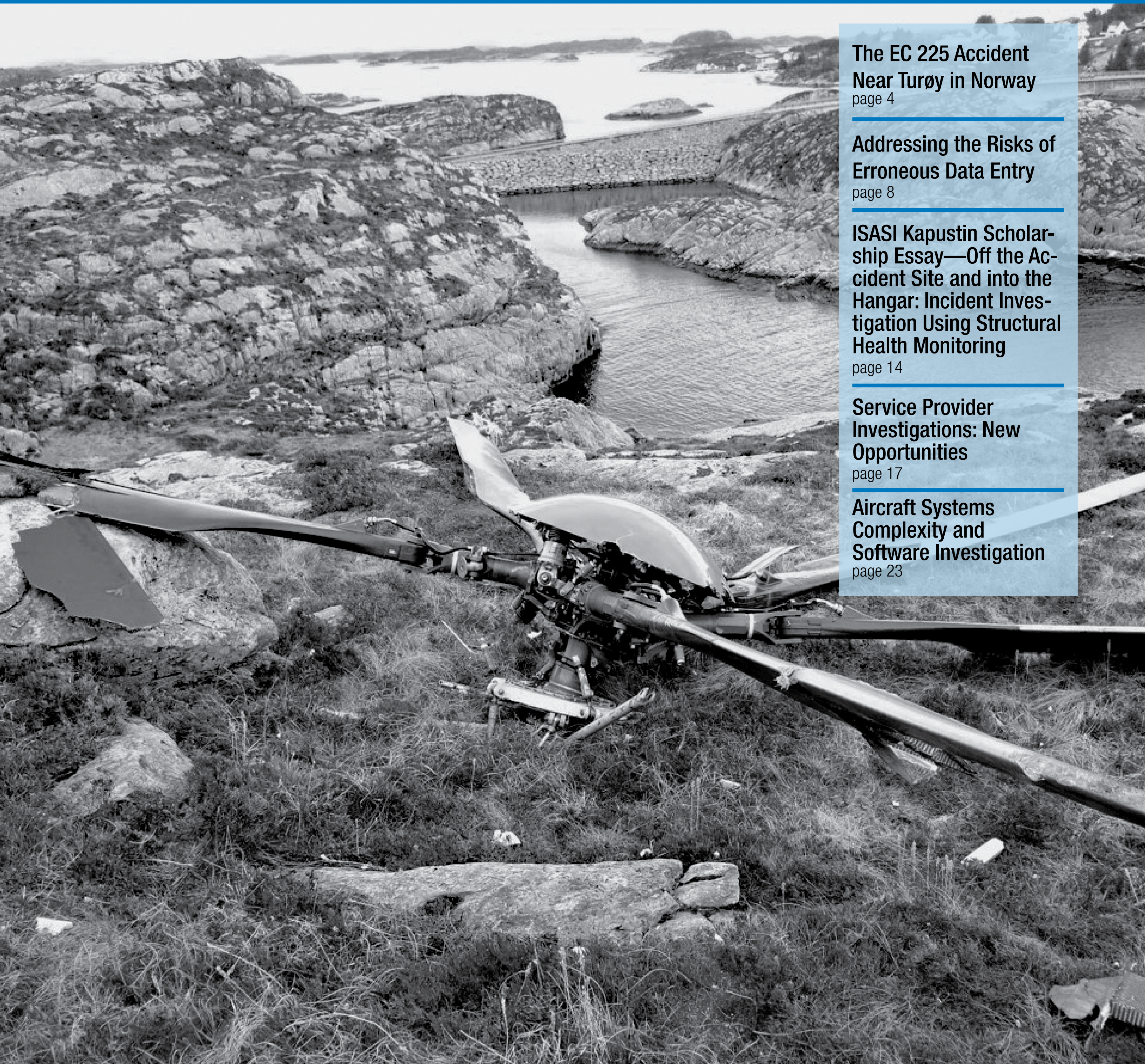
FORUM

Air Safety Through Investigation

APRIL-JUNE 2019

Journal of the International Society of Air Safety Investigators



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ABOUT THE COVER

The main rotor suddenly detached from an EC 225 LP Super Puma helicopter in 2016 that was transporting oil rig workers to a platform in the North Sea. Wreckage parts were spread over a large area both on land and in the sea near Turøy, Norway. The main rotor landed on an island about 550 meters north of the crash site. The impact forces destroyed the helicopter before most of the wreckage continued into the sea. Fuel from the helicopter ignited and caused a fire on shore.

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AIR SAFETY INVESTIGATORS

INCORPORATED AUGUST 31, 1964

POSITIONS ON AIR SAFETY INVESTIGATION ISSUES

All of us who are or have been professional accident investigators and aviation safety personnel can benefit from reviewing ISASI's official *Positions on Air Safety Investigation Issues* document that is posted on our website. The purpose of the document, which was last updated in May 2015, is to codify our approved positions on matters concerning ISASI's role and policies for air safety.

The positions are evolutionary in nature and are updated periodically. A team is currently reviewing the positions document for possible updates or inclusion of new issues. These positions are not mandatory for ISASI members but reflect policies, best practices, and concepts that are beneficial to Society members. These published positions are especially helpful when we're approached by the news media or other entities regarding our views on air safety issues. The document currently covers 13 topics.

Chapter 1: Introduction—defines ISASI and why the Society was formed in 1964. It addresses the process for establishing policy standards and ISASI's acceptance of International Civil Aviation Organization (ICAO) manuals and definitions that ensure investigations are conducted worldwide in a well-documented, uniform manner.

Chapter 2: General—defines the purpose of air safety investigation as the prevention of accidents and incidents and that our members are to adhere to the ISASI Code of Ethics and Conduct. This section provides guidelines for conduct during an investigation.

Chapter 3: Accident and Incident Investigations—discusses that the conduct of the investigation should be accomplished in accordance with ICAO Annex 13 or other internationally accepted investigative framework. This section also covers the importance of quality control and using ISASI, *ISASI Forum*, the annual ISASI and regional seminars, and other similar arenas as a means of disseminating lessons learned and successful techniques during an investigation to other investigators. Investigators are urged to determine all causes and contributing factors influencing human and organizational performance as well as precursors discovered during previous investigations.

Chapter 4: Investigation Organizations—addresses the authority of the organization and the investigator and the need for independence. This section provides a framework for states to ensure that their investigation organization has the authority to properly conduct their tasks.

Chapter 5: Investigator-in-Charge—outlines the need to appoint an investigator-in-charge(IIC), the role an IIC plays creating the investigation report, and the importance of keeping a draft report confidential until the investigation authority publishes the final report.

Chapter 6: Investigators—addresses the qualifications and experience for investigators and their initial and recurrent training.

Chapter 7: Documentation—provides minimum standards for documenting investigations, disclosure of the master file for review or research within legal restraints, and data retention.

Chapter 8: Witnesses—addresses the importance of conducting witness interviews as soon as possible after an occurrence, the conduct of the interviewer, and the rights of witnesses. Witness statements, except where confidentiality is granted, should be made available on a need-to-know basis but not outside of the investigation.

Chapter 9: Recorders—addresses the use of flight recorders, cockpit voice recorders, in-flight video recording, and the use of such devices. This section affirms that protection from inappropriate disclosure and misuse of recordings through legal and or technical measures is a high priority. ISASI supports the full-time tracking of aircraft.

Chapter 10: Accident Report—addresses review and consultation of a draft report, the final accident report, the recommended format, and the formation of safety recommendations.

Chapter 11: Actions on Reports and Safety Recommendations—addresses the processing of safety recommendations and the process of petition for review.

Chapter 12: Prevention/Safety Programs/Accident Prevention Program—addresses the need to examine safety programs as a routine part of the investigation.

Chapter 13: Miscellaneous—suggests that the investigative authority should designate an official to work with the news media. This individual should provide approved and validated information to the news media without speculation about causes or contributing factors. ISASI's positions on unlawful interference and family assistance are outlined.

This "President's View" should only whet your appetite to review all 17 pages of the Society's official positions. I strongly recommend anyone who is an investigator or works in the aviation safety field to review these positions to enhance your overall understanding of the process and to promote safety through investigation. ◆

Frank Del Gandio
ISASI President

THE SECOND LOSS OF A HELICOPTER MAIN ROTOR—NEED FOR A CHANGE IN CERTIFICATION AND CONTINUED AIRWORTHINESS OF LARGE ROTORCRAFT?

THE EC 225 LP ACCIDENT NEAR TURØY IN NORWAY

By Kåre Halvorsen and Tor Nørstegård, AIBN

On April 29, 2016, the main rotor suddenly detached from a helicopter registered LN-OJF, an Airbus Helicopters EC 225 LP Super Puma, operated by CHC Helikopter Service AS. The helicopter transported oil workers for Statoil and was en route from the Gullfaks B platform in the North Sea to Bergen Airport Flesland. The flight was normal, and the crew received no warnings before the main rotor separated. All 13 persons on board perished instantly when the helicopter hit a small island and continued into the sea. Losing a main rotor is unacceptable. This was the second rotor loss for this helicopter type.

This presentation will focus on the following topics:

- The accident site.
- Building a robust investigation team.
- Challenges faced during the investigation.
- The metallurgical investigation.
- Certification and continued airworthiness.

The accident site

Wreckage parts were spread over a large area both on land and in the sea. The main rotor landed on an island about 550 meters north of the crash site (see Figure 1). The impact forces destroyed the helicopter before most of the wreckage continued into the sea. Fuel from the helicopter ignited and caused an onshore fire.

There were many witnesses to the accident. In addition, the combined voice and flight data recorder was picked up from the seabed and successfully downloaded. Furthermore, with information from the vibration health monitoring system, the accident sequence could be reconstructed.

However, it was necessary to find as many pieces as possible to determine why the main rotor separated, and parts from the main gearbox and its attachments had special focus. On the second day, the main wreckage was lifted from the sea (see Figure 2), and the main rotor was recovered (see Figure 3). A number of key parts from the main gearbox were also found at this time, including two segments of a fractured second-stage planet gear that later became of vital importance.

A large search operation was initiated that included members of the Norwegian Civil Defence who searched onshore using metal detectors. Divers from the Norwegian Armed Forces and the Bergen Fire Department performed a total of 354 dives. A remotely operated vehicle was used in areas not covered by kelp forest, and a purpose-built magnet sledge was used to search for steel parts on the seabed. Following the accident, Navy divers used the area for training purposes, and the last major part—the second-stage planet carrier—was found and recovered in late February 2017.

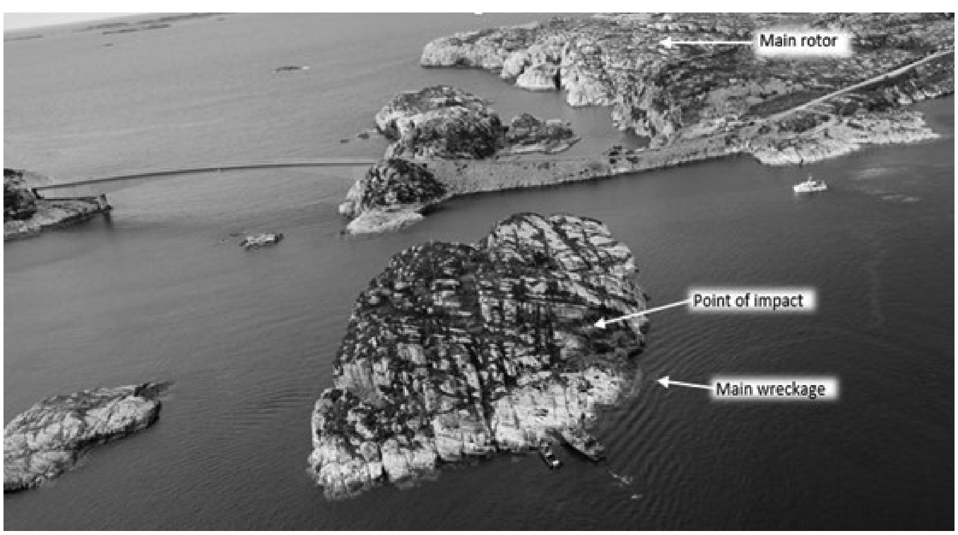

Figure 1. The accident site.

Building a robust investigation team

Building a robust investigation team is of vital importance. In accordance with International Civil Aviation Organization (ICAO) Annex 13, the French accident investigation organization (BEA) was notified as the state of design and the state of manufacture. The BEA appointed an accredited representative to lead a team of investigators from the BEA and advisors from Airbus Helicopters, Safran Helicopter Engines, and later the French bearing manufacturer. In accordance with Regulation (EU) No. 996/2010, the European Union Aviation Safety Agency (EASA), the regulator responsible for the certification and continued airworthiness of the helicopter, was notified of the accident and participated as advisor to the Accident Investigation Board of Norway (AIBN). The Norwegian Civil Aviation Authority (CAA-N); the operator, CHC Helikopter Service AS; and the Norwegian Defence Laboratories were also advisors and part of the team.

The UK Air Accidents Investigation Branch (AAIB), along with the metallurgical laboratory at QinetiQ, Farnborough, UK, had relevant experience from the investigation of a similar fatal helicopter accident of an Airbus Helicopters AS 332 L2, registered G-REDL, off the coast of Scotland in 2009. For that reason, they were asked to assist during the investigation. The AAIB appointed an accredited representative and advisors from QinetiQ as part of the team. Advisors with expertise in tribology and certification of

Figure 2. Main wreckage being lifted from the sea.

(Adapted with permission from the authors' technical paper titled AIBN the EC 225 LP Accident near Turoy in Norway *presented during ISASI 2018, Oct. 30–Nov. 1, 2018, in Dubai, the United Arab Emirates. The theme for ISASI 2018 was "The future of Aircraft Accident Investigation." The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Kåre Halvorsen

Tor Nørstegård

helicopters later joined the team.

The German accident investigation organization was later notified as the state of manufacture of the fractured gear bearing.

The transparent cooperation among these team members turned out to be a success. Documents were shared via controlled access to a secure file cloud.

Challenges faced during the investigation

Shortly after the accident, the EC 225 LP helicopter was grounded by the CAA-N and the CAA-UK. In early June 2016, the AIBN submitted a safety recommendation asking EASA to take immediate action to ensure the safety of the main gear box. EASA issued a flight prohibition for both helicopter types, AS 332 L2 and EC 225 LP. The flight ban was lifted by EASA five months later, based on an agreed-upon corrective actions package for return to service between EASA and Airbus Helicopters. In this situation, EASA had at least two different roles: being responsible for continuing airworthiness and an advisor to the AIBN. This pressure was high for all parties involved and influenced to some degree the sharing of information. From the AIBN's perspective, it sometimes seemed that lifting the flight prohibition was the first priority.

The AIBN came to understand that patience is necessary when asking for certification and design information. The AIBN appreciates EASA's obligation to follow its procedures as a public administrative body. However, the AIBN waited between two to six months before receiving some of the documents from EASA. The ABIN also understands that design information is sensitive and proprietary, but studying requested documentation at Airbus Helicopter's premises is not an effective way of reviewing such information. Additionally, legal issues drew resources away from the investigation. The AIBN notes that Regulation (EU) No. 996/2010 states, "free access to any relevant information or records," whereas ICAO Annex 13 states, "unhampered access to wreckage and all relevant material." Safety recommendations SL No. 2018/10T and SL No. 2018/11T are issued based on this experience.

The metallurgical investigation

Two recovered segments of the fractured second-stage planet gear, which makes up approximately half of a gear, got special attention (see Figure 4, page 6).

Detailed metallurgical examinations carried out at QinetiQ confirmed that the gear had fractured due to fatigue. The different examinations revealed the se-

Figure 3. The main rotor gear.

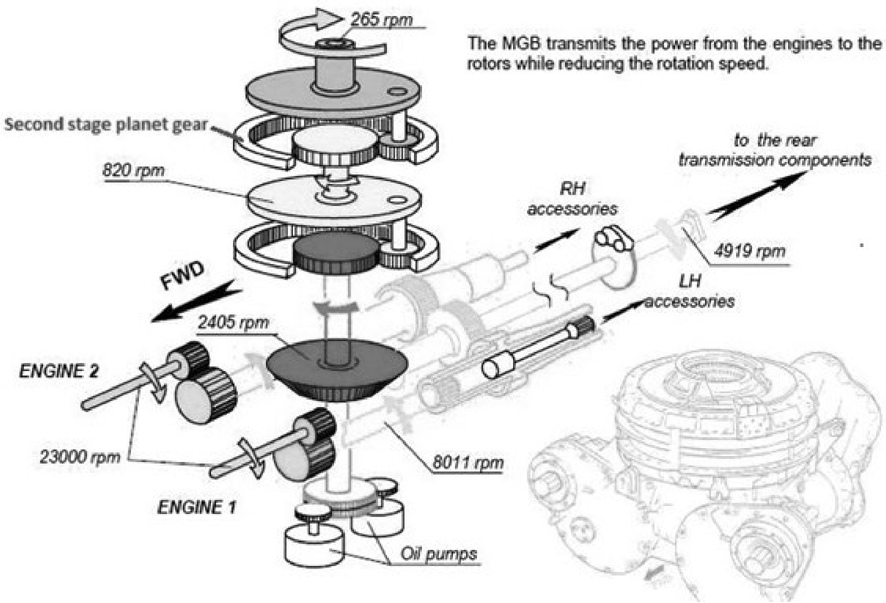

Figure 4. The rotor gear assembly showing the second-stage planet gear.

quence of the breakup of the gearbox (see Figure 5).

The fractured gear clashed teeth with other gears and caused an abrupt seizure and rupture of the gearbox, which lost its structural integrity.

The fatigue fracture initiated from a surface micro-pit in the upper outer race of the bearing (inside the second-stage planet gear), propagating subsurface while producing a limited quantity of particles from spalling before turning toward the gear teeth and fracturing the rim of the gear. Four spalls were observed centered along the line with maximum contact pressure (see Figure 6).

It is probable that the failure was initiated by debris caught within the bearing and scratching one or more rollers. This likely caused a band of local work hardening and associated micro-pitting at the outer race. The AIBN concluded that the fatigue fracture was neither a consequence of a mechanical failure or misalignment of another component nor due to material unconformity. More research is needed to understand the fatigue behavior of the material. It has not been possible to determine a conclusive crack propagation rate, but it must have developed within a maximum of 260 flight hours since the gearbox was inspected and repaired at Airbus Helicopters. The repair was done following a road transport incident.

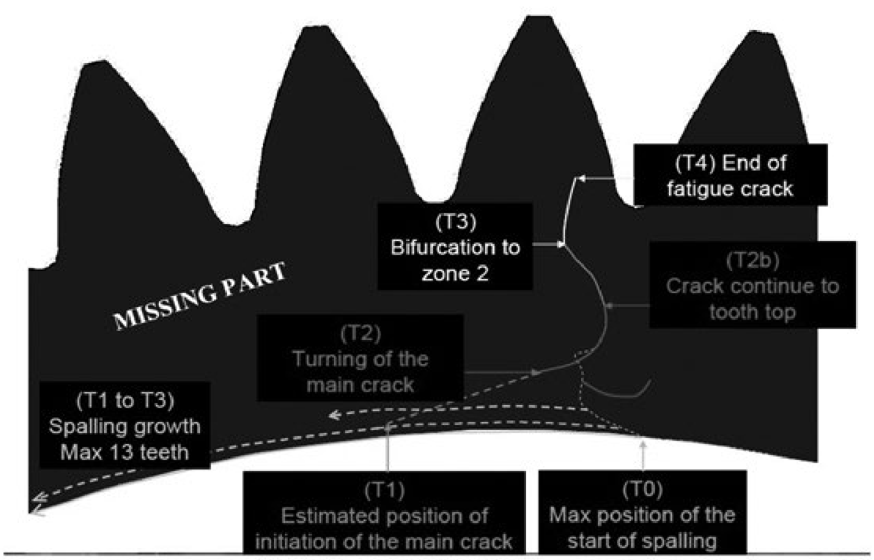

Figure 5. An estimate of the fracture sequence.

Certification and continued airworthiness

The helicopter main gearbox is both a mechanical drive train and a structural element without any redundancy. Any structural failure during flight will be catastrophic. The helicopter main gearbox must be regarded as one of the most safety critical components in the aviation industry.

The EC 225 LP is the latest member of the Super Puma family that started with the SA 330 in 1970. The EC 225 LP is derived from the earlier AS 332 L2. The 2004 certification of the EC 225 LP is based on JAR 29 Change 1. The second-stage planet gears were certified under FAR 29.571, Fatigue Evaluation of Flight Structure Paragraph C replacement time evaluation: "It must be shown that the probability of catastrophic fatigue failure is extremely remote within a replacement time furnished under section A29.4 of Appendix A."

Crack initiation and propagation with limited spalling was not expected or foreseen during design and type certification in 2004. It was assumed that if rolling contact fatigue occurred, spalling would result and be detected prior to gear failure. The AIBN believes that more could have been learned from the AS 332 L2 accident in 2009. The AS 332 L2 and EC 225 LP have near-identical gearboxes. Using all information and hypothesis might have challenged the design basis. Even though small changes were made to the main gearbox following the 2009 accident, the certification aspects were not adequately reviewed.

Less than 10 percent of all second-stage planet gears in the AS 332 L2 and EC 225 LP helicopters ever reached their intended operational time before being rejected during overhaul inspections or nonscheduled main gearbox removals due to signs of degradation. Airbus Helicopters did not perform systematic examination and analyses of unserviceable and rejected second-stage planet gears in order to understand the full nature of any damage and its effect on continued airworthiness.

Two catastrophic events (G-REDL and LN-OJF) and the service experience with many planet gears removed from service after relatively short service exposure may suggest that the operational loading environment on both AS 332 L2 and EC 225 LP is close to the limit of endurance for the design.

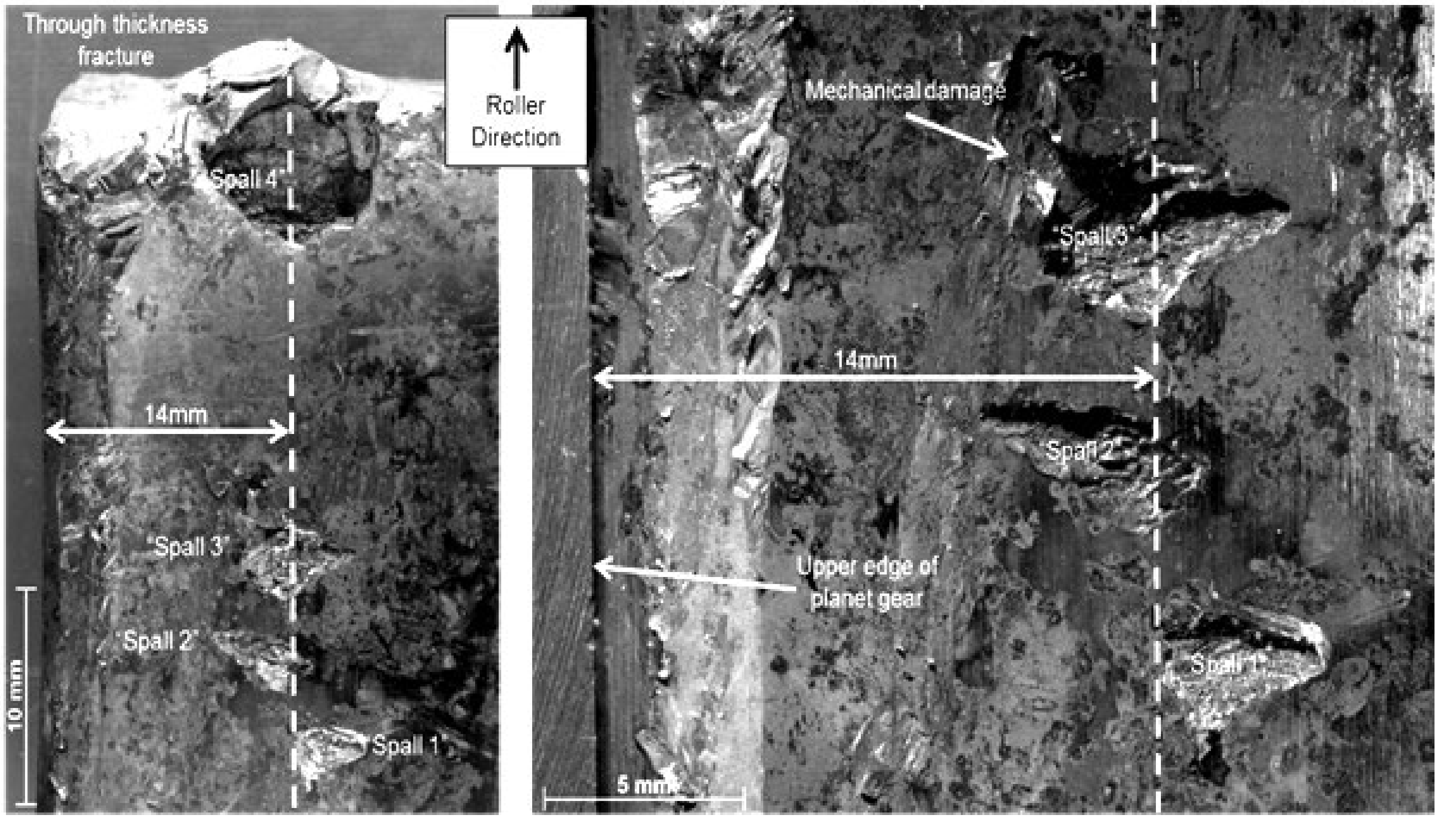

Figure 6. Investigators found spalling inside the second-stage planet gear.

The EC 225 LP satisfied the requirements in place at the time of certification. However, the AIBN has found weaknesses in the current EASA certification specifications for large rotorcraft (CS-29), and the AIBN has issued nine safety recommendations addressing these shortcomings.

The following safety recommendations were issued in order to enhance certification specifications and continued airworthiness of large rotorcraft:

SL No. 2018/01T

The AIBN recommends that EASA researches crack development in high-loaded, case-hardened bearings in aircraft applications. An aim of the research should be the prediction of the reduction in service life and fatigue strength as a consequence of small surface damage such as micro-pits, wear marks, and roughness.

SL No. 2018/02T

The AIBN recommends that EASA assesses the need to amend the regulatory requirements with regard to procedures or instructions for continued airworthiness for critical parts on helicopters to maintain the design integrity after being subjected to any unusual event.

SL No. 2018/03T

The AIBN recommends that EASA amends the acceptable means of compliance to the certification specifications for large rotorcraft in order to highlight the importance of different modes of component structural degradation and how these can affect crack initiation and propagation and fatigue life.

SL No. 2018/04T

The AIBN recommends that EASA revises the certification specifications for large rotorcraft to introduce requirements for main gearbox chip detection system performance.

SL No. 2018/05T

The AIBN recommends that EASA develops main gearbox certification specifications for large rotorcraft to introduce a design requirement that no failure of internal main gearbox components should lead to a catastrophic failure.

SL No. 2018/06T

The AIBN recommends that EASA develops regulations for engine and helicopter operational reliability systems that could be applied to helicopters that perform offshore and similar operations to improve safety outcomes.

SL No. 2018/07T

The AIBN recommends that EASA makes sure that helicopter manufacturers review their continuing airworthiness program to ensure that critical components found to be beyond serviceable limits are examined so that the full nature of any damage and its effect on continued airworthiness is understood, either resulting in changes to the maintenance program; design, as necessary; or driving a mitigation plan to prevent or minimize such damage in the future.

SL No. 2018/08T

The AIBN recommends that EASA reviews and improves the existing provisions and procedures applicable to critical parts on helicopters in order to ensure that design assumptions are correct throughout service life.

SL No. 2018/09T

The AIBN recommends that EASA researches methods for improving the detection of component degradation in helicopter epicyclic planet gear bearings. ◆

ADDRESSING THE RISKS OF ERRONEOUS DATA ENTRIES

By Florent Duru and David Nouvel, BEA

The safety issue related to the use of erroneous parameters at takeoff has been addressed these past years by a number of safety investigation authorities (SIAs). This paper is based on an investigation that went beyond human error to address systemic factors—in particular, how regulators and industry have endeavored to address these risks.

The investigation also analyzed the handling of previous safety recommendations on the same issue. Such an approach, which takes into account state safety programs (SSPs) and safety management systems (SMSs), also aims to provide more convincing safety recommendations, as laid out in the BEA's strategic plan for 2018–2022.

The F-GUOC serious incident

A serious incident occurred during takeoff from Paris' Charles de Gaulle Airport on May 22, 2015, and involved the B-777-F registered F-GUOC and operated by Air France. The captain (PM), the copilot (PF), and two relief copilots were on board for this commercial air transport (CAT) operation (cargo) to Mexico.

The B-777 took off at low speed (see Figure 1), and the tail strike protection of the airplane was activated. The aircraft did not gain altitude. The crew then applied full thrust (TOGA). The airplane flew over the opposite threshold at a height of approximately 170 feet and continued to climb. During the climb, the crewmembers discussed the causes of the incident and realized they had made a mistake of 100 tonnes in the weight used to calculate the takeoff performance parameters. The crewmembers continued their flight to the destination without any further incident.

Erroneous data entry during flight preparation

After deciding on an extra fuel load, both the captain (PM) and the copilot (PF) tried to anticipate the new takeoff weights and made some calculations. Both entered the same erroneous weight in their respective electronic flight bag (EFB) performance tool, off by 100 tonnes from the correct weight. As a result, they departed with highly incorrect takeoff speeds, configuration, and thrust settings. A detailed description of the scenario will be available in the final report.

Effective barriers and associated limitations

Tail strike protection provides a timely elevator input to help avoid tail strikes on takeoff. If the tail strike protection had not been activated during this takeoff, Boeing estimated that there would have been runway contact about one second after the activation of the protection. This was an effective barrier against one of the possible outcomes associated with the use of erroneous parameters at takeoff. However, it does not provide protection against other associated major outcomes such as collision with an obstacle or a high-speed runway excursion.

Moreover, it took the crew eight seconds to opt for TOGA thrust and to apply it. This period seems consistent with the element of surprise, the unknown problem. The application of full thrust is not the sole and obvious solution. Indeed, it can be counterproductive (the risk of tail strike, some cases of engine failure) and therefore cannot be considered a robust barrier.

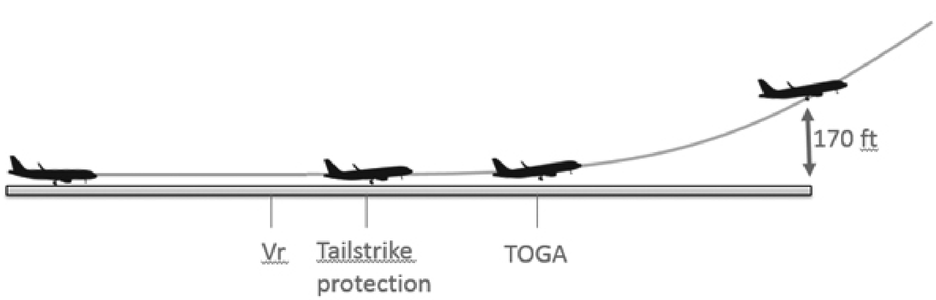

Figure 1

Specific improvements to be undertaken (operator/manufacturer)

Uniformity of weight data handled

The analysis pointed to the variety of weight data formats and denominations handled by the Air France crew during the flight preparation. Homogenization of the data among the media would make it possible to both facilitate simple equality checks and reduce the cognitive load. The goal is to give meaning to the numbers handled in order to allow a better acquisition of the usual values and a more systematic use of orders of magnitude.

The BEA will address a safety recommendation to Air France.

Checking robustness of procedures

Air France, aware of the error-prone nature of the procedures associated with the calculation and entry of takeoff parameters, had initiated an internal working group concerning the use of the EFB performance tool. One of the main objectives of this group was to prevent the use of erroneous parameters at takeoff. The work of this group was not carried through to completion. Following the serious incident, modifications were made, clarifying certain sequences and adding an overall consistency check among the weights of the three media (EFB, final load sheet, and FMS). While these modifications introduce beneficial features, they add further checks to already demanding procedures—the robustness of which must be assessed not only during implementation but also over time.

The BEA will address a safety recommendation that asks Air France to check, in operational conditions, the robustness of the procedures for calculating and entering takeoff parameters in order to take into account the constraints inherent in the flight preparation phase.

Protections against entering erroneous speeds on the B-777

Following the serious incident, the Dutch safety board (DSB) contacted the BEA because it had to investigate two very similar serious incidents involving B-777s in which an error of 100 tonnes was made. The F-GUOC serious incident is the third low-speed takeoff on a B-777 in which flight crews did not detect or understand the "V Speeds Unavailable" FMS message that is triggered when the FMS can no longer compute reference speeds. The message was not sufficiently salient and explicit and can be deleted directly by the crew. Boeing's operational documentation on the calculation of reference speeds and on the conditions in which the V Speeds Unavailable message is activated is incomplete. It does not allow operators to assess the risks and develop robust procedures. The request from operators for Boeing to improve the flight crew operating manual documentation about this message was not followed up. In addition, the aircraft systems do not warn crews of the loss of protection preventing the entry of speeds below V1min, VRmin, and V2min normally calculated by the FMS. In the F-GUOC event, because the system authorized the crew to enter the speed data, the crew thought that takeoff was possible.

The BEA will address two safety recommendations to Boeing to update documentation and to review its alerting systems.

Use of erroneous parameters at takeoff: background overview

Previous safety investigations and safety studies

From 1999 to 2015, more than 30 accidents and serious incidents related to the use of erroneous parameters for takeoff led to safety investigations worldwide. In addition to these case-by-case safety investigations, the BEA (2008), the Australian Transportation Safety Board (2009), and NASA (2012) published safety studies focusing on this issue.

One of the immediate findings of the safety studies was that these incidents and accidents have involved different aircraft manufacturers and different aircraft models operated by various operators around the world. They are equipped with different systems to process takeoff parameters. It was also observed that flight preparation is prone to errors at multiple points and that these errors are frequent but generally detected by the application of standard operating procedures (SOPs) or by individual techniques.

Previous safety investigations and safety studies mainly led to the identification of three areas of concern:

- operational procedures,
- knowledge of orders of magnitude, and
- existing software user interface.

In the scope of these safety investigations and safety studies, SIAs addressed several safety recommendations to certification authorities worldwide; 13 have been listed in the F-GUOC safety investigation report (nonexhaustive list). The listed safety recommendations focused on the following systems:

- Onboard weight and balance systems: two safety recommendations since 2005.
- Gross error detection/warning systems: six safety recommendations since 2006.
- Takeoff performance monitoring systems: three safety recommendations since 2006.
- EFBs: two safety recommendations since 2011.

F-GUOC and historical areas of concerns: converging findings

Regarding the F-GUOC serious incident, the BEA concluded that the following elements may have contributed to the 100 t error not being detected and its propagation:

- the crew's handling of takeoff weight data in numerous formats, on various media, and with various denominations.
- the "nonmobilization" of orders of magnitude partly related to the increasing use of performance optimization tools.
- the number of basic checks required, incompletely taking into account the operational context and how the crew works. These procedures are notably based on an independent double calculation, a simple verbalization undermining this independence. These procedures did not include a means of detecting gross errors or a simultaneous check of the three media using weight data (final load sheet, EFB performance tool, and FMS).

These three elements are in line with the main areas of concern highlighted by previous safety investigations and studies. One of the F-GUOC investigation team members, a human factors specialist who participated in the BEA study in 2008, confirmed this convergence. This is why the BEA decided to steer the focus of the investigation toward why the general situation seems not to have improved.

Risk management by Air France

The risk of an entry error has been the subject of several initiatives by Air France, either continuously or following a significant incident in 2004 on one of the airline's A340s. These initiatives took the form of ad hoc analyses, notably on the basis of incident reports collected via aviation safety reports, the inclusion of the topic in

(Adapted with permission from the authors' technical paper titled Investigating How Regulators and Industry Endeavor to Address the Risks of Erroneous Data Entries *presented during ISASI 2018, Oct. 30–Nov. 1, 2018, in Dubai, the United Arab Emirates. The theme for ISASI 2018 was "The future of Aircraft Accident Investigation." The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Florent Duru

David Nouvel

the training program, the modification of certain operational media, requests for modifications addressed to manufacturers, or internal publications.

When EFB performance tools were introduced from 2009 on the airline's B-777-F (cargo), Air France launched an internal working group and participated in the study conducted by the BEA. Nevertheless, the working group did not continue its discussions because Air France was beginning to use manufacturers' documentation. Air France considered that these documentation changes were making this internal work less relevant.

Flight audits have limited effectiveness in this area due to the focus on compliance. The checks carried out by type rating examiners are not intended to assess the robustness of the reference frames but essentially the crews' performance within these reference frames.

Before the F-GUOC serious incident, Air France had begun exploring two ways of detecting such events through its flight data monitoring (FDM). While an incident such as the one concerning F-GUOC was actually detectable, the system was still not considered effective enough to detect the various data entry errors that can be made. In this initiative, Air France reported not having received the expected assistance from manufacturers.

Systems developed by the aviation industry

The aviation industry is searching for systems to reduce the number of takeoff-related incidents and accidents. These systems are either intended to reduce manual entries, detect input and output errors by built-in crosschecks in takeoff performance–related aircraft systems, or ultimately by monitoring the actual takeoff performance.

The BEA noticed that solutions developed by industry were very heterogeneous. Currently, it depends on the manufacturers' philosophy. Some solutions are optional or provided by third parties, which means that the choice remains with the operator.

This range of approaches will be wider in the future, and this also raises the issue of retrofit.

Onboard weight and balance system

An autonomous onboard weight and balance system (OBWBS) provides pilots with actual weight and balance information. This information may serve as a cross-check (secondary system) or as the source (primary system) for the weight and balance values used in the performance data process.

Airbus and Boeing successfully developed OBWBS. Airbus certified it on the A330/340 in 1993, and a system is currently in use on the B-747-8. However, it is available on a very limited number of aircraft models and leads to operational constraints and additional maintenance costs. Airbus has no plans to develop any new OBWBS.

Automated entries or checks related to aircraft takeoff performance

Airbus developed a takeoff securing function that detects inconsistencies in the parameters entered in the FMS. It includes, in particular, checks and dedicated warnings for the zero fuel weight range, takeoff speed consistency with takeoff weight, trim setting, aircraft position, and takeoff distance.

Boeing implemented different checks and associated alerts in the FMS. Some examples for the B-777 include

- V speed checks (minimum V speed protection, relative V speed check),
- configuration checks,
- an optional feature to uplink FMS data to the EFB in order to reduce manual entries. A comparison feature can warn the crew if the difference between the FMS weight and EFB weight is too great.

Solutions are not limited to aircraft manufacturers. For example, LINTOP (Lufthansa systems) is an on-the-ground remote-performance calculation system that can compare the weight entered in the ACARS page by the crew with the weight used during flight preparation. If the deviation is too high and if the weight entered is lower, the crew is warned (in percentage of difference).

Takeoff performance monitoring system

A takeoff performance monitoring system (TOPMS) monitors the acceleration of the aircraft during takeoff by comparing the performance data entered. The system makes it possible to detect an erroneous takeoff weight, a degraded aircraft performance, or an abnormal contamination on the runway. It provides pilots with associated warnings.

A takeoff monitoring (TOM) system was developed by Airbus in 2015 and certified on the A380 in February 2018. A retrofit on other programs is planned.

To the BEA's knowledge, Boeing did not develop a TOM.

Investigating SMS

Early analysis and decision

On starting the investigation into this new serious incident, the BEA assessed the situation as follows:

- Use of erroneous parameters at takeoff still occurs frequently.
- Outcomes are still potentially catastrophic.
- Safety barriers still consist mainly of SOPs and of the appropriate detection and reaction by crewmembers.
- In this context, the BEA had in mind its own input in this safety issue, as well as the inputs from its counterparts worldwide:
- Previous findings have shown that operational safety barriers are important; however, numerous events and studies have shown that there are occasions where they are not effective.
- For 15 years, SIAs have issued safety recommendations regarding the introduction of technology to prevent and/or detect erroneous parameters.

Based on this initial analysis and on the apparent status quo, the BEA considered the appropriate scope for this new investigation. Carrying out an in-depth analysis of operational deficiencies, assuming that sufficient data is available in the absence of CVR data, could contribute once again to the experience feedback. However, what would the benefits be with regard to the global state of knowledge and to this status quo? Therefore, what would the actual benefit be in terms of risk management?

Naturally, the decision was to focus on "risk-based approaches," in particular at the level of aviation authorities. In the scope of this paper, the term designates

- Risk management as part of continued airworthiness, especially from the certification authorities' points of view, as they were the addressees of various safety recommendations;
- Safety management as defined by ICAO in Annex 19. In the context of this investigation, it refers to SMSs to be implemented by operators and to SSPs to be implemented by authorities.

Through new protocol questions recently included in its audit program related to Annex 19, ICAO invites SIAs to analyze SMSs and SSPs in the scope of the investigations.

Investigation principles

Like other organizations and authorities, SIAs have limited resources. It is their responsibility to define the scope of their investigations, taking into account this constraint and the lessons that can be drawn for the improvement of aviation safety.

In this context, SSPs and SMSs are one possible line of investigation. The BEA does not systematically explore this line but assesses on a case-by-case basis the relevance of investigating safety management processes. Detailed criteria for this do not exist. Nevertheless, there are situations that raise questions. This is the case, for instance,

- when the type of event is recurrent, potentially catastrophic, and when the remaining safety barriers, if they exist, have a robustness that raises questions.
- when the type of event is potentially catastrophic and, during the investigation, the organizations involved do not seem to demonstrate their ability to manage the risk effectively.

The BEA's overall investigation methodology aims to identify and analyze safety principles that are intended to

- prevent an unsafe situation from appearing,
- ensure recovery from this unsafe situation, or
- mitigate the consequences of the possible subsequent accident.

In this respect, the investigation of SMS is consistent with the BEA's methodology.

The BEA has not developed a formal method to explore risk-based approaches. In any case, an investigation has to adapt to the specific processes implemented by the stakeholders. Bearing in mind the usual steps of a safety management process, the only principle followed by the BEA is to explore the consistency between

- the data available to the safety manager/analyst,
- their implicit reasoning (processing of data),
- their explicit arguments,
- their decisions, and
- their actions.

In doing so, the BEA pays particular attention to avoid the following two biases:

- To limit its analysis to the observation that risk management failed. Even if the assertion is exact, it could be considered the expression of a retrospective bias.
- To express a disagreement with a managerial decision based on a value judgment only (e.g., regarding the acceptability and hierarchy of risks, choice of mitigation measures, etc.). SIAs should understand and accept that decisions are the responsibility of safety managers (within competent authorities, operators, etc.). Inputs from SIAs are limited to risk analysis.

Management of this safety issue by aviation until the F-GUOC incident

As mentioned, in the scope of previous safety investigations and safety studies, SIAs addressed several safety recommendations to certification authorities worldwide. Among the listed safety recommendations, two concerned OBWBS, six concerned gross error detection/warning systems, three concerned TOPMS, and two concerned EFB.

EFB—EASA's work on EFBs resulted in the publication of Acceptable Means of Compliance (AMC) 20-25 in 2014, providing guidance material (risk assessment, main principles regarding the interface design or SOPs, testing program, etc.) to operators for their use prior to their implementation or any changes. At the time of the F-GUOC serious incident, Air France had not had the opportunity to refer to AMC 20-25 for its B-777 fleet, since no change was scheduled or being conducted regarding the use of EFBs.

Even if relevant with regard to the failures highlighted by the F-GUOC serious incident, AMC 20-25 puts the ball in the operator's court. Previous safety investigations and studies have already demonstrated that because of organizational and operational contingencies, operators cannot completely manage the risk alone. Incomplete and ineffective initiatives by Air France before the serious incident are one example. This meant that the BEA had to pay particular attention to what had been undertaken (designed, developed, certified, standardized, or implemented) with respect to aircraft systems.

OBWBS—A working group was initiated in 2010 by EASA under the auspices of the European Organization for Civil Aviation Equipment (EUROCAE). Past initiatives by manufacturers were reviewed by this group. In 2013, the working group stated that it was in favor of standardizing such a system. It was only at the end of 2015, after the serious incident involving F-GUOC, that the group was reactivated with the new mandate to define minimum operational performance standards. In the meantime, EASA left the chairmanship of the group to the industry, thus accepting that it would be less able to control actions and timelines.

Gross error detection/warning systems—In 2009, in response to safety recommendations from the U.S. National Transportation Safety Board, the U.S. Federal Aviation Administration (FAA) released acceptable means of compliance applicable to new airworthiness approvals of FMS, including warning systems intended to detect grossly erroneous parameters. However, the FAA decided not to extend them to existing FMSs, considering that operators' policies (e.g., including normal cross-check procedures) were sufficient barriers. For its part, EASA did not conduct a review of these systems as the agency had suggested it would do in 2011, following the BEA's recommendation issued in 2008. However, gradually various aircraft and equipment manufacturers, based on different approaches, have developed systems to deal with gross errors. As with the serious incidents involving the F-GUOC and two similar incidents identified by the DSB, several accidents and serious incidents among those identified by EASA resulted from entering clearly erroneous parameters into the FMS, which such systems could have detected and brought more clearly to the attention of the crews.

TOPMS—From 2006 onward, Transport Canada (TC), in response to a safety recommendation issued by the Transportation Safety Board of Canada, has indicated that there was not any suitable system to monitor takeoff performance. It has also stated that the industry was the best placed to take the lead in developing a TOPMS. The research project established by the TC in 2007 came to a standstill in 2009 due to the lack of appropriate funding. In 2012, in response to a safety recommendation issued by the BEA, EASA initiated a dedicated working group under the auspices of EUROCAE. The group concluded in 2015 that standardization was not possible. Despite that conclusion, it should be noted that in parallel Airbus started to develop its own TOM system, which meets certain TOPMS criteria.

Summary of management of this safety issue until the F-GUOC serious incident

The overall approach of the civil aviation authorities regarding the previously mentioned systems has been to let the industry decide on both the development and certification of advanced systems and to decide whether to standardize. The authorities did not closely monitor the progress made by the industry regarding design features to better protect against risks associated with erroneous takeoff parameters. This did not allow these authorities to

- influence the timing of the standardization activity, as evidenced by the recent postponements of the conclusions regarding the possibility to standardize OBWBS.
- encourage the introduction of the most effective features, in particular the retrofit of aircraft systems (e.g., to make the improved warning of the B-787 available to the B-777).
- detect that the state of the art had become favorable to the development of new and relevant systems (e.g., sufficiently mastered technology enabling Airbus to communicate on the TOM system in 2015).

Work conducted by major aviation authorities, particularly through their handling of safety recommendations, did not lead to the F-GUOC being equipped with sufficiently reliable systems to prevent the use of erroneous parameters at takeoff. The industry had progressively developed more effective systems than those on the F-GUOC, but authorities either seemed to ignore these developments or did not consider how their use could be extended and what their own role could be in this respect.

Since 2015: safety management by EASA related to erroneous data entry

Authorities in charge of rulemaking, certification, and continued airworthiness, as well as safety oversight in other domains, have started implementing ICAO Annex 19 requirements regarding safety management, in particular those related to SSPs. EASA has recently designed and implemented a new process called safety risk management (SRM). EASA has also restructured to organize its activities (certification and operational standards) on this risk-based approach.

The use of erroneous parameters at takeoff was one of the first safety issues processed through the SRM process; analysis started two months before the serious incident. EASA continued its work in parallel with the investigation performed by the BEA. Some of the documents were provided to the BEA during the investigation. EASA issued specific cautions regarding their reading, noting that

- the documents provided to the BEA are draft versions; they were not shared with advisory bodies and could not be considered as officially validated.
- the SRM process is ongoing; findings should not be considered definitive.
- the whole process is still in development. As an example, data sources for risk monitoring and assessment are not consolidated. Therefore, quantitative results have to be considered carefully.

Nevertheless, the conclusions and findings of this work were directly used to define EASA's action plan on this topic.

The SRM process designed by EASA includes five steps: risk identification, risk assessment, determination of safety actions, implementation of safety actions, and risk monitoring.

In March 2015, EASA initiated a review and assessment of the safety issue relating to the use of erroneous parameters at takeoff. It considered 31 investigation reports and several safety studies issued since 1999. Among the 31 events during CAT operations that were listed in this review, there were three fatal accidents (outside EASA member states).

Based on these occurrences, EASA stated that the risk level associated with this safety issue was "secure" (level 6 out of 10), which corresponded to the following definition according to the Aviation Risk Management Solutions (ARMS) Working Group methodology: "The risk level and its trend needs to be monitored continuously…in order to prevent escalation to an unacceptable level. Reinforcement of existing measures should be discussed at the next convenient opportunity…and taking further reduction measures should be considered."

Moreover, the fact that serious incidents and accidents continue to occur almost every year means, according to EASA, that the current risk barriers are inadequate and insufficient.

However, the largest number (five) of new actions listed by EASA concerned barriers to be managed by operators. Regarding aircraft systems, the list includes the continuation of work on OBWBS and the acknowledgement that work on TOPMS had come to a standstill. EASA also suggests that manufacturers should improve their FMSs to make them more sensitive to erroneous parameters inputs and calculated data, compared to current gross error checks.

Preliminary impact assessment

Preliminary impact assessments (PIAs) are new activities that evaluate the impact of actions envisaged by EASA in terms of cost efficiency and implementation time criteria. The PIA carried out by EASA in 2016 regarding the use of erroneous parameters at takeoff was the first one that it had ever conducted. It was in line with the safety analysis conducted in 2015. The updated version provided to the BEA in 2018 was still in draft form.

The objective claimed by the agency at the beginning of the document was to reduce the severity level of the risk from "secure" to "monitor" ("monitor throughout the routine database analysis" according to ARMS methodology).

Three actions were listed.

- Action 1: publication of a safety information bulletin (SIB) on the "use of erroneous parameters at takeoff."
- Action 2: OBWBS EUROCAE Working Group 88—on board weight and balance system.
- Action 3: EASA Rulemaking Task (RMT) .0601—improve the use of EFB with the updated provisions of AMC 20-25.
- To assess the safety benefit of the SIB (Action 1), a survey was conducted by EASA between October and December 2015. Eighty-six operators answered this survey, reporting 128 occurrences during the 2010–2014 period. These operators were divided into three categories:
- Category 1: operators without FDM.
- Category 2: operators with FDM but without criteria related to this issue.
- Category 3: operators with FDM and adapted criteria to this issue.

Based on the comparison between operators in Categories 2 and 3, EASA concluded that an operator could reduce the number of incidents of this nature by at least 70 percent with an adequate FDM system. Data collected through this first survey was considered not sufficiently reliable by EASA to complete the comparison. The BEA agrees with EASA on the difficulty of estimating safety benefits based on such a dataset. However, the BEA believes that this incomplete reasoning may have led to an overestimation of the overall safety benefit of the SIB. Indeed, the data collected through the survey indicates that many operators estimate they already have an adequate FDM system and that their contribution to the total number of commercial flights is 80 percent. As a result, based on this data the overall benefit for the SIB would be 14 percent. Even if not accurate, this is an order of magnitude that questions the impact of measures to be implemented by operators, and EASA should take this into account. In comparison, EASA estimated the safety benefit of the OBWBS at 50 percent.

On a scale of 0 (low) to 10 (very high), the cost of publishing the SIB was assessed at 3, and the implementation time was assessed to be two years. EASA could not assess the cost and the time for the implementation of OBWBS because these parameters depend on the results of the EUROCAE working group, which was still preparing the specifications at the date of publishing the investigation report. The timing of the associated RMT.0116 has been revised (postponed) several times in recent years.

The third action (EFB) was not assessed in the first versions of the PIA.

EASA has temporarily concluded that the SIB to alert operators and flight crew of operational mitigation measures would be the most cost-effective measure. In the event that it does not lead to the expected outcome (following a monitoring assessment), the regulatory action on the development of specifications for the OBWBS could be the second-preferred option, once the EUROCAE working group has confirmed the feasibility of such specifications.

Based on this action plan, EASA estimated that the remaining risk would be at the "monitor" level.

EASA published the SIB "use of erroneous parameters at takeoff" on Feb. 16, 2016. The objective of the SIB was to increase the awareness of operators and competent authorities with respect to the safety issue of using erroneous parameters at takeoff and to manage this safety issue. EASA recalled that among the risk mitigation measures that can be implemented are systems such as OBWBS or systems to detect gross errors in the values entered. It has to be noted that the development and the availability of these systems is not the responsibility of the operators to which the SIB is addressed. Nevertheless, this is a first step to promote technology, and it would benefit from more details about products available for each aircraft type.

European Risk Classification Scheme

More recently, this safety issue (use of erroneous parameters at takeoff) was assessed by EASA through the European Risk Classification Scheme (ERCS). According to this work, the "entry of aircraft performance data" is not a priority as it is ranked as the 23rd safety issue. It is not up to the BEA to challenge the prioritization of risks. However, the BEA in its safety study released in 2008, other SIAs, and EASA have already pointed out the fragility of operational barriers against errors that occur frequently and that could have catastrophic outcomes. The F-GUOC serious incident is an additional confirmation. The ERCS score is based on these three criteria. In the future, in order to convince aviation stakeholders, EASA could describe its methodology to both assess individual occurrences and to aggregate each occurrence assessment to arrive at a global score for a safety issue.

Certification of the Airbus-designed TOM system for the A380

As noted, the TOM system was certified by EASA for the A380 in February 2018. Regarding this improvement, EASA explained that

- since the risk level does not reflect an "unsafe condition" as defined in AMC 21.A.3B(b) related to Regulation (EU) No. 748/2012, such a system could not be made mandatory (i.e., by an airworthiness directive).
- calling for a standardization directly based on this existing product is impossible since it would create a competitive advantage to one manufacturer detrimental to the market.
- organizing the promotion of this newly certified system had not yet been considered.

This tricky situation highlights the need for aviation authorities to closely monitor the early progress made by industry so that they preserve the maximum number of possible levers. As a last recourse, the promotion of aircraft systems related to identified safety issues has to be systematized.

Summary of postserious incident safety management by EASA

The BEA fully understands that aviation authorities and the industry set priorities, even and especially when it comes to dealing with safety issues. In this, the above observations must be considered with reference to the priority level of this particular safety (No. 23 in the CAT airlines portfolio).

However, overestimating the capacity of operators and crews to preclude gross parameter errors by relying only on procedural barriers could compromise the assessment of the priority level of this risk, the intended safety benefit for the SIB, and therefore the consistency of the action plan. For these reasons, it could be reasonable not to wait for the SIB performance monitoring and for the unknown future conclusions of the EUROCAE working group regarding OBWBS prior to drawing up a wider action plan. In this respect, it would be necessary to assess the potential benefits of the different technologies among those available or to come. Then an informed decision could be made in coordination with each type certificate holder regarding the most appropriate technology(ies) for the types of aircraft. In this respect, the BEA will address several safety recommendations to EASA to be coordinated appropriately with the FAA and other certification authorities.

Conclusion

By focusing on and investigating the safety management performed by aviation authorities, the intention of the BEA was not to lead to a situation in which there was less commitment from crews and operators. The immediate conclusions of the investigation refer to human errors and to the poor effectiveness of the operator's SOPs. New systems (standardized or not) should be considered as complementary safety barriers only, meaning that efforts have to be made locally to improve safety. However, the F-GUOC serious incident again highlights that flight preparation is prone to errors at multiple points and that the operators should not be considered as able to manage the risk completely alone.

(Continued on page 30)

ISASI Kapustin Scholarship Essay

The following article is the third of four essays from the 2018 Kapustin scholarship winners. The number of scholars selected each year depends upon the amount of money ISASI members donate annually to the scholarship fund. Details about scholarship applications and additional information can be found on the ISASI website at www.isasi.org. Application and essay deadlines are mid-April of each year.—Editor

OFF THE ACCIDENT SITE AND INTO THE HANGAR:

INCIDENT INVESTIGATION USING STRUCTURAL HEALTH

By Katrina Ertman
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Improvements in aviation safety arise mainly from two places: preaccident and postaccident. Postaccident—the air safety investigation—examines the sequence of events that led to an accident. The recommendations that emerge are invaluable to aviation safety. Preaccident—namely regulators, operators, maintenance, and manufacturers—strives to improve how to detect and repair flaws. The procedures developed keep aircraft airworthy and safer for longer.

Thanks to decades of improvements in both areas, commercial aviation accidents and incidents have decreased steadily. This begs the question: What comes next for air safety investigation? Incidents still occur daily, but there is usually little investigation into their circumstances. Yet these incidents present an opportunity to investigate why they happen, why they did not develop into an accident, and what could be done in the future to prevent them. In the case of nonaccident structural faults, a promising technology emerging from the preaccident realm, continuous structural health monitoring (SHM), could assist in preventing future occurrences.

Katrina Ertman

SHM: the new big data

The declining number of commercial aviation accidents and incidents lends itself not only to air safety investigations, but also to developments in ensuring continued airworthiness during an aircraft's lifetime. The aviation industry has come a long way from the days of safe life and fail safe maintenance philosophies, an era that generally neglected in-service ageing effects and contributed to a number of accidents, such as those involving the de Havilland Comet.[1] In 1988, following Aloha Airlines Flight 243, there was a shift toward modern, damage-tolerant maintenance procedures.[2] Current methods revolve around the nondestructive inspection (NDI) of structures at specified intervals.[13] The future of aviation will see the utilization of big data to further our knowledge and propel the industry forward, evidenced by the theme of the American Institute of Aeronautics and Astronautics (AIAA) SciTech Forum in January 2018, "Seizing the Next Digital Transformation."[14] This future will unquestionably include the integration of continuous SHM into aircraft.

The rapid development of SHM is a key research area for aviation safety and provides numerous benefits. From a damage perspective, it can offer early detection of small cracks and flaws, pinpointing of damage initiation sites, and eventually multiple-site damage detection and monitoring.[3] Not only is damage detection possible, but also the collecting of information regarding loads and the operating environment.[4] Combined with flight data, a more representative picture of an aircraft's lifetime can be established. Over this lifetime, this information has the potential to assist in establishing patterns and connecting the dots.

Already, advancements in SHM have shown promising results. In 2009, Airbus outfitted an A380 with surface-bonded and sandwiched SHM sensors for conducting full-scale fatigue tests.[3] Extensive academic research into sensing systems, including acoustic-ultrasonics, fiber bragg grating, and comparative vacuum monitoring (CVM), continues to push the field forward.[4,5] In 2017, a pilot program involving Boeing, Delta Air Lines, and Sandia National Labs began in-service validation of CVM.[6] In conjunction, the Federal Aviation Administration (FAA) began conducting a study into the development and implementation of SHM certification.[6] Future research will undoubtedly see the refinement of these systems and their eventual use in daily operations. Neglecting this development would be a missed opportunity for air safety investigations.

The changing face of air safety i nvestigations

Air safety investigation is not a static field. Every incident and accident presents new challenges, and more knowledge is gained on how to improve investigations. More comprehensive investigations, better recommendations, and increased collaboration between involved parties[7] have been critical to the decline of commercial aviation fatalities in recent years. However, the focus of air safety investigations has historically centered on postaccident analysis. This reveals the paradox of air safety investigation: investigations improve and aviation safety improves; therefore, fewer accident investigations are necessary. With no signs of this trend stopping, how can air safety investigations continue to contribute positively to aviation safety? In short, the postaccident analysis model as a standalone is unsustainable and demands a shift in focus.

Nothing ever occurs in isolation. A major accident is hardly ever a single-component failure or crew oversight, but rather the disastrous combination of multiple factors. In a postaccident investigation, it may be virtually impossible to determine every contributing factor. Given only the information from an accident site, flight recorder data, various records, and witness statements, the investigation seeks out probable cause and makes recommendations, highlighting the most safety-critical factors. Changes arising from investigations help to prevent the accident with a similar chain of events, but not the one with a different failure path. This is where taking a proactive approach is critical, by looking at incidents and collecting and analyzing relevant data over long periods of time.

Aviation incidents, nonaccident events that affect the safety of operations,[7] still occur on a daily basis. These incidents are reported, but unless they fall under the category of "serious incident," they are very rarely given a second look. Even reporting agencies give little attention to incidents. It is not difficult to find information about the number of accidents and fatalities in commercial aviation. Yet incident statistics are not so easily obtainable. But planes do not fly in a vacuum. An incident could easily become an accident under the right circumstances. Therefore, it is critical to understand why these incidents occur, why they did not become accidents, and subsequently recommend changes. Some organizations have already begun this process. For instance, the Australian Transport Safety Bureau (ATSB) developed the Systemic Integrated Analysis Model (SIAM),[8] and the FAA collects and analyzes information with the Aviation Safety Information Analysis and Sharing (ASIAS) system.[9]

The Future Air Safety Team (FAST), a collaborative group of various aviation professionals, works to establish areas of change (AOC) within the aviation industry.[10] One such AOC identifies the "increased need to monitor incident and accident precursor trends," pointing to the development of programs such as ASIAS. They caution, however, that while these systems can help build knowledge about what happened, identification of why things happened may be more difficult.[11] Knowing "why" could be the difference between an incident and an accident. This requires the acquisition of data and information that can help identify why.

SHM and air safety investigations: a way forward

In the not-so-distant future, commercial aircraft will be host to thousands of onboard sensors, providing detailed information about the state of the airframe, engines, hydraulic systems, and observed loads. Though the focus has remained squarely on the impact for maintenance and operations, safety boards should be equally invested in SHM's development.

The future of air safety investigation will see safety boards taking on a more proactive role in aviation safety in the absence of accident data points. Without this change, a vital component of aviation safety will be lost. ASIAS and SIAM are already leading the way, providing a framework for establishing trends and finding links between various incidents. And while general trends can already be established, continuous SHM data can provide a more in-depth view of the exact state of an aircraft up to and during an incident. This will help fill in the gaps, and from here air safety investigators can establish patterns, searching for both commonalties and abnormalities.

Parallel to incident investigation, the incorporation of long-term SHM data analysis into air safety investigations provides a unique opportunity to study the health of composite structures over their lifetime. Though composite materials are now being increasingly used in aviation, there is still uncertainty about their behavior after several years in service.[12] SHM integration could offer insightful information about the continued airworthiness of composite-based aircraft and recognize trends that could potentially be disastrous in the future.

Despite these immense benefits, this combination is not without its potential pitfalls. An influx of data, particularly quantitative data, can be a comforting presence. However, it will be critical to exercise caution and not rely exclusively on analytical systems. A good investigation begins with good investigators. Additionally, a new collaboration between aviation safety specialists, SHM experts, and big data analysts must be established. With this, it will be critical for all parties to understand the issues and limitations of each other's fields. It will also be important to acknowledge that, while a vast amount of information will be available, monitoring every square millimeter of structure is virtually impossible. This links with an overreliance on data sans a human presence. Continuous SHM data will provide another set of data points, some helpful, some not. It is the job of investigators to take this information and use it as one of many tools rather than a silver bullet.

Conclusion

Though the full integration of continuous SHM into commercial aviation is still several years away, that does not mean safety boards should be standby. To be able to take full advantage of SHM in air safety investigations, a platform must be ready. This will mean strengthening existing programs by ensuring they are prepared to handle this type of data, stimulating the development of incident investigation programs, and working to further this collaboration not only among safety boards, but also with regulators, operators, and data specialists.

The declining number of major commercial aviation accidents presents the field of air safety investigation an incredible opportunity. One could choose to continue as normal or to consider what will be important in the future. The future of air safety investigation will depend on investigating nonaccident events and monitoring trends in order to continue contributing positively to aviation safety. To do this, SHM must be an integral part of that future. ◆

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SERVICE PROVIDER INVESTIGATIONS: NEW OPPORTUNITIES

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(Adapted with permission from the authors' technical paper titled Investigating Service Provider Investigations: New Opportunities *presented during ISASI 2018, Oct. 30–Nov. 1, 2018, in Dubai, the United Arab Emirates. The theme for ISASI 2018 was "The future of Aircraft Accident Investigation." The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Note: The views, thoughts. and opinions expressed in this paper are those of the authors and may not necessarily reflect the policy or position of the Qantas Group, the Australian Transport Safety Bureau, or other entities.

Approximately 4.1 billion travelers flew safely on 41.8 million flights in 2017. The rate for major jet accidents—measured in jet hull losses per 1 million flights—was 0.11, which is the equivalent of one major accident for every 8.7 million flights. There were no fatal accidents of International Air Transport Association (IATA) member airlines in 2017.

"The top-line safety figures for 2017 convey a persuasive message about our industry: flying is safe. The reasons are simple. There were no passenger fatalities on jet transport aircraft last year."

—Gilberto Lopez Meyer, Senior Vice President Safety and Flight Operations, IATA.

The 2017 International Civil Aviation Organization (ICAO) safety report identifies that accident statistics for the last five years show a decrease in both the number of accidents as well as the accident rate. In 2016, the downward trend in the number of accidents continued with an 18 percent decrease from 2015. Over the same period, there was an increase in scheduled commercial departures. The result is a global accident rate of 2.1 accidents per million departures—down by 25 percent from 2015. ICAO's stated aspiration safety goal is "zero fatalities worldwide." This objective now seems possible if the trend persists.

"We cannot and shall not pat ourselves on the back and say, 'job done' because, of course, it is not."*—Stephen Hough, Chairman, Accident Classification Technical Group, IATA*

These improvements in safety performance were made possible by the prodigious efforts of professionals throughout our industry, notably including accident and incident investigators. The predominately downward trend in accidents (although acknowledging the events of 2018) conceivably provides us with an opportunity to reconsider the role of state accident investigation authorities and their investigators. This paper will propose that they are well situated to play a major role in the continued progression of the safety performance of the state by leveraging their vast knowledge of safety investigation to empower industry safety efforts. This may enable a move from reactively responding to accidents and serious incidents to one of cooperatively skilling and supporting service providers to address incidents and safety issues with more robust insight, therefore diminishing the opportunities for escalation of occurrences.

High-level guidance—GASP

ICAO Doc. 10004 Global Aviation Safety Plan (GASP) 2017–19 established a strategy for prioritization and continuous improvement of global aviation safety. The GASP and the Global Aviation Navigation Plan (GANP) promote coordination and collaboration among international, regional, and national initiatives aimed at delivering a harmonized, safe, and efficient international civil aviation system.

The GASP "objectives" call for states to put in place robust and sustainable safety oversight systems and to progressively evolve them into more sophisticated means of managing safety. These objectives align with ICAO's requirements for the implementation of a state safety program (SSP) by states and safety management systems (SMS) by service providers. The objectives are set in the context of growing passenger and cargo movements worldwide and the need to address efficiency and environmental challenges.

The GASP sanctions states to make safety improvements through four "safety performance enablers":

- standardization,
- resources,
- collaboration, and
- safety information exchange.

A global "aviation safety road map" has also been developed to provide guidance to assist the entire aviation community to ensure that safety initiatives deliver the intended benefits associated with the objectives in a coordinated manner, thus reducing inconsistencies and duplication of effort.

To contextualize these safety endeavors, the GASP requests that regions and states establish regional and national "safety plans." The national safety plans should include goals and targets that are consistent with the regional safety plan, aligned with the GASP objectives, and based on the nation's operational safety needs.

Further, the GASP requires SSPs to implement a risk-based approach to achieve an "acceptable level of safety performance." The acceptable level of safety performance is defined as "the minimum level of safety performance of civil aviation in a state, as defined in its state safety program, or of a service provider, as defined in its safety management system, expressed in terms of safety performance targets and safety performance indicators." The GASP advocates that international organizations work with their members to help develop their safety performance indicators (SPIs) and provide guidance material and training to assist with addressing global safety priorities and SMS implementation. To ensure congruence between SSP and SMS indicators, states are urged to actively engage service providers in the development of SMS SPIs.

In this context, the role of the state evolves to include the establishment and achievement of safety performance targets as well as effective oversight of its service providers' SMS. Collaborative efforts between key stakeholders, including service providers and regulatory authorities, are essential to the achievement of safety performance targets. Coordination of safety management activities between states, as well as across all operational domains, is essential. Some of the key aviation stakeholders include, but are not limited to, ICAO, states, regional accident and incident investigation organizations, industry representatives, air navigation service providers, operators, aerodromes, manufacturers, and maintenance organizations.

Management of safety—Annex 19

ICAO Annex 19 supports the continued evolution of a proactive strategy to improve safety performance. The foundation of this proactive safety strategy is based on the implementation of an SSP that systematically addresses safety risks. This requirement provides the regulatory authority to the GASP intent.

The SSP applies to all relevant state authorities or agencies. Annex 19 notes that "relevant authorities or agencies" is used in a generic sense to include all authorities with aviation safety management and oversight responsibility that may be established by states as separate entities, such as civil aviation authorities, airport authorities, air traffic services (ATS) authorities, accident investigation authorities, and meteorological authorities.

Specifically, SSPs—including accident investigation authorities—have a role in the creation of a safety program, establishing safety performance indicators and safety performance targets and working together with industry to identify harmonized safety metrics that will enable sharing and exchange and safety analysis to identify and mitigate safety risks. All of this is done with the expressed aim of improving the safety performance of the state.

Annex 19 also heeds that the purpose of the safety data and safety information analysis performed by the state is to identify systemic and cross-cutting hazards that might not otherwise be identified by the safety data analysis processes of individual service providers and operators.

Hazard identification—Annex 19

It is clear what the state's responsibilities are with regard to safety performance, but what about service providers? In relation to safety management, Annex 19 uses the term "service provider" to refer to a very specific range of organizations (listed in its Chapter 3) that are required to implement and employ SMSs to mitigate safety risks.

These organizations include, but are not limited to, the following:

- certified operators of airplanes or helicopters in accordance with Annex 6,
- operators of a certified aerodrome, in accordance with Annex 14, and
- ATS providers, in accordance with Annex 11.

It is notable that ICAO Doc. 9859 Safety Management Manual (SMM), which provides guidance to Annex 19, uses the term service provider more broadly to refer to an aviation industry organization implementing SMSs, whether on a mandatory or voluntary basis.

Annex 19 requires service providers to develop and maintain a process that ensures analysis, assessment, and control of the safety risks associated with identified hazards. It requires that service providers conduct hazard identification that is based on a combination of reactive and proactive methods. The SMM notes that there are a variety of methods for hazard identification—one of these being the results of internal safety investigations.

Some conditions that may merit more detailed investigation by the service provider include

- Reactively: When the organization experiences an unexplained increase in aviation safety-related events or regulatory noncompliance or
- Proactively: When there are significant changes to the organization or its activities (otherwise known as change management).

The SMM states that hazard identification by service provider safety investigations be continuous and part of the service provider's ongoing activities.

State safety data analysis—Annex 19

Annex 19, Chapter 5, requires states to establish safety data collection and processing systems (SDCPS) to capture, store, aggregate, and enable the analysis of safety data and safety information. The objective of the SDCPS is to ensure the continued availability of safety data and safety information in support of safety management activities.

Related to the SDCPS is the requirement for states to establish a mandatory safety reporting system that includes the reporting of incidents and a voluntary safety reporting system for the collection of other safety data and safety information not captured by the mandatory safety reporting system. Annex 19 recommends that state authorities responsible for the implementation of the SSP have access to the SDCPS and specifically notes that this includes accident investigation authorities.

Annex 13 also requires states to establish and maintain an accident and incident database to facilitate the effective analysis of information on actual or potential safety deficiencies and to determine any preventive actions required. Annex 13 points out that the aim of this is to promote accident prevention by collection and analysis of safety data and by a prompt exchange of safety information as part of the SSP. These requirements, as mentioned above, are also included in Annex 19 and, to this effect, are applicable to Annex 13.

The opportunity

State accident investigation authorities have made a significant contribution to the world's improved safety record. Their professional and diligent approach to their discipline provides a model and an inspiration to the whole aviation industry. State accident investigation authorities and individual investigators are highly skilled. They have garnered knowledge and skills from their activities and have much to contribute to continued safety improvement of global aviation as aviation investigation practitioners, educators, and mentors to service provider safety investigators.

State accident investigation authorities' investigations are extremely effective at analyzing actual occurrences, accidents, and serious incidents and disseminating the lessons learned to reduce the likelihood of similar events in the future.

Service provider safety investigations differ in scope and severity, but the intention is the same: to reduce the consequences and/or likelihood of similar negatively impacting occurrences in the future. Service provider safety investigations have the benefit of shorter cycle times. They identify and apply the lessons learned quickly and effectively. The two investigation types have, arguably, equal value. What many service provider safety investigations lack, though, include

- deep skills and experience and exposure to the tools necessary to conduct safety investigations to the same degree of rigor and quality as state safety investigations.
- standardized approaches.
- the authority and the mandate to investigate safety incidents or hazards that transcend organizational boundaries. In many cases, the boundaries themselves (the organizational interfaces) are a significant source of risk.

Consequently, this has provided a significant opportunity to better understand service providers safety investigations and their link to the SSP.

State safety programs and the link to service provider safety investigations

> "As aviation safety professionals, we must keep focus and continue with our work: the promotion of safety first."—*IATA*

State accident investigation authorities are ideally situated to play a major role in the continued progression of the safety performance of the state. This can be achieved by refining the relationship between service providers and state accident investigation authorities and refocusing the role of accident investigation authorities from a largely reactive stance to a proactive one in which state accident investigation authorities and service provider safety investigation teams work more closely to improve the safety performance of each individual service provider and the overall safety performance of the state. State accident investigation authorities have

- privileged access to safety data and information from across all sectors in the state and from other states. This information can be judiciously shared with service provider safety teams to proactively improve their safety performance.
- skilled and competent investigators who are in a position to educate and mentor service provider safety investigators, driving better quality and more sophisticated and more standardized service provider safety investigations.
- cross-sector vision and access contributing to more comprehensive cross-sector investigations addressing hazards within and between sectors.

The service provider's contribution

The maturity and quality of a service provider's SMS and investigations vary across the world—from investigation reports with organizational and root cause analysis that are large in both breadth and depth to assessments examining only the technical aspects of an occurrence to the nonexistent.

Recent industry mergers and acquisitions have forced service providers to consolidate, downsize, or do more with less. This includes safety and investigation personnel. State-run investigations will ultimately provide assurance to the service provider that the traditional safety of flight aspects of an occurrence are thoroughly examined. The service provider, however, can make its own contribution to the improvement of safety through internal investigations in a variety of ways, even with limited resources.

Analysis of areas that are traditionally outside the scope of state-run investigations such as ground operations, workplace health and safety, environment, corporate policy, and culture are valuable in revealing systemic issues that lie dormant within an organization and ultimately lead to safety of flight risks. A quality internal investigation that examines these areas will always be of benefit to the service provider; however, the concept of a joint investigation with the state opens the opportunity to share resources and widen the investigation scope.

The service provider has the advantage of having immediate access to information and evidence, especially perishable evidence, in the initial stages of an investigation. Most investigators would agree that waiting on third parties for relevant data is the source of much frustration. While legislation dictates that formal notices requesting information from a service provider are required, a close working relationship between the parties will result in the state obtaining this information in far shortened time frames. Evidence such as crew rosters, company-owned closed-circuit television footage, manuals, procedures, and access to the crew can all be obtained quickly, resulting in the initial analysis being conducted and risks quickly identified and treated.

Further, Annex 19, Chapter 5, requires states to establish safety data collection and processing systems, providing them access to safety data and information across all sectors. Service providers can contribute their own internal data analysis, trending, and information on similar occurrences outside of state interests, such as ground operations occurrences. If utilized, this data can lead to a more robust analysis resulting in a quality report.

For service providers with limited budgets, the possibility of leveraging the state's technology and resources also exists. Flight data analysis and animations, human factors analysis, and laboratory testing, for example, may not be within the reach of all service providers. The state, however, may have the facilities to process information and in turn reap the benefits from obtaining a broad range of data from the service provider that may not be accessible in current conditions. For this to occur, an environment of trust needs to be well established.

As previously discussed, the state can provide mentorship to less-experienced investigators representing the service provider; however, the service provider can make its own contribution in the form of subject-matter experts to support the state.

Having access to consult with operational staff on internal policies, procedures, and the culture of an organization, outside of formal interviews, is invaluable to any investigator. Such consultation will ultimately result in a better understanding of internal processes and company culture, which in turn will produce a quality report. This knowledge need not be discarded by the state at the end of the investigation, but retained for future investigations for, or preferably with, that service provider.

All of this ultimately points to timeliness and capacity. Hazards uncovered can be treated in a timelier manner due to the service provider's access and proximity to the topics of the investigation. Operational crew can be returned to duty promptly when risks are identified and treated, rather than being withheld from service until an investigation report is released. States can produce their reports quicker and provide more capacity for additional workload. Expeditious action and maximum usage of available resources is essential in minimizing disruption to our ultimate goal of the business of transporting passengