's schedule of events, and as a result, chose to depart on the visual flight rules flight over mountainous terrain at night in marginal weather conditions".
1/26/2020	S-76B	"The accident pilot was the client's preferred pilot, whom the client trusted to fly his children. The pilot's relationship with the client was friendly, and he likely did not want to disappoint the client by not completing the flight".

Table 1. Accident Highlights

training in aeronautical decision-making can help a pilot understand risks associated with plan continuation bias and how to avoid it.

Research on prospect theory suggests that if pilots normally frame their decision of whether to continue a flight into deteriorating weather in terms of potential losses (e.g., time wasted) they will be more likely to be risk seeking in their choices.

On the other hand, pilots who focus on anticipated gains (get the passenger home safely) will behave in a risk-averse manner. Operators play an important role in helping frame company expectations on risk and pilot behaviors and discussing what is and is not acceptable according to company policy.

There have been several accidents related to a pilot experiencing self-induced pressure and plan continuation bias, and Table 1 only represents a subset of those accidents. This table highlights accidents in which pilots had a personal engagement with an event or personal relationship, and they experienced self-induced pressure and/or plan continuation bias.

What are some mitigations that a pilot and operator might use to reduce risks and hazards related to self-induced pressure and plan continuation bias? The pilot should fill out a company flight risk-assessment form by assessing risks related to self-induced pressure and plan continuation bias and discuss mitigations with company management. Based on the pilot's relationship with their friend or affiliation with a personal event, the pilot should ask the following questions so that they can understand the full scope of risks associated with self-induced pressure and plan continuation bias:

- How should I let my friend know that it may not be the best time to fly and to reschedule?
- Are my decisions going to have a negative impact on my relationship with my friend?
- Does my friend understand the importance of flight safety and getting them to their destination safely?
- Should I reschedule my flight to the personal event or find another mode of transportation?
- What questions should I ask company management personnel so that they may help me make the most informed decision?
- How can I voice concerns regarding self-induced pressure and plan continuation bias with the company safety committee?
- How can a company develop training scenarios with pilots and help them understand risks and hazards associated with self-induced pressure and plan continuation bias?
- Since it is the pilot's decision to take off or continue a flight, making the most informed decisions can reduce or eliminate risks and hazards related to self-induced pressure and plan continuation bias.

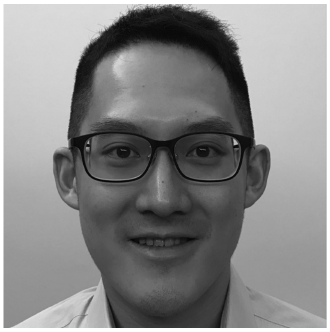
Conclusion

Overall, this paper has provided methods, examples, and best practices for managing risks and hazards and ensuring that operators constantly monitor pilot performance through FDM and SMS. Self-induced pressure and plan continuation bias are factors that can negatively impact pilot performance. Therefore, the company must be aware of potential unnecessary risks that pilots may take to achieve a mission and to assist pilots to exercise good aeronautical decision-making. ◆

CULTURAL EFFECTS ON STANDARDIZATION AND INTERNATIONAL COOPERATION

By Wesley Chan, B-777 Pilot, Crew Resource Management Trainer, Hong Kong ALPA, Aviation Lecturer, University of South Australia (Hong Kong External Campus), and Dr. Wen-Chin Li, Senior Lecturer, Safety and Aviation Investigation Center, Cranfield University, UK, Chartered Ergonomist and Human Factors Specialist of the Institute of Ergonomics and Human Factors, and Aviation Human Factors Specialist of the European Association of Aviation Psychology

(This article was adapted with permission from the authors' technical paper presented during ISASI 2021, a virtual seminar hosted from Vancouver, B.C., Canada from Aug. 31 to Sept. 2, 2021. The theme for the seminar was "Staying Safe, Moving Forward." The full technical paper, Training for Future Investigators: Understanding Cultural Effects on Standardization and International Cooperation, *is available on the Society's website, www.isasi.org, in the Library section under the Publications & Governance/Technical Papers tabs.—Editor)*



Wesley Chan

Wen-Chin Li

Introduction

On Oct. 31, 1999, a B-767 operating as EgyptAir Flight 990 departed from normal cruise flight and crashed nose down into the Atlantic Ocean approximately 60 miles off the coast of Nantucket, Massachusetts, killing all 217 people on board. As the accident occurred in international waters, both the U.S. National Transportation Safety Board (NTSB) and the Egyptian civil aviation authority (CAA) were involved in the investigation. The NTSB determined that the probable cause of the accident was the result of the relief first officer's deliberate and suicidal control inputs. However, the Egyptian CAA contested these findings, attributing mechanical failure as the most plausible cause.

Exactly one year later, on Oct. 31, 2000, a B-747 operating as Singapore Airlines Flight 006 (SQ006) from Chiang Kai Shek International Airport to Los Angeles International Airport crashed into construction equipment after the pilots mistakenly attempted to take off on a runway that was closed for repairs. The collision resulted in the separation of the aircraft into three pieces, killing 83 of the 179 occupants on board. Investigators from the Taiwan Aviation Safety Council concluded that the misalignment with a closed runway was predominantly due to pilot error, whereas Singaporean investigators believed the root cause was inadequate airport signage and lighting (see Figure 1).

A goal of accident investigation is to objectively identify the root causes and causal factors of incidents, and the attribution of a given condition should not be dependent on who is making the attribution.

However, in both the EgyptAir and Singapore Airlines examples, investigators from different professional, organizational, and national cultural backgrounds can come up with completely different conclusions, even when investigating the exact same incident. In the Singapore Airlines Flight 006 investigation, Taiwanese investigators focused on pilot error as they believed that it was the pilots' fault for failing to check notices and charts that were readily accessible to them, whereas their Singaporean counterparts insisted that had better airport lighting and markings been available, these defenses would have stopped the airplane (see Figure 2).

Cross-Cultural Issues in Accident Investigation

Accident investigations commonly involve diverse, cross-cultural working groups with representatives from the multitude of states of occurrence, registration, manufacturer, and operator, among others. Cross-cultural evaluative work, such as accident investigation, are commonly challenged in reliability and validity. The EgyptAir and Singapore Airlines investigations are a fitting demonstration of unreliability in the accident investigation process as the exact same incident was somehow interpreted to have different causes. Regarding validity—can the investigation successfully determine the causal circumstances in the lead-up to an incident or accident?

The evaluation of human factors is known to be affected by the relevance paradox as human investigators have a natural inclination to seek out factors that are readily explainable in their own cultural contexts. Investigators may also confuse their own context of reality with the context of the people involved in the occurrence, possibly leading to inappro-

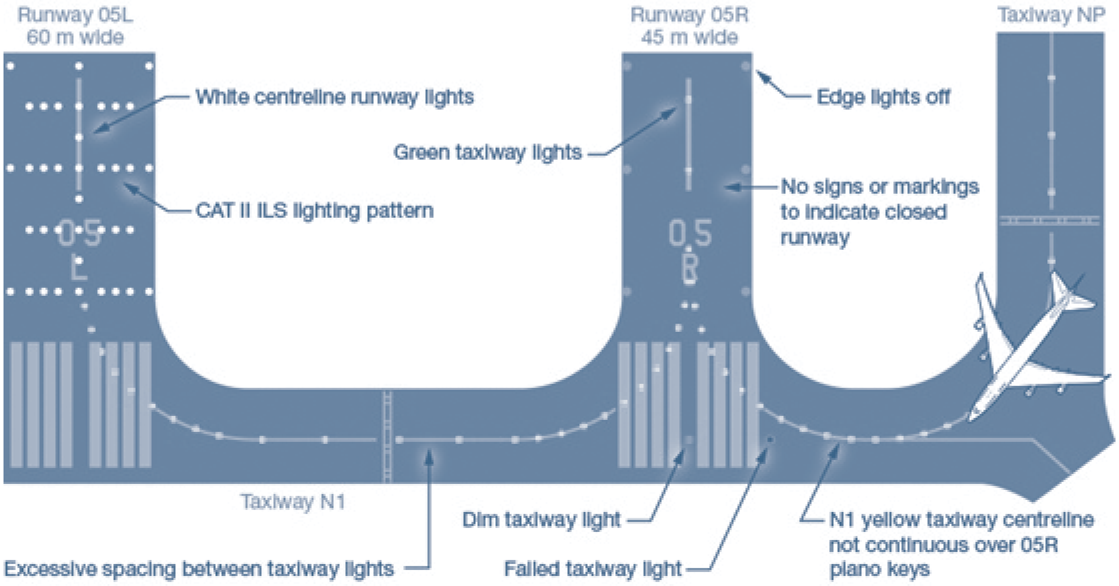


Figure 1. Runway and taxiway layout of Chiang Kai Shek International Airport (Franzi, 2014). Approaching from Taxiway N1, SQ006 mistakenly lined up on the closed Runway 05R (Taiwan Aviation Safety Council, 2002).


SQ 006 • FINAL REPORT

One crash, two conclusions

The Taiwan and Singapore reports differ on what could have prevented SQ 006 from turning onto the wrong runway. **LESLIE KOH** *looks at the opposing views*

TAIWAN

SINGAPORE

PILOTS SHOULD HAVE CHECKED

DEFENCES WOULD HAVE STOPPED PLANE

Figure 2. Contradictory findings between Taiwanese and Singaporean investigators for the SQ006 investigation. Taiwanese investigators insisted that the "Pilots Should Have Checked," whereas the Singaporean investigators believed that "Defences Would Have Stopped Plane" (The Straits Times, 2002).

priate and assumption-driven attributions of blame. These cultural biases were confirmed in Li et al.'s publication in *ISASI Forum* in 2007, which found that investigators' cultural stigma attached to adverse physical states resulted in more-frequent interpretation of human factors issues into culturally less blameworthy perceptual contexts.

According to the Ripple Model of safety culture, cultural elements outside of an organization have profound effects on the overall safety culture within the group (see Figure 3, page 10). To illustrate, government concerns for fostering a positive image of its own country's aviation safety, societal influences on how people act in relation to social roles and cognitive processes, and actions of the regulator in training and oversight can all work together to change how safety is perceived. In the investigation of EgyptAir Flight 990, differences in societal influences (expectations and interpretations of how people act) between the U.S. and Egyptian investigators may have possibly caused the varied interpretation of the pilot's prayer to God that was captured on the cockpit voice recorder.

These influences and their consequences on human performance assessment are still a hot topic at recent ISASI seminars and in technical papers. Examples include Barafani and Zambonini's paper in 2019, which suggested that investigators' personal experience and attributes can negatively affect the integrity and impartiality of investigation. This was supported by another technical paper published in the same year by Bramble and colleagues, who added that investigators' own biases can make the integration of human performance factors chaotic. Other ISASI publications show that even within identical national cultural environments, variations in the attribution of failure causes can arise from organizational and regulatory disparities, as well as from differences in investigator training and education. However, in these cases the influential "layers" of the investigators' own contextual understanding and cultural attributes were not identified.

Culture's Consequences

As cultural attitudes and values provide guidelines for communication, acceptable behaviors, and cognitive contexts to make sense of the world, their differences play a large part in the interpretation and analysis of human factors associated with aircraft incidents and accidents. Cultural dimensions of Dutch researcher Geert Hofstede's framework are often used to assess cultural differences in the aerospace and other high-reliability domains. Of particular interest are the power distance and individualism dimensions:

- Power distance (PD) assesses the accepted degree of equality or

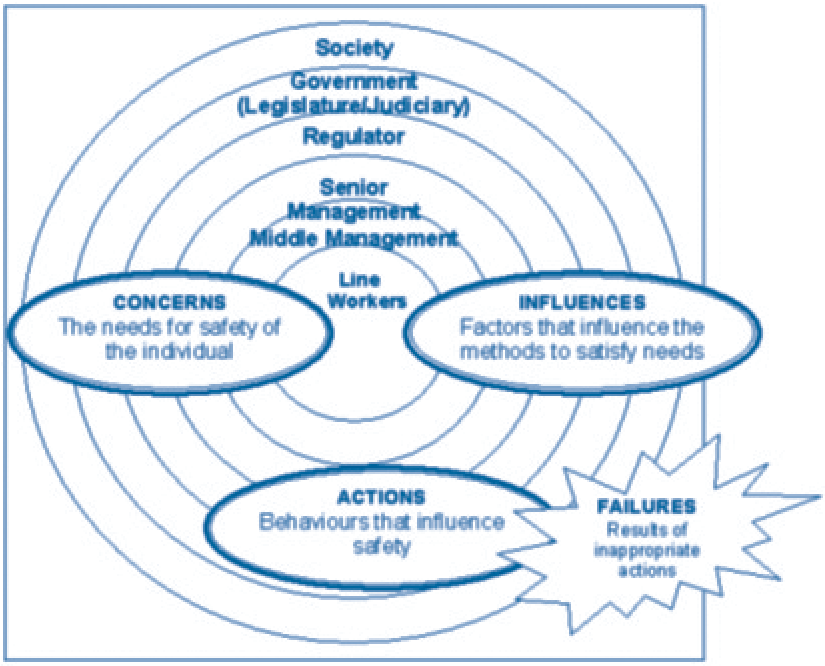


Figure 3. Layers of influence in the open (Ripple) model of safety culture (Morley & Harris, 2006).

inequality between superiors and subordinates in a hierarchical society. A low power distance results in informal relationships with open discussions and ability-based decisions, whereas a high power distance reflects a top-down, command-driven flow of decisions and information.

- Individualism (IDV) describes the balance between individual or societal achievement and responses to incentives. In highly individualistic cultures, people are driven by personal incentives, tasks prevail over interpersonal relationships, and there is a lesser desire to conform to group norms and social inhibitions.

Research found PD and IDV to significantly correlate with human error in military aviation accidents, and PD and IDV are considered to have the greatest explanatory power in the attribution of suboptimal processes in the run-up to aviation accidents. PD and IDV differences in multicultural teams can affect the interpretation and sharing of contextual information, the raising of safety issues, and the collection of data on human performance deviations.

The PD and IDV dimensions, therefore, span the various layers of influence in the Ripple Model. Closer to the center layers, previous studies have reported that higher PD investigators were less likely to attribute errors to frontline decisions, and inadequacies in supervisory and managerial practices were more frequently found in accidents involving people of high PD and low IDV cultures. It is plausible that these findings are due to influences from the outer, societal layers of the Ripple Model, as accident investigators of high PD and low IDV national cultures (typically Eastern backgrounds) are also known to view events more holistically and in relation to the wider context.

Research on the performance of culturally mixed teams in aviation shows that cultural differences do not disappear simply by making people from different backgrounds work in mixed teams for a period of time. A training program for cultural awareness is, therefore, required so that investigators can better understand cultural issues in the incident under review, as well as facilitate improved teamwork within investigative teams. However, as people can simultaneously belong to many cultures with differing and possibly conflicting core values, if the dimensions of power distance and individualism are used in an unabridged manner for this purpose then our understanding of cultural values and attitudes will be restricted to two data points—hiding the granularity required to understand the finer underlying factors driving these cultural differences. In its unabridged format, only the layers in the Ripple Model will be considered. The concerns, influences, and actions will be overlooked.

In this study, a more-detailed approach is taken. The constituent elements for the PD and IDV dimensions are independently examined alongside accident investigators' attribution of human factors failures. The cultural elements are then dynamically interpreted using the Instructional Systems Development (ISD) Model, which contains five phases.

First is the analyze phase, in which inadequacies in task performance that are not caused by gaps in skills or knowledge are identified. Cultural biases are a good example of these inadequacies, as they detract from investigation objectiveness yet are not the result of skill or knowledge gaps on the part of individual investigators.

Second is the design phase, where entry behaviors are determined and compared with overall system goals. As a main goal of accident investigations is to come up with objective recommendations for safety improvements, in the design phase the aim is to develop methods to remedy cultural biases in the accident investigation process through personnel training and standardization.

The develop, implement, and evaluation phases follow, with the gaps between the objectives and the investigators' cultural profiles narrowed through the development of instructional material and conducting instructional activities and then finally reviewed and revised through evaluation.

Method

Participants

Data was collected from N=147 accident investigators, including trainee and active airline pilots and airline safety managers.

Material

The Values Survey Module Questionnaire, which assesses participants' cultural values and sentiments on six cultural dimensions was used in this study. Of particular interest are the eight items on power distance and individualism, which are presented in Table 1.

For the accident investigation exercise, stimulus data was derived from the narrative description of the mid-air collision between a B-757 and a Tupolev Tu-154 over Uberlingen, Germany, on July 1, 2002. The Human Factors Analysis and Classification System (HFACS) framework was utilized to classify the contributing factors of the accident. The HFACS framework has a proven track record for interpreting human-associated causes of accident investigations.

(Hofstede & Minkov, 2013)

1. How important is it for you to be consulted by your boss in decisions involving your work?
2. How important is it for you to have a boss (direct superior) you can respect?
3. How often, in your experience, are subordinates afraid to contradict their boss (or students their teacher)?
4. To what extent do you agree that an organizational structure in which certain subordinates have two bosses should be avoided at all costs?
5. How important is it for you to have security of employment?
6. In an ideal job, how important is it for you to have sufficient time for your personal or home life?
7. How important is it for you to have a job respected by your family and friends?
8. How important is it for you to do work that is interesting?

Table 1. Survey Items Assessing Participants' Cultural Dimensions

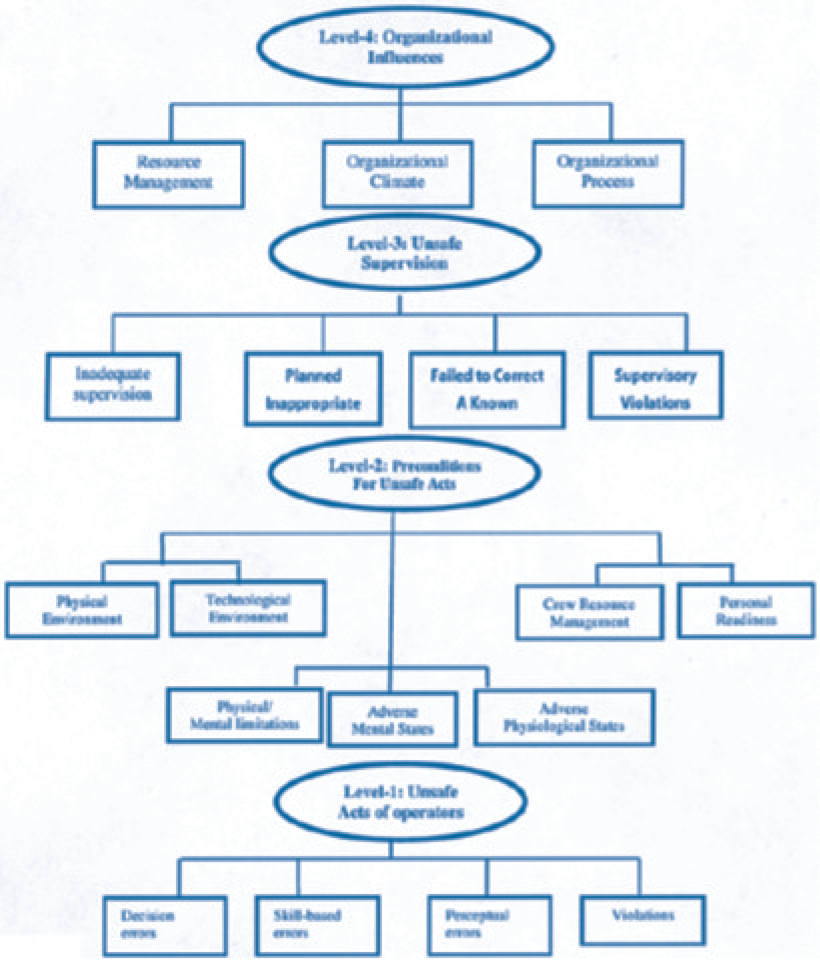


Figure 4. The HFACS framework.

It is based on the concept of active and latent failures. Active failures are those affecting the performance of frontline operators, and latent failures are associated with inadequacies originating from higher system levels that may be dormant for a long time until triggered by other factors. HFACS describes failures across four levels in the system, with each level being affected by latent failures in the levels above (see Figure 4). At the bottom, representing active failures of frontline operators, is the unsafe acts level. Proceeding upward are the levels of preconditions for unsafe acts, unsafe supervision, and organizational influences, which are representative of latent failures in the wider system. Each level contains categories identifying active and latent failures that occurred in the lead-up to the event.

Procedure

The investigation process was conducted entirely online. The web-based system began with demographic questions that included the power distance and individualism items. These were followed by a tutorial on the use of the HFACS categories and a synopsis of the Uberlingen mid-air collision. In the final stage, a checkbox-based coding form was presented to the participants for coding contributing factors underlying the Uberlingen accident into HFACS categories.

Results and Discussion

Differences in the Attribution of Human Factors Precursors

The relationship between the coding outcomes for each HFACS category (presence or absence) was statistically compared with the participants' responses for the power distance and individualism items by logistic regression. The results indicate that only four of the eight cultural items related to power distance and individualism had any significant influence on accident investigators' attribution of causal factors, and only the first three levels of HFACS were affected. Table 2 (a–d), pages 12–13, presents the odds ratios of logistic regression of cultural assessment items with the indication of an HFACS category as a factor. For each point increase in the cultural items, by how much did the frequency of attribution of HFACS categories change?

Three of the four items assessing power distance elements influenced the investigators' coding of the incident factors, including

- How important is it for you to be consulted by your boss in decisions involving your work?

Table 2a. Results at HFACS Level 1 (Unsafe Acts of Operators)

	Odds Ratios (*p<0.05)			
Cultural Dimensions Item	Decision Errors	Skill-Based Errors	Perceptual Errors	Violations
1. How important is it for you to be consulted by your boss in decisions involving your work?	0.999	0.530*	0.926	0.625*
2. How important is it for you to have a boss (direct superior) you can respect?	0.890	1.132	1.160	1.052
3. How often, in your experience, are subordinates afraid to contradict their boss (or students their teacher)?	0.737	0.764	1.493	0.989
4. To what extent do you agree that an organizational structure in which certain subordinates have two bosses should be avoided at all costs?	0.687	1.069	0.953	1.321
5. How important is it for you to have security of employment?	0.836	0.905	0.804	1.115
6. In an ideal job, how important is it for you to have sufficient time for your personal or home life?	1.355	0.955	1.424	1.217
7. How important is it for you to have a job respected by your family and friends?	1.286	1.166	1.103	0.928
8. How important is it for you to do work that is interesting?	0.962	1.179	1.049	1.358

Table 2b. Results at HFACS Level 2 (Preconditions for Unsafe Acts)

	Odds Ratios (*p<0.05)						
Cultural Dimensions Item	Adverse Mental States	Adverse Physical States	Mental/ Physical Limitations	Crew Resource Mgt	Personal Readiness	Physical Env't	Technical Env't
1. How important is it for you to be consulted by your boss in decisions involving your work?	1.205	1.230	0.917	0.840	0.697	1.111	1.194
2. How important is it for you to have a boss (direct superior) you can respect?	0.708	1.819	0.620	1.473	0.890	1.003	0.894
3. How often, in your experience, are subordinates afraid to contradict their boss (or students their teacher)?	1.143	0.630	0.735	1.038	1.218	1.084	1.709
4. To what extent do you agree that an organizational structure in which certain subordinates have two bosses should be avoided at all costs?	1.167	2.305*	1.101	0.845	1.012	0.765	0.663
5. How important is it for you to have security of employment?	0.855	1.885	1.502	0.905	0.540*	1.759	0.323*
6. In an ideal job, how important is it for you to have sufficient time for your personal or home life?	0.853	2.358	0.807	0.644	1.925	0.772	1.066
7. How important is it for you to have a job respected by your family and friends?	1.086	0.533	0.884	0.855	1.159	1.008	0.696
8. How important is it for you to do work that is interesting?	0.929	1.970	1.256	0.931	1.498	0.941	1.668

Table 2c. Results at HFACS Level 3 (Unsafe Supervision)

	Odds Ratios (*p<0.05)			
Cultural Dimensions Item	Inadequate Supervision	Planned Inappropriate Operations	Failed to Correct a Known Problem	Supervisory Violations
1. How important is it for you to be consulted by your boss in decisions involving your work?	1.120	1.374	1.384	1.009
2. How important is it for you to have a boss (direct superior) you can respect?	0.557*	1.324	0.994	0.942
3. How often, in your experience, are subordinates afraid to contradict their boss (or students their teacher)?	1.139	1.160	1.545	1.335
4. To what extent do you agree that an organizational structure in which certain subordinates have two bosses should be avoided at all costs?	0.991	1.381	1.526*	0.752
5. How important is it for you to have security of employment?	1.727	1.001	1.975*	1.203
6. In an ideal job, how important is it for you to have sufficient time for your personal or home life?	0.907	1.262	0.749	0.693
7. How important is it for you to have a job respected by your family and friends?	0.773	1.097	0.876	1.046
8. How important is it for you to do work that is interesting?	0.949	1.341	0.990	1.069

Table 2d. Results at HFACS Level 4 (Organizational Influences)

	Odds Ratios (*p<0.05)		
Cultural Dimensions Item	Resource Management	Organizational Climate	Organizational Process
1. How important is it for you to be consulted by your boss in decisions involving your work?	0.956	1.063	1.234
2. How important is it for you to have a boss (direct superior) you can respect?	0.764	1.066	0.787
3. How often, in your experience, are subordinates afraid to contradict their boss (or students their teacher)?	0.741	1.064	1.052
4. To what extent do you agree that an organizational structure in which certain subordinates have two bosses should be avoided at all costs?	1.024	1.433	1.192
5. How important is it for you to have security of employment?	0.747	1.068	1.171
6. In an ideal job, how important is it for you to have sufficient time for your personal or home life?	0.833	1.138	0.603
7. How important is it for you to have a job respected by your family and friends?	1.085	0.765	0.690
8. How important is it for you to do work that is interesting?	1.137	1.193	0.891

- How important is it for you to have a boss (direct superior) you can respect?
- To what extent do you agree that an organizational structure in which certain subordinates have two bosses should be avoided at all costs?

People who thought it was more important to have a boss they can respect utilized the inadequate supervision category less often; and stronger agreement with the statement that subordinates should not have more than one boss was associated with greater utilization of the supervisory level failed to correct known problem category. These were unsurprising. It is not difficult to understand why those who have a greater desire for hierarchical, autocratic leadership will hesitate to directly blame their bosses for inadequate supervision. Yet when faced with problems, their hierarchical attitudes also means that they are more likely to consider the root cause to be due to the lack of action from higher supervisory levels.

However, a more interesting finding is that those who desired a more-consultative leadership style were less likely to attribute blame to the operator level skill-based errors and violations category. As preference for a consultative leadership style is reflective of low PD distance, this finding stands in contrast with previous studies that found low PD to be associated with more attributions to frontline errors at HFACS Level 1 and greater emphasis on the autonomy of action at the frontline levels. This highlights the benefit of splitting cultural dimensions such as PD into its constituent elemental items as it showcases that not all items have comparable consequential effects.

For individualism factors, only the item on the importance of employment security had a significant effect on HFACS attribution. Accident investigators who thought job security was more important attributed fewer accident causal factors into the HFACS personal readiness and technological environment categories at HFACS Level 2 and used to a greater extent the failed to correct known problem category at HFACS Level 3. As greater desire for job security (higher score for this item) is an indicator of less individualistic (and hence more collectivistic) cultural values, the finding of a positive relationship between the expressed importance for employment security with the usage of the supervisory-level failed to correct known problem category is unsurprising. It is known that in collectivistic, high PD cultures the supervisory and organizational levels (i.e., HFACS Levels 3 and 4) are considered to have a greater influence on accidents. This was complemented by their reduced utilization of HFACS Level 2 categories of operator-level personal readiness and technological environment faults, which are reflective of existing knowledge that less individualistic cultures tend to avoid personal confrontation and dissent due to an undesirability for the loss of face.

The finding that only half of the component items assessing power distance and individualism had significant influence on the attribution of causal factors supports the use of the present methodology of analyzing cultural values at an item-by-item level rather than as whole dimensions in the traditional manner of Hofstede's model. The results have identified cultural items that did not significantly influence the investigators' categorization of human factors issues, and items that behaved in contrary to that expected when PD and IDV are considered as whole dimensions.

Identifying Cultural Components Across the Layers of Influences

In the Ripple Model, the threads of concerns, influences, and actions run through the multiple layers of influence across different system levels (see Figure 3, page 10). For example, governments respond to society's concerns by changing the actions of the regulator that then influence safety initiatives. The interrelationship among the three threads can impact subsequent safety outcomes to varying magnitudes. A high level of concern at the outer system layers, coupled with a low level of influence, may be ineffective in bringing about change in the central layers of the system. Yet low concern associated with high influence may be able to effect cultural changes on the front line.

The cultural items that achieved significant results in this investigative exercise show that concerns and actions had the greatest impact on the evaluation of human factors issues, particularly within the central layers of the Ripple Model relating to senior and middle management and frontline workers. The investigators' concerns for having a consultative, respectable boss, as well as security of employment, affected their acceptance or rejection of operator-level skill-based errors and violations (HFACS Level 1), personnel and environmental issues as preconditions of unsafe acts (HFACS Level 2), and supervisory inadequacies (HFACS Level 3). Similarly, actions, reflected by the item assessing acceptance of subordinates having two bosses, likewise had an impact on the attribution of human performance precursors. Its effects may possibly expand toward the outer levels of the Ripple Model as the government, regulator, and senior and middle management levels can be all considered "co-bosses" in setting, monitoring, and enforcing standards.

It is also interesting to highlight cultural items that did not significantly affect the investigators' categorization of human factors issues, including

- How often, in your experience, are subordinates afraid to contradict their boss (or students their teacher)?
- In an ideal job, how important is it for you to have sufficient time for your personal or home life?
- How important is it for you to have a job respected by your family and friends?
- How important is it for you to do work that is interesting?

The common thread among these items that did not significantly affect the attribution of human factors issues is that they can all be considered as influences. Influences are defined as "those factors present within a system that determine the actions available," and at the frontline level this includes the sense of ownership and empowerment felt by the workforce. Relations and respect with family and friends can also be considered as societal influences.

Thus the items concerning the nature of an ideal job span the entire Ripple Model. As these items were not found to significantly affect the attribution of human factors issues, it is plausible that influences can only affect change through a multistep process, rather than a singular "through" thread. This is compatible with principal components analysis that found the category of influences to be more closely associated with a particular level, rather than being able to cross the numerous layers of the Ripple Model. This is relevant for the development of investigator training programs that aim to standardize responses toward safety concerns.

If future safety and training management solely focus on the Ripple Model's outer layers, such as management and regulatory modifications, then the eventual outcomes may be ineffective as the resulting changes in concerns and actions may not transfer into the central operator levels due to insufficient influence.

Suggestions for Standardization and International Cooperation

Interservice Procedures for Instructional Systems Development (IPISD) provides a comprehensive, state-of-the-art framework for the development of training and assessment program, with demonstrated benefits in training effectiveness and both cost and time efficiency. The framework can be used for the development of accident investigator standardization and training programs that will be beneficial for cross-cultural teamwork during investigative activities and to ensure integrity and impartiality in future investigations.

While a completely impartial and objective "truth" is said to be impossible to achieve, enhanced cultural awareness will nonetheless enhance the performance of international investigative teams. For example, had the investigators involved in the Singapore Airlines and EgyptAir investigations been given cultural awareness training in cognitive and emotion orientations, then rather than disagreeing with each other's investigative findings and causing diplomatic disputes, they could have complemented and enriched each other's interpretations.

The IPISD framework covers five major phases. The first, analyze phase, is concerned with the identification of the job performance goals, determining the performance gaps between preexisting trainee abilities and those performance goals, and selecting aspects that should be included in the training program. These performance gaps then transition into the design phase, where learning objectives, training requirements, and instructional tasks and strategies are determined with the trainees' entry abilities and experiences taken into account. Following these are the develop, implement, and control phases in which the instruction material and activities are prepared, carried out, and evaluated for future revisions.

Findings of this study are particularly relevant for the first two IPISD phases of analyze and design. For the analysis phase, the job performance goal is to reduce cultural biases in the attribution of human factors issues. The present findings have identified that certain components of power distance and individualism can create differences in how accident investigators attribute human factors issues, including

- Preexisting trainee preferences for hierarchical, autocratic leadership leads to the overattribution of supervisory faults.
- Personal preferences for consultative leadership resulted in fewer issues being blamed on the front line.

Investigators who considered job security to be personally more important had a greater tendency to attribute errors to supervisory failures to correct known problems but underused categories of operator-level personnel and environmental factors.

These differences in the interpretation of the sequence of events in the lead-up to the same accident highlights performance gaps in the supposedly objective accident investigation process. Following the IPISD framework, appropriate learning objectives and instructional strategies must be determined in the design phase to close these performance gaps.

The results show that the participants' concerns, attitudes based on the prevailing culture, can be subject to manipulation of frontline to senior management levels, whereas actions, the behaviors that can directly impact safety (both positively or negatively), have more expansive effects and can reach the higher regulator and government levels.

In the design phase, course developers should take these findings into account to ensure that instructional resources and strategies are spent at the appropriate level. For example, if one were to design a training program to educate accident investigators in cultural differences in the perception of threats and personal abilities, as these notions fall into the thread of concerns (emotive acceptance or rejection of threats), interventions spanning the frontline to senior management levels will likely lead to more successful training outcomes as concerns are able to cross the different levels throughout the system. On the other hand, interventions focusing on operators and investigators' influences are more ideal when focused on one specific level as the results suggest that influences have limited cross-layer transferability.

Conclusion

There is a large amount of evidence to confirm that when accident investigators are asked to interpret human factors issues, the exact same events will be attributed into different categories by investigators from different cultural backgrounds. There is an obvious need for cross-cultural training so that future investigators can become aware of these differences, but the conventional use of dimensional measures to assess cultural characteristics negates the finer underlying factors behind these cultural differences.

In this study, the evaluation of investigators' individual-level cultural dimensions on an elemental, item-by-item basis highlighted cultural effects on the attribution of causal factors that should be considered when determining performance gaps in accident investigation training.

The analysis of these performance gaps using an open system model have also highlighted specific systemwide threads in which training for standardization and cultural awareness are more likely to be successful. The results present useful focus points for the instructional systems development process. While it is often said that there is no objective truth in accident investigation, better cultural awareness through carefully developed investigator training can improve the performance of cross-cultural investigative teams and help to avoid diplomatic disputes when people from different cultures disagree on investigation outcomes. ◆

DART—Distress Assistance with Real-Time Aircraft Telemetry

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(This article was adapted with permission from the authors' technical paper presented during ISASI 2021, a virtual seminar hosted from Vancouver, B.C., Canada, from Aug. 31 to Sept. 2, 2021. The theme for the seminar was "Staying Safe, Moving Forward." The full technical paper, DART—Distress Assistance with Real-Time Aircraft Telemetry, *is available on the Society's website, www.isasi.org, in the Library section under the Publications & Governance/Technical Papers tabs.—Editor)*

A significant number of aviation incidents and accidents occurred because flight crews were unaware or misinformed about the status of their aircraft. In many of these cases, the pilots would have likely been able to prevent an accident, or at least been able to significantly improve the outcome, had they been able to derive actionable information from data hidden in the flight data recorders.

The increasing availability of satellite datalink bandwidth for secure flight deck communications increasingly enables airlines to significantly improve their operational performance. Considering this development, it is justifiable to look at ways this data and information could also be used to open up new avenues of assistance that either help prevent abnormal situations from occurring in the first place or at least help crews to promptly rectify them. This approach may improve the chances of aircrews to prevent situations from deteriorating to the point where a serious incident or accident becomes unavoidable.

The Operational Benefits of Real-Time Flight Data and Available Systems

Let us start by reminding ourselves of the typically available sources of data. First, there is crash-survivable flight data recorder data, which is mandated by regulations and manufacturers. A real-time transmission system could listen to the digital flight data recorder data (DFDR) echoing what it is recording and send the information if that data is very carefully characterized by sampling rate and latency and formatted by a data-acquisition unit.

Second, the DFDR data plus other airline-specified parameters are recorded in a quick access recorder (QAR) system that typically transmits data on the ground and may record on a removeable medium. QAR data is typically used by Flight Operations Quality Assurance (FOQA) programs to improve operational safety and efficiency.

Third, a part of the QAR system will format engine reports that may be transmitted in real time over ACARS, if urgent or required by contract, and if not sent in real time, marked for transmission on the ground.

Fourth, ECAM/EICAS alert and warning messages transmitted typically by ACARS and presented to the flight crew trigger appropriate actions or precautions.

Fifth, operators are increasingly installing aircraft information devices (AIDs) that may be interfaced to the same concentrated sources as the DFDR and QAR systems and to data communication systems. The AID typically processes data to and from electronic flight bag (EFB) computers. The AID + EFB system is more easily configurable—from both regulatory and technical perspectives—than a QAR system. For example, the AID with real-time communication links may be commanded from the ground, or manual flight deck trigger, to send certain data in real time over IP links or ACARS. These IP links may be over any available medium such as Inmarsat's SwiftBroadband or Iridium's Certus® for assured cockpit communications—or communications links shared with the in-flight entertainment (IFE) system. Of course, this data is typically encrypted and/or sent over a VPN. Routinely, EFBs may send air data and engine parameters for flight path optimization, including adjustments for weather, by ground-based systems.

The goal of routinely transmitting aircraft data (e.g., engine and systems performance) to the ground in real time, and by supplying crews with information—updates to weather, traffic and more—as the flight progresses is to gain benefits that exceed the costs of data transmission. A growing number of operators are learning how to leverage this technology for long-term economic, operational, and environmental benefits. Therefore, actionable information about flights in progress is becoming increasingly available.

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With an IP connection open, the cost of sending a few parameters every minute can be very low. A system on the ground can sound alarms if one of these position/condition reports is not received on time or one or more parameters exceed their normal operating range. It can also be interfaced with a system receiving alert messages over ACARS and a database of appropriate automated responses.

Potential for Distress Assistance and Better Outcomes

Distress assistance with real-time aircraft telemetry (DART) is the concept for a program to systematically enable an aircraft operator to use real-time flight data already available for the purpose of rendering assistance in abnormal situations. The primary way in which this works is by breaking the chain of causation that leads to an undesirable outcome and change it so that it leads to a more-desirable outcome.

A common and relatively benign case may be a decision on whether to divert, and if so, where best to divert to. A notable such incident took place in 2018 over the Pacific Ocean, where a widebody airliner diverted due to a recurring error message (reference withheld and case anonymized on request of the operator). In this case, dispatch and the aircrew correctly followed procedure and were right to err on the side of caution. The total cost of the incident was estimated by the operator to amount to just more than US$150,000. A readout of the QAR and a diagnosis of the aircraft's systems, however, revealed that the error message was a false alarm. With access to certain data—and the ability to ask for selective transmission, including replay—ground personnel might have been able to verify the false alarm.

Similarly, an incident at Frankfurt International Airport caused the grounding of an airliner by more than 2 hours until a local maintenance crew was able to read out the QAR to confirm that a fault indication was, in fact, itself incorrect (anonymized on request of the flight crew and operator). The carrier had no maintenance personnel stationed at Frankfurt International Airport at the time of the incident, and no cost estimates were released in this case. Nevertheless, the reader may estimate the cost based on typical costs of a delayed departure for narrowbody airliners.

There are other fairly common events in which access to data can resolve issues and help plan maintenance work in borderline cases. These include flap extension at possibly excessive speed, degree of turbulence, vertical acceleration on landing (and was there a roll component), minor engine near exceedances, and even cabin temperature.

A rarer but more dramatic situation would be the correct identification and isolation of faults when the aircraft starts acting and/or reacting unexpectedly to flight control inputs. A notable example is the well-publicized incident of Qantas Flight 32 where fragments of a ruptured IP turbine disc on an Airbus A380 caused a significant change in the aircraft's performance and flying characteristics while severing several electrical harnesses inside the wing structure. This caused an abnormally high number of ECAM messages that the crew was only able to deal with because of the five flightcrew members on duty that day, including a check captain and a supervising check captain. The additional crewmembers could help with damage assessment while the captain and first officer focused on controlling an aircraft with operating characteristics that had significantly changed from those of any normal configuration of this aircraft type.

In the most extreme circumstances, pilots have lost control in flight of an aircraft otherwise in good working order, both mechanically and electrically. In many such cases, no adverse circumstances affected the aircraft other than the incorrect situational awareness of the pilot flying, often triggered by a minor malfunction that would normally have been rectified easily. In such circumstances, it may be an off-duty on-call (OD-OC) crew responding to an unusual attitude alert, advising the crew flying the aircraft of the additional information available to them. In the notable case of China Airlines Flight 006, the asymmetric thrust from a rolled-back No. 4 engine of the B-747 caused an aircraft attitude upset that went unnoticed and led to a rapid and uncontrolled descent during which g forces exceeding 5 g severely injured two passengers and caused significant mechanical damage to the airframe. Only after breaking through the cloud cover at around 11,000 feet was the captain able to orient himself and recover the flight.

Although the captain noticed the increasing bank and pitch angles on the attitude indicator, he wrongly concluded that the indicators had failed. In this scenario, the No. 4 engine's deterioration preceding its flameout, the lack of rudder input in response to an increasing turn and pitch rate immediately after flameout, the discrepancy between the autopilot's roll inputs and the aircraft's roll and turn rates, the subsequent exceedance of bank and pitch angles, and the large variations in g forces would have all been detectable by an automated flight data monitoring system, allowing an OD-OC crew to provide additional input to the flightcrew members that would have helped them rectify the situation at several stages before its nearly catastrophic deterioration.

While China Airlines Flight 006 eventually landed safely, Air France Flight 447 did not. In this well-publicized case, it was an unreliable airspeed reading that caused the crew of an airliner otherwise in good working order to make flight control inputs that led to the demise of the flight. While Air France Flight 447 is similar to China Airlines Flight 006 in that the lack of visual cues compounded the problem, it is notably different in so far as some telemetry was available through ACARS; however, no one picked it up until after the fact. Even then, the limited amount of data transmitted during the final minutes of the flight offered little clues as to what transpired that night.

This highlights the necessity for a fully trained crew to remain available and alert to current events and an assured and secured big data analysis system that can reliably alert the crew to potential departures from expected parameters, querying the aircraft for additional data sets and displaying them to the assistance crew in an actionable manner.

Atlas Air Flight 3591 is a recent and well-publicized example that illustrates the limits of human intervention. Due to its proximity to its destination, Atlas Air Flight 3591 was so close to the ground that the flight deteriorated so rapidly (32 seconds) that an automated action would have been necessary to overcome the underlying training and situational awareness issues.

Lastly, DART offers the possibility to identify and discourage dangerous flying habits. In the case of the 2017 Learjet accident at Teterboro Airport, the probable cause was determined to be the pilot-in-command's (PIC) "attempt to salvage an unstabilized visual approach, which resulted in an aerodynamic stall at low altitude." Contributing to the accident was "the PIC's decision to allow an unapproved [second-in-command] to act as [pilot flying], the PIC's inadequate and incomplete preflight planning, and the flight crew's lack of an approach briefing. Also contributing to the accident were [the operator's] lack of safety programs that would have enabled the company to identify and correct patterns of poor performance and procedural noncompliance." A DART program not only helps when in distress, but also flags recurring departures from standard procedures, discouraging unsafe practices and identifying training needs.

Certainly, in the cases of significant master caution alarms or warnings, it is appropriate to switch from low-volume updates to streaming the whole live FDR frames along with selected data beyond that. There are plenty of software systems that take FDR data and can reconstruct the appearance of the cockpit instruments in flight ops centers for pilots who may be on standby duty and the dispatcher.

As these examples illustrate, DART offers four avenues of breaking the chain of causation to improve the outcome of abnormal situations:

- Provision of actionable information not otherwise accessible to aircrews or dispatchers/maintenance.
- Workload reduction when a breakdown in automation or change in flight characteristics as a result of the malfunction increases the workload of the pilot flying the aircraft. With real-time data, ground staff can ask fewer but better questions by voice calls.
- Unbiased appraisal of the situation and related crew advice when the mental picture of the crew flying the aircraft begins to deviate from reality or when a routine alert is followed by a nonstandard response.
- Long-term monitoring of flight data to discourage reckless behavior and identify training needs.

Following the International Civil Aviation Organization's (ICAO) Global Aeronautic Distress and Safety System initiative in the aftermath of the disappearance of Malaysia Airlines Flight 370 and related regulation coming into effect this decade, some airlines may in the future be required to install ejectable flight data recorders. But we believe the DART concept can have operational benefits that pay for themselves and even make ejectable flight data recorders unnecessary (with DART, you will know where your airplane went down). We emphasize the larger point that DART can be an economical complement to ejectable flight data recorders because of operational benefits.

Recognizing the economic and safety potential of real-time flight data transmissions, the European Union Aviation Safety Agency (EASA) has commissioned a quick recovery of flight recorder data study.

Analysis of requirements and prerequisites

Providing assistance based on real-time telemetry is not a new concept. Both in motorsports and spaceflight operations, real-time telemetry is often the only means by which assistance can be provided. A Formula 1 car is so small that it can only carry the driver. Similarly, spaceships and space stations are often too small to carry anyone in addition to the mission-critical astronauts. Unmanned spacecraft, such as satellites and interplanetary probes, have no one on board to begin with and must be operated entirely remotely.

To understand what is necessary to use real-time aircraft telemetry to improve the chances of a successful outcome (be it minimizing the cost of the outcome or maximizing survivability), we can, therefore, turn to experience gained in space mission operations and Formula 1 racing and compare the key lessons learned to reports of selected past aviation incidents and accidents in which the provision of additional information, or the lack thereof, had a significant impact on the outcome of the situation.

Taking this into account, we can learn the following lessons:

- Distress assistance is not a root cause analysis.
- Good training and well-established operating procedures are a key success factor.
- Integration with crew resource management is a key success factor.
- Efficient and effective data processing and display are a key success factor.

Lesson 1: Distress Assistance Is Not a Root Cause Analysis

While a party assisting a flight crew in an abnormal situation may well identify the root cause of an issue, whether they conclusively do is less important than gaining the consequential knowledge required to resolve the situation satisfactorily. The classic example of this prioritization is the recovery of an upset spacecraft attitude. With the main parabolic dish no longer pointing toward Earth, communication can be established by way of omnidirectional antennas aboard the spacecraft. While the data rate through these means of communication is low, sufficient telemetry and telecommanding can be communicated to restore accurate pointing toward Earth and to avoid any attitude that may overheat the spacecraft by exposing the wrong panels to sunlight for too long. The root cause analysis can follow once the vehicle attitude is recovered.

Similarly, the pilots aboard Qantas Flight 32 had no knowledge of the burst stub oil pipe that caused the chain of events leading to the turbine disc failure, much less the manufacturing flaw causing it to fail in the first place. Nor would that knowledge have been of much consequence to them. The consequential knowledge they needed to obtain was which of the ECAM error messages had to be taken seriously, which ones to leave for later, how the aircraft could be safely flown, and the best available runway at the time of the incident. With a flow of data, flight ops and maintenance personnel on the ground could assess the data and talk with the crew or be on a party line with air traffic control even in the more likely event of just two pilots aboard the aircraft.

Lesson 2: Good Training and Well-Established Operating Procedures

This lesson should hardly come as a surprise to anyone. A DART program is no different than any other operations program or set of procedures in that it works best when its various elements are well rehearsed on a regular basis. To that end, space operations crews frequently train with spacecraft simulators (digital representations of the spacecraft in question) to practice emergency recovery procedures, fault isolation skills, and crew cooperation. Similarly, dispatchers, maintenance crews, and OD-OC flight crews can rehearse typical scenarios for quicker reaction times and to establish a particular kind of operational culture that is accustomed to working in such an environment.

Lesson 3: Integration with Crew Resource Management

What Qantas Flight 32 also demonstrated is that the five crewmembers in the cockpit that day were able to distribute the workload quickly, efficiently, and effectively among each other. DART is no different in this respect. On the contrary, the fact that the assisting party is not on board the incident aircraft, but instead located in a facility many thousands of miles away, requires even greater discipline in crew resource management.

Current satellite voice communication services offer a telephony service at best, and future services may offer sufficient bandwidth for full-duplex video conferencing probably using entertainment/passenger connectivity bandwidth. But they will, inevitably, be connected through an electronic device that will suffer from the same limitations as any other such means of communications, including microphone issues, bandwidth issues, general understandability issues, and a certain risk of misunderstandings. This is nothing new in spacecraft operations. Even in the operations of interplanetary probes, a contributing party may be in another control center, at one of Earth's receiving stations or simply in an adjacent building.

Lesson 4: Efficient and Effective Data Processing and Display

Experience with spaceflight control center development, but also battle space management for maritime and aerial defense, shows how critically important ergonomic design, efficient and effective data processing, and their ergonomic display are. Even the best-trained crewmembers can only be as good as the consequential knowledge they can efficiently and effectively learn from the actionable information displayed to them—and the reliability and integrity of the underlying data sources.

For example, the fatal accident of Alaska Airlines Flight 261 was attributed to a worn-out ACME nut that formed part of the horizontal trimming actuator and failed in flight. The nut threads failed because insufficient lubrication caused excessive thread wear. This excessive wear put additional strain on the actuation motors, which in turn would have shown an excessive current draw on the power bus on every actuation of the electrical trimming system. Without prior knowledge of the accident sequence, this may be difficult to identify among the many thousands of parameters available.

However, a big data analysis code may have been able to flag the correlation of trimming system actuation and above-average current draw to engineers, who would then have had cause to inspect the system to identify the root cause of the additional force required to operate the system. During the accident flight, the increasing friction caused the actuation motors to initially get stuck, leading to a spike in the bus current draw. This information would have, in turn, allowed an engineer to advise the flight crew not to operate the trimming system and to fly to a convenient airport for a straight-in, high-speed landing that requires minimal configuration changes impacting the aircraft's horizontal trim.

Whether engineers might have come to the correct conclusion remains, of course, speculation. But at the time, the information was not available to anyone until after the accident, and so DART would have opened up a credible opportunity to save the flight. For this opportunity to exist, however, it is important that the collected data is reliable, secure, available at an instant, and processed quickly and efficiently. OD-OC crews and maintenance engineers must then be able to identify the malfunction quickly, for which ergonomic and well-laid-out telemetry displays are of critical importance.

In terms of technical and economic requirements, we note that the required data volume is small by comparison to common IP applications but may nevertheless generate significant cost when using exclusively safety-approved radio spectrum. The data stored in a standard, 1,024-word DFDR can be always streamed inside a 9.6-kilobits-per-second datalink and could easily be streamed using safety-approved services in the L-Band spectrum, such as, for example, Inmarsat's SwiftBroadband or Iridium's Certus®. The advantages of these services are the relatively small antenna footprint; resiliency against all kinds of weather; physical separation from other, nonsafety related users; and global coverage. Their downside, however, is their comparatively high price per megabyte of data.

Ka- and Ku-Band satellite communication services, along with ground-based infrastructures such as the European Aviation Network, offer much lower data transmission costs, but they share bandwidth with entertainment users, are susceptible to moisture attenuation in the atmosphere, and rarely offer true global coverage.

With an IP connection open, the cost of sending a few parameters every minute can be very low—10 bytes every second is only 36 kilobytes per hour. A system on the ground can sound alarms if one of these position/condition reports is not received on time. It can also be interfaced with a system receiving ECAM messages over ACARS and a database of appropriate automated responses.

ECAM warnings, including some not presented to flight crews in flight, can be triggers for later artificial intelligence/machine learning exercises. Think of them as ideas or faults to be investigated later. If so configured, the contents of a buffer of recent data could be expedited to the ground if needed in an emergency. In the case of emergency, it could be very important to have some data from before the start of the event.

Approximate data transmission costs for L-Band can be estimated from publicly advertised sources such as the Satellite Phone Store. Pricing is highly dependent on the monthly volume. ROM cost is on the order $1 per megabyte. For IFE Ka-Band connections, industry sources say they strive for about $0.01 per megabyte. With careful DART configuration, admittedly to be refined by testing, the added communication cost would be low even at L-Band but worth every dollar for an abnormal flight.

A key-technology to allow widespread use of real-time aircraft telemetry is, therefore, an onboard data-processing system that can provide the most cost-efficient and assured data routing, depending on the circumstances. Currently available real-time data transmission systems come integrated into the AID, part of the EFB, integrated into the flight recorder, integrated into the satellite terminal, or come stand-alone.

To be economically viable, future systems supporting a DART program should also dynamically query the aircraft's systems for relevant data depending on its current status and dynamically route that data through assured and secured VPN channels across the best available network. In an emergency distress situation, the system may even route data through all available channels. Lastly, the system may prioritize certain types of data in accordance with current ICAO guidance for the timely recovery of flight data.

Establishment of a DART Program

How a DART program can best be setup so that it becomes economically advantageous depends on the circumstances of the operator. A commercial airline with a large fleet and its own maintenance section may wish to establish its own in-house DART program. Smaller commercial carriers with fewer resources may either rely on data analysis programs offered by major aircraft manufacturers or subcontract a third-party subscription service, of which a number have become available over the recent years.

Most of the basic elements of a DART program already exist. A large carrier based in Asia (name withheld on request of the operator) established a real-time telemetry program in 2017, including a database and data-analysis software developed in house, with some aircraft transmitting data through modified AIDs. Similarly, a large European carrier (name withheld on request of the operator) ran trials of a comparable nature, transmitting flight data through an in-house-developed EFB app that could be activated at the captain's discretion. In the case of the European carrier, it is noteworthy that an agreement with the pilots' union had to be reached before the system could go live.

While major airframe manufacturers already have real-time and nonreal-time telemetry-analysis programs in place, many smaller carriers, and operators of an older fleet or operators of a small number of corporate business jets, have opted to go with third-party aftermarket suppliers that, aside from offering the required hardware, also offer service-level agreements for flight data storage, analysis, and distress-alerting functions. To remain commercially neutral, we chose not to refer to any such products by name in this paper.

As for training, simulation, crew resource management, and flight data displays facilitating quick decision-making, the author's company, CGI UK Ltd., has created, built, and operated many highly successful and state-of-the-art solutions for space operations centers and defense-related applications of a similar nature. The author has operated interplanetary spacecraft and used simulators and training facilities, provided by CGI, for this very purpose. While the defense-related capabilities are classified, the basic principles are nevertheless the same: secure and assured data communication, processing, storage, and dissemination systems that enable operators to obtain consequential knowledge in a quick, efficient, and effective manner, thereby enabling a timely reaction to events as they unfold

DART is no different in this regard. To remain commercially neutral, we again refrain from mentioning specific product names and reference projects. We believe the demonstrable capability as evidenced by the routine application of these services across several sectors, especially space operations, provides sufficient evidence to prove the wider point that a DART program can be established relying exclusively on proven and well-tested technology. The only new aspect is the combination of these elements with the intent of not only improving the economic performance of an aircraft operator, but also opening new avenues of intervention when consequential knowledge about an aircraft's status or performance may not otherwise be accessible in time to improve the outcome of a particular set of circumstances.

Conclusion

The analysis shows that data that can benefit an operator economically can also be used to both help flight crews avoid abnormal or distress situations altogether and to assist them in the event that an abnormal or distress situation cannot be prevented. Enabling technologies and processes already exist. However, the analysis also shows that such assistance can only be rendered effectively if it is integrated with crew resource management and associated training, and if the DART program includes systematic big data analysis based on secure and assured data sources, ground support operations training, and integration with existing FOQA and safety management systems. In essence, these are many of the same steps that are required to reap the economic and operational benefits of real-time aircraft data.

While the establishment of a DART program requires expenses on top of and beyond the provision of data used to improve economic efficiency, preventing a single event can make it all worth it.

It is, therefore, not hard to imagine a future in which having a DART program, much like FOQA today, is part of the airline industry's best practices. Not having one may be seen as reckless. We are very excited about EASA's project regarding flight data recovery and look forward to the results of this study. ◆

COMPOSITE MATERIAL FIRES AND ASSOCIATED RESPONSE PROTOCOLS

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Introduction

Metals, beginning in the 1930s, have been frequently used as the material of choice for aircraft construction. Common metals used in the aviation industry range from alloyed and heat-treated aluminum to titanium, magnesium, and superalloys, the latter used in specialized applications. A shift in aircraft construction—specifically in terms of the materials used—began in the 1970s, as composite materials were introduced into commercial aircraft. Among others, the increased use of composited materials was—and still is—propelled by the ability to manufacture comparative lightweight and aerodynamically shaped components and structures that allow for reduced fuel costs while simultaneously retaining excellent strength and performance characteristics

However, safety is a crucial factor in aviation, and as such critically impacts material choices. Therefore, when selecting materials to use for aircraft construction, both design parameters, such as weight and strength, and safety elements, including failure modes and characteristics, must be considered. It is also crucial to understand how composite materials will behave in the event of a failure or when damaged, such as in an aircraft accident.

Accident Investigation Process

An aircraft accident provides compelling evidence of hazards and failures within the aviation system. A well-conducted aircraft accident investigation should identify all causal and contributing factors of a mishap as well as provide effective safety recommendations to enhance aviation safety. Thus, the aircraft accident investigation process is a pillar for the continuous development of the aviation industry. As defined by the International Civil Aviation Organization (ICAO), the primary—and only—purpose of an aircraft accident investigation is to prevent future aircraft accidents and incidents.

To this end, the investigation process follows an organized, systematic, and methodological approach, focused on the identification of the causal factors of the aircraft accident under consideration. The accident investigation process can be divided into the following three phases, each with a distinct focus: data collection, data analysis, and presentation of findings. As the name indicates, the first phase—data collection—is centered around the gathering of applicable information and evidence, an ongoing process throughout the investigation. The second phase—analysis of data—is conducted in tandem with the data collection phase, both complementing each other. The third phase—presentation of findings—completes the accident investigation process by outlining the information obtained and corresponding conclusions drawn based on the previous two phases. The investigative findings obtained and the conclusion of the investigation are ultimately used to formulate safety recommendations, such as preventive actions, with the goal of increasing safety and preventing aircraft accidents.

Composite Materials and Aircraft Accident Investigation

With a specific focus on aircraft accidents as well as accident-related elements and investigations, certain characteristics, properties, and behaviors of composite materials may present challenges that require further consideration. For instance, depending on the specific circumstances, an aircraft accident investigation may require an in-depth analysis of the structural materials to determine failure modes. Per ICAO, a so-called Structures Group can be formed—depending on the details of each accident—to analyze, among others, airframe structural failures.

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Furthermore, once the on-site/field phase of an aircraft accident investigation is completed, select structures and the respective failures may require further analysis in a laboratory setting to determine the exact causal factors and failure modes. However, a crucial factor to consider during the postaccident laboratory analysis of failed composite-based structures is that composite materials and the associated structures present different, more-complex failure modes than traditional long-established aircraft metals.

The importance and criticality of understanding the failures of composite materials, especially in aircraft structures, are illustrated by American Airlines (AA) Flight 587, the first commercial accident involving a composite-based structural failure in flight. In the case of AA Flight 587, the added complexity of composite material failures, coupled with the comparative novelty of the materials and the resulting reduced volume of literature in the field of fracture and failure analysis, added a further obstacle to the accident investigation process.

Composite Aircraft Fires

In addition to presenting further complications during the material analysis steps of an accident investigation, composite materials also introduce health hazards to aircraft accident investigators and first responders. Like other materials under combustion, composite materials release smoke to, and reduce the content of oxygen in, the atmosphere, subsequently worsening the surrounding air quality. Furthermore, ICAO lists composite materials alongside other potential hazards present at an accident investigation site such as oxygen system components, batteries, and fuels.

Common materials and chemicals used for composite aircraft construction—including carbon, aramid fibers, fiberglass, and epoxies—may release noxious gases or small fragments, presenting respiratory hazards when damaged or upon burning. A range of organizations, institutions, and authors have recommended and enumerated guidelines and protective steps to control and reduce the hazards presented by composite fire byproducts.

Common examples include, among others, wearing specific personal protective equipment (PPE) with filtering respirators and containing the release of dangerous substances by extinguishing the fire and by applying hold-down or fixant solutions.

A specific focus, in terms of fires in composite-based aircraft components and structures, are aircraft engines, as they commonly employ composite-based structures for the construction of engine blades, cowlings, nacelles, and pylons. Furthermore, aircraft engines are classified fire zones, defined by the U.S. Federal Aviation Administration as "a flammable fluid leakage zone that contains a nominal ignition source." Therefore, the risk for fires, coupled with the abundance of composite materials used, makes aircraft engines critical health hazard areas after an aircraft accident and the subsequent investigation.

Focus Statement

This project focuses on how engine composite structures during powerplant fires may affect first respondents, search-and-rescue efforts, and the accident investigation. The health hazards and consequences presented by burning composites will be explored in relation to their impact on the subsequent materials analysis. How the hazardous materials handling protocols for composite materials previously mentioned affect the damaged materials and the associated fractographic evidence will be evaluated.

In this research, consequences of specif-

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ic hazardous, burning composite material handling protocols will be assessed from the material analysis perspective with the purpose of identifying the effect on the material fractographic study, highlighting potential detrimental impacts on the surfaces studied that may reduce the investigative analysis depth. Within the specific scope of the present study, the first two phases of an accident analysis process—data collection and data analysis—are of interest.

The data collection phase applies to the collection of materials-related evidence at the accident site, while the data analysis phase relates to the examination of the collected material evidence in the laboratory. If issues arise that impact these two first phases, e.g., through the application of hazardous/burning composite material protocols to burning composite-based aircraft structures, the findings obtained can be affected, potentially derailing the original intent of the investigation: developing effective safety-enhancing recommendations.

Aircraft Engines, Composite Materials, and Fires

Composite structures are frequently employed for the construction of engine blades, cowlings, nacelles, and pylons. Even though the hot section of a turbine engine, comprised of the combustion chamber, turbine blades, and exhaust, is primarily reliant on metallic- and ceramic-based materials due to the extreme temperatures, the cold section offers prime conditions for the implementation of polymer composites.

Sandwich-based composite structures are used to line engine cowlings and nacelles due to the ability of sandwich cores to act as a sound absorbent/suppressor while allowing for reduced weight. The liners used include materials such as fiberglass, epoxy, and aramid-honeycomb sandwich cores. Carbon/epoxy-based composite material is used to manufacture larger, but lighter, complex-shaped engine fan blades and fan containment cases. Engine pylons, due to their structural significance, rely on aramid/Kevlar® fibers for damage protection. In addition to epoxy thermosetting resin, thermoplastic resins including polyether ether ketone (PEEK) and polyphenylene sulfide (PPS) are also used in aircraft engine applications as matrix materials.

In addition to the inherent failures from an accident, composite structures exposed to a fire may be damaged from the combustion process itself. Common failure modes observed in composite material samples when subjected to fires and high temperatures are delamination and matrix cracking. Similarly, char formations are found on burnt composites. These charred regions, however, can present benefits related to fire propagation, as char can act as a thermal insulator and oxygen blocker. These elements are further considered during the material analysis steps. As previously mentioned, the combustion byproducts of composite materials used for the construction of engine structures present a line of hazards for first respondents to the accident scenes, ranging from toxic smoke and combustion gases to potentially respirable fiber fragments.

Hazards Presented by Fiber Dispersion

Small-sized fibers released during the combustion of fiber-reinforced composite materials present a number of health effects, ranging from the irritation of skin and eyes to respiratory difficulties resulting from the inhalation of fibers. Fibers between 0.7 µm and 7 µm in diameter present risks to the human respiratory system. Each material, however, presents differing health hazards dependent on the materials' intrinsic virgin fiber size and combustion characteristics.

Carbon Fiber Combustion: Virgin carbon fibers, with an approximate diameter of 7 µm, are on the upper limit of the respirable particle size. However, through combustion, the diameter of the fibers is decreased through chemical processes to dangerously small sizes. Various elements impact the decomposition of the carbon fibers in a fire, thus influencing the volume of dangerous respirable carbon fiber released. On one hand, fires with comparatively low temperatures—for example, average temperatures below 600° C (~1,110° F) are generally not expected to yield a critical quantity of carbon fiber fragments. On the other hand, the presence of aircraft fuel as well as oxygen (through large exposed surfaces) result in further carbon fiber decomposition and a greater chance of critical fiber fragment formation. The intrinsic—initial—fiber size, moreover, is an influential factor in the formation of fiber fragments of respirable size.

Fiberglass Combustion: While the diameter of carbon fibers can decrease in a fire, glass fibers do not present the same behavior. Glass fibers are observed to melt at temperatures above 600° C (~1,110° F), thus not decomposing into smaller fiberglass fragments. Furthermore, the diameter of virgin glass fibers (~12 µm) is above the upper limit of respirable particle size, thus not presenting an inhalation hazard per se.

Nevertheless, fiberglass dust or pulverized fibers, which could potentially present an inhalation hazard, can be a result of impact- or collision-type events such as aircraft accidents.

Aramid Fiber Combustion: Aramid fibers are a form of high-performing organic fibers. At temperatures ranging from 500° C (~930° F) to 550° C (~1,020° F), aramid fibers commence charring and decomposing, resulting in potential respirable particles.

It is important to note, however, that even though potentially respirable, virgin carbon fiber, virgin glass fibers, and virgin aramid fibers do not present short-term toxicological hazards upon inhalation. Nevertheless, health risks resulting from inhaling postcombustion fibers cannot be ruled out, as fibers involved in the combustion process of composite materials may be contaminated with potentially hazardous materials and chemicals. Postcombustion fibers have been reported to present char, matrix residuals, phenols, aromatic compounds, and polycyclic aromatic hydrocarbons (PAHs) on their surfaces, adding further health concerns.

Hazards Presented by Thermal Decomposition

As the combustion of fibers is accompanied by airborne, and potentially respirable fiber particles and fragments, the decomposition of polymeric matrix materials and the aforementioned fibers introduces a volume of toxic chemicals that are released upon combustion. From experimental studies conducted over the last three decades, byproducts formed and released during the thermal decomposition of fibers and matrix materials have been identified. Even though the exact composition of byproducts obtained as well as their relative proportion are dependent on the combusted material, general trends recognized from literature reference carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), hydrogen cyanide (HCN), alkylated phenols, and aromatic ethers as byproducts resulting from epoxy resin matrix material combustion.

During the thermal decomposition of the thermoplastic matrix PEEK, phenol is the primary observed gas together with a combination of further organic gases. PPS thermoplastic matrix, on the other hand, yields benzene, benzenethiol, and a range of dimers, trimers, and tetramers. Furthermore, both types of thermoplastic resins described—PEEK and PPS—are observed to yield comparatively large volumes of char. In composite materials reinforced by carbon fibers, aromatic compounds, phenols, as well as PAHs, including quinoline and toluidine, were observed.

Byproduct yields from thermally decomposing aramid fibers include nitrogen oxides (NO_x), CO, CO_2, HCN, and aromatic compounds, such as toluene and benzene. Similar byproducts—including hydrochloric acid (HCl), CO, CO_2, acetone, propylene, styrene, toluene, benzene, and further aromatic compounds—are observed in experiments including glass fiber-reinforced composites. The chemical compounds listed here, as well as the compounds contaminating burnt fibers previously discussed, can present short- and long-term negative health effects, including, but not limited to, harm to the eyes, skin, kidneys, thyroids, and liver, as well as the respiratory, blood, nervous, and cardiovascular systems. Furthermore, it is important to note that certain substances are carcinogenic. The exact health impacts and respective hazards, however, are dependent on the particular concentration and mixture of materials and are unique to each scenario.

While the byproducts previously mentioned are separated in terms of the specific composite materials, it is important to note that matrix materials and fibers interact with one another in a real composite system. Therefore, the combustion byproducts produced by fibers and matrix materials—and especially the associated health effects—are to be considered in conjunction, as the combined toxicity may be increased. Furthermore, to reduce the flammability or to improve flame-retardant properties, composite materials are frequently modified through the use of coatings, the addition of compounds into the matrix, or by chemically modifying the matrix, among others. However, even though these methods may delay the onset of fires or improve flammability properties, in some cases, they may result in more-toxic emissions, thus worsening health effects.

Adjusted Processes for Composite Fire Handling

In light of the health hazards presented by burning composites during an aircraft accident involving a fire, the corresponding response protocol has been adjusted by the according aircraft accident investigation authorities. Specifically, the procedures impact personnel involved in the handling of the composite material, such as first responders and aircraft accident investigators, during and/or postcombustion. For the protection of individuals required to handle composite materials, PPE is used as the first-defense mechanism. A general, overarching list of PPE to be worn includes

- Respiratory protection: Respirators (full- or half-face) to protect from the inhalation of fiber fragments/particulates, vapors, and fumes.
- Eye protection: If half-face respirators are worn, additional eye protection—in the

	Respiratory Protection	Eye Protection	Skin Protection
Burning/ Smoldering Composites	Self-contained breathing apparatus (SCBA)	Self-contained breathing apparatus (SCBA)	NFPA 1971 standard: Full-body suit, gloves, and boots No rubber/nitrile gloves
Broken/ Splintered Composites	Full- or half-face respirators with dual cartridge filters: Dust/mist protection and high efficiency particulate air (HEPA)	Goggles (if a half-faced respirator is worn)	Tyvek®-type full-body suits Leather and rubber/nitrile gloves Hard-soled, steel-toe boots
Peripheral Area	High-efficiency particulate air (HEPA) disposable or reusable respirators	Safety glasses or goggles	Long-sleeve clothing Leather and rubber/nitrile gloves Hard-soled, steel-toe boots

Table 1. Specific PPE Requirements at a Burning Composite Material Accident Site

form of fitting safety glasses or goggles—is required to reduce and prevent the exposure of eyes to fiber fragments/particulates.

- Skin protection: Coveralls, gloves, and boots to reduce and prevent dermal exposure to fiber fragments/particulates. The coveralls should be fastened with duct tape around potential opening points (e.g., wrists and ankles) to intercept penetration of fiber fragments/particulates. The gloves should be made out of puncture-resistant materials (e.g., leather) and be complemented by nitrile/rubber gloves to prevent further exposure to chemical hazards such as fluids. Footwear guidelines include steel-toe, hard-soled boots.

The listed PPE guidelines are highly dependent on each individual scenario and are impacted by factors such as environmental conditions, condition of the hazardous material, and distance to the hazardous area. The U.S. Army Combat Readiness Center (USACRC) defines a 25-foot (~ 7.5 meter) boundary around burning composites as the high-risk-of-exposure area in which the PPE requirements outlined above are to be stringently followed. However, the exact size of the high-risk-of exposure area is not fixed, but rather dependent on environmental factors.

For instance, high winds may aid the dispersion of fibers and other hazardous materials, resulting in an increased high-risk exposure zone or rainy conditions may reduce the dispersion of hazardous materials, narrowing the high-risk exposure zone. Outside the high-risk exposure zone—in the so-called peripheral area—less-restrictive PPE protocols are recommended. Similarly, the exact condition of the damaged and burned composite materials in question influences the choice of PPE.

Composites that are burning or smoldering require more-protective respiratory protection and clothing, while not permitting the use of nitrile/rubber gloves. Protective equipment for the handling of composite materials that are broken or present splintering, such as after a fire, oppositely, includes rubber/nitrile gloves as well as respirators instead of self-contained breathing apparatuses. A summary of the specific PPE requirements for each scenario is outlined in Table 1.

In addition to adjusted PPE guidelines, burning composite handling protocols include procedures to mitigate further fiber dispersion. So-called fixant solutions are suggested to be applied over burning and smoldering composite fires to secure loose fibers and particulates stemming from a composite fire. Fixant solutions currently in place include acrylic floor wax (mixed with water) and polyacrylic acid. Application of fixant solutions can be conducted through backpack sprayers, hoses, and spraying guns and should be directed to thoroughly cover all surfaces (aircraft structures and others) that may contain fiber particulates, regardless of whether the composite structure in question is burning. After application, the fixant should be allowed to dry. When the fixant is dry, the coated parts may be further protected through wrapping in plastic films or sheets. The wrapped parts may, in turn, be placed in plastic bags of at least 0.006 inches (0.15 millimeters) in thickness.

Impact of Adjusted Handling Procedures on the Material Analysis

As part of the second phase of the aircraft accident investigation, the data analysis phase, material evidence may be subject to a series of laboratory tests to determine—as applicable and necessary—failure modes and causes of aircraft components and their effect on the accident causal factors and sequence. Among others, tests and tools used for the fractographic examination of composite failures include stereomicroscopes (optical microscopes), scanning electron microscopes, transmission electron microscopes, X-ray, X-ray computer tomography, ultrasound, infrared spectroscopy, thermomechanical analysis, dynamic mechanical analysis, differential scanning calorimetry, and electron spectroscopy for chemical analysis.

However, in order to use these techniques, the specimens under examination may require special preparation. Consequently, in light of the requirements, needs, purpose, technology, and limitations of the specific material analysis techniques that may be used, it is crucial to consider how the methods employed to handle the hazards presented by burning composites at an aircraft accident site interact with the subsequent material analysis process. Previously mentioned literature presents and highlights potential detrimental impacts of the aforementioned hazardous material handling procedures on the material analysis steps because spraying fixant may interfere with the analysis of evidence.

To analyze the material evidence in a laboratory, the parts and components in question need to be moved from their accident location to the adequate analysis facility. Furthermore, as noted, the analysis of material evidence requires, in certain instances, specific preparation of the specimens. However, both steps may result in disrupting the fixant coating applied, detrimentally impacting the prevention of fiber dispersion. To prevent further dispersion of fibers, the Australian Transport Safety Bureau recommends not handling or moving composite structures that may have been involved in a fire.

Moreover, certain analyses require the fixant application to be completely removed. In these cases, so-called stripping solutions, frequently based on ammonia or trisodium phosphate, can be used to remove the fixant solution from the surfaces to be studied. However, stripping solutions, similar to the fixant solutions themselves, present dangers to the material analysis process. The stripping solutions can interact with the material evidence on which it is applied, potentially damaging the part, and thus removing evidence during the accident investigation process.

Studies have focused on analyzing the effectiveness of different fixant solutions at reducing the fraction of dangerous respirable fibers. However, literature related to the interaction between fixant and stripping solutions with the materials evidence is scarce. Therefore, research in the area of fixant and stripping solution compatibility with burning modern composite materials is required to minimize the tradeoff between minimizing health hazards while ensuring critical evidence is not removed or destroyed. If material evidence is damaged or destroyed, the depth and detail gathered during the material analysis process may be detrimentally impacted, potentially compromising the overall accident investigative effort.

Moreover, as noted, fiber release during the material analysis steps, specifically as fixant solutions are disturbed and specimens are cut, is to be considered, specifically as it relates to the hazards presented to the specialists conducting the material analysis steps. The health hazards presented during the study of the material evidence drive the PPE requirements to be followed in the corresponding laboratories. Nevertheless, it is crucial to ensure that the mandated PPE does not interfere with the ability of specialists to conduct the required analyses.

Conclusion, Practical Implications, and Future Work

Composite materials, when involved in an aircraft accident fire, can present a range of health hazards to first responders and aircraft accident investigators. In response to the dangers presented, authorities have developed novel protocols and procedures that aid in mitigating the previously mentioned hazards. However, these procedures—especially the application of fixant/hold-down and stripping solutions to reduce the dispersion of respirable fibers—have the potential to detrimentally impact the fractographic analysis of the involved composite structures. Consequently, the investigative depth of the accident investigation process may be reduced.

Therefore, as is suggested in previous studies, the application of fixant and stripping solutions needs to be carefully considered against the potential impact on the subsequent steps of the accident investigation. Furthermore, specific factors that may impact the interaction between fixant/stripping solutions and the material evidence can be explored to aid in the decision-making process.

Examples include specific composite materials used, intrinsic health hazards of each of the materials employed, importance and criticality of the structures in question on the accident investigation process, and combustion characteristics such as temperature, length of exposure, and chemicals involved in the fire. Understanding these factors is critical considering the development of composite materials in the aeronautical realm, as they are increasingly used for primary structures and the materials used are continuously evolving. Similarly, by evaluating potential impacts of the factors outlined, accident investigation authorities may better balance the minimization of health hazards while maximizing critical composite-based evidence. ◆

NEWS ROUNDUP

ISASI Executive Officer Elections Are Finalized

The ISASI biennial Executive Officer elections are complete with the following individuals now beginning their 2022–2024 terms of office:

- International President—Barbara Dunn
- International Vice President—Robert Carter
- International Secretary—Chad Balentine
- International Treasurer—J. Eric Prince
- International Councilor—Caj Frostel
- USSASI President—Steve Demko

Frank Del Gandio will now serve as the executive administrator, stepping into the position that Dick Stone held since 1998. ◆

ASASI Says Aviation Emerging from COVID

John Guselli, president of Australian Society of Air Safety Investigators (ASASI), reports that the state of the Australian aviation industry continues to improve as it emerges from the pandemic. Domestic travel is approaching pre-Covid levels while international travel demand has declined due to world economic downturns and the price of fuel.

He added that ISASI 2022 was held at the Pullman Hotel in Brisbane, Australia, August 30 to September 1. The hybrid format meant that delegates either attended in person or participated virtually. Details of the gathering will appear in the next issue of *ISASI Forum.*

Keynote speakers included

- Angus Mitchell, chief commissioner of the Australian Transport Safety Bureau,
- James Redgrove, general manager of safety systems for Dreamworld/White Water World Skypoint,
- David Anderson, managing director of Flight Safety Foundation Ltd.,
- Group Capt. Dennis Tan, director of the Defence Flight Safety Bureau,
- Professor Graham Braithwaite, director of transport systems at Cranfield University, UK, and
- Greg Hood of Airservices Australia.

Renowned human factors consultant Malcolm Brenner, Ph.D., delivered an after-dinner presentation that focused on speech analysis as a new investigative technique utilizing major U.S. National Transportation Safety Board and international case studies. ◆

ISASI-ICAO Working Group Attends AIGP Meeting

Mark Clitsome, chair of the Society's ISASI-ICAO Working Group, reports that the International Civil Aviation Organization (ICAO) held its seventh meeting of the Accident Investigation Group Panel (AIGP) on May 24–27 in Paris, France. These meetings are typically held in person at ICAO in Montréal, Canada, but due to the city's COVID restrictions, ICAO policy didn't allow in-person meetings in Montréal at that time.

The meeting in Paris was hybrid with both in person and virtual attendance. The number of participants varied from day to day with in-person participation in the 20s and virtual attendance in the teens. ISASI-ICAO Working Group members Ron Schleede, Robert MacIntosh, and Clitsome attended virtually.

The purpose of these yearly meetings is to allow states and international organizations to propose improvements to Annex 13 and its supporting documents. These proposals can come from the panel members, the Air Navigation Commission, the Secretariat, or from other ICAO platforms such as the Assembly sessions.

In 2021, Marcus Costa, the chief of the section and a longtime ISASI member, retired. Andre de Kock became the acting chief. He retired on June 30, 2022. The new chief of the section is Thor Thormodsson, a longtime employee of ICAO and an accident investigator from Iceland. ◆

Singapore Hosts Fifth International Accident Investigation Forum

The Transport Safety Investigation Bureau of Singapore (TSIB) co-organized the fifth International Accident Investigation (IAI) Forum with the Singapore Aviation Academy on May 18-20. It was attended by approximately 90 delegates, including government officials, senior aircraft accident investigators, experts from 31 states and administrations, and safety professional from the aviation industry. Delegates attended the IAI Forum in person, with some presentations conducted virtually.

As with past forums, this one received strong support from the International Civil Aviation Organization (ICAO), the European Civil Aviation Conference (ECAC), the Flight Safety Foundation (FSF), ISASI, and Curt Lewis & Associates, LLC. The TSIB wishes to express its gratitude and appreciation to these organizations for their support.

The keynote speaker at this year's forum was Stephen Creamer, director of ICAO's Air Navigation Bureau. During the three-day IAI Forum, delegates were informed of the upcoming amendments to Annex 13 to the Convention on International Civil Aviation on Aircraft Accident and Incident Investigation. The delegates discussed the challenges and lessons learned from recent investigations, as well as emerging challenges for aviation professionals, including safety investigations post the COVID pandemic, new technologies available to improve safety investigation, and more. The forum included a visit to the Air Traffic Management Research Institute at Nanyang Technological University during which the delegates received a presentation on "Current and Future Considerations in Safe Unmanned Aerial System Traffic Management—R&D Efforts Toward Risk-Based Unmanned Aerial Vehicle [UAV] Operations in Urban Airspace." The visit concluded with a tour of the

Participants of the fifth International Accident Investigation Forum gather for a group photo.

ATC tower simulator, ATC radar simulator, and the UAV flight room.

The TSIB will be hosting the sixth IAI Forum in 2025. ◆

EASA Seeks Lithium Battery Detection Solution

The European Union Aviation Safety Agency (EASA) published a notice on July 13 on its website seeking development proposals (tenders) for possible identification of prohibited items using airport security equipment. EASA noted, "There is a need to investigate possible technical, operational, and regulatory solutions to support safety requirements (in particular detection of lithium batteries not transported in line with applicable safety rules) without affecting the performance of screening operations."

The agency observed, "Lithium batteries, whether or not contained in equipment, are one of the main causes of the incidents reported in the cabin. The main risks are fire and smoke, which can lead to catastrophic events. Certain restrictions apply to the carriage by passengers of lithium metal and lithium ion batteries in accordance to ICAO [International Civil Aviation Organization] Annex 18 and the ICAO Technical Instructions for the Safe Transport of Dangerous Goods (ICAO Doc. 9284)."

For information related to the project, visit EASA.2022.HVP.21 on www.easa.europa.eu. The value of the final project was estimated at €350,000 and will be funded from the European Union's Horizon Europe research and innovation program. ◆

Flight Safety Foundation Develops RPAS Safety Program

The Flight Safety Foundation, an ISASI corporate member, announced that as part of its Basic Aviation Risk Standard (BARS) Program and working in collaboration with some of the world's largest mining and resource companies, it's developed a Remotely Piloted Aircraft Systems (RPAS) Audit and Registration Program to provide the industry with a more efficient means of monitoring, assessing, and analyzing risks associated with RPAS.

With airspace more accessible than ever and RPAS technology outpacing many legal and safety frameworks, there's an urgent need for greater oversight of RPAS operations to ensure the safety of those living and working around them.

The RPAS Audit and Registration Program will help businesses manage RPAS risks more efficiently and effectively through a variety of measures, including detailed reporting of events and information sharing.

An RPAS audit using registered BARS audit companies and accredited RPAS auditors provides evaluation of operations and technical management systems of an RPAS operator. It's a comprehensive audit with the objective of clearly articulating and verifying what procedures, processes, and systems the RPAS operator has in place to mitigate risk.

"RPAS are critical to business operations for a range of sectors and used within a multitude of operations enabling data collection, enhancing security, and improving productivity," said David Anderson, BARS Program director. "However, with new technology comes new risks, and RPAS-related accidents and incidents can result in expensive damage to property and infrastructure, as well as injuries and even fatalities," he noted.

As part of the program, a global data analysis program will record knowledge and intelligence on the hazards and risks associated with the use of RPAS vehicles. This information will be used to ensure that the appropriate controls within the audit standard are in place, updated, and effective.

"Enabling organizations to more effectively mitigate risk is critical to continually improving the safety and reliability of their RPAS operations," said Dr. Hassan Shahidi, president and CEO of the foundation. "In addition, the adoption of a global standard should result in a broad safety improvement across the sector," he observed.

Information about the RPAS Audit Program is available on the BARS Program website, flightsafety.org/resource/basic-aviation-risk-standard/. ◆

MOVING? NEW E-MAIL ACCOUNT?

Member Number

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

Old Address (or attach label)

Name

Address

City

State/Prov.

Zip

Country

New Address (Do not forget to change employment and e-mail address.)

Name

Address

City

State/Prov.

Zip

Country

E-mail

(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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CHANGE SERVICE REQUESTED

WHO'S WHO: HELIOFFSHORE

(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)

UK-based HeliOffshore, a new ISASI corporate member, is the global safety-focused association for the offshore helicopter industry. Our mission is to lead a collective safety conversation, identifying the right priorities, supported by the right resources, delivering the right actions, to transform frontline safety performance.

Our vision is a safer front line served by an open, responsive, and aligned industry so that no lives are lost in offshore aviation. We lead a collective safety conversation among offshore operators, aircraft manufacturers, energy companies, financial and support services, regulators, and other industry associations to develop the tools, technology, and training necessary to transform frontline safety.

HeliOffshore has more than 110 members across seven continents. Our members join a collective conversation to identify the priorities, resources, and activity required to transform frontline safety performance through five active workstream activities.

The operational effectiveness workstream focuses on the frontline tools, techniques, and training required to improve current safety performance. Activity includes supporting developments to enhance takeoff and landing safety performance. The system reliability and resilience workstream helps the industry develop designs, implement procedures, and manufacture systems that remain safe even when tested by human failure.

The HeliOffshore Safety Intelligence Program (HSIP) is the collective name for the safety intelligence-gathering and analysis capability developed within HeliOffshore. It is a collaborative effort drawing on the support, expertise, and commitment of our industrial partners and members. Members undertake confidential sharing and analysis of data through HSIP to

- measure the current state of daily safety performance in a number of areas including accidents, incidents, fleet distributions, and usage data;
- prioritize and support workstream activities, and;
- close the loop and monitor the effectiveness of safety actions.

The Helideck Work Group includes representatives from energy companies, helicopter operators, industry associations, and regulators who collaborate to review, define, and standardize helideck safety opportunities.

The Wind Farm Work Group focuses on the use of helicopters to support offshore wind farms, which involves a diverse range of tasks including surveys, inspections, cleaning, monitoring, maintenance support, search and rescue, medical support, and the transfer and heli-hoisting of people and cargo to and from helidecks. These complexities create a number of safety concerns. With data analysis, we directly address these safety concerns, offer workshops, and create processes and procedures to ensure that no lives are lost through offshore aviation.

We hold an annual conference each year, bringing members together to discuss additional ways to collaborate and navigate challenging market conditions. ◆

HeliOffshore
Safety Through Collaboration

HeliOffshore CEO Tim Rolfe addresses attendees during a recent conference.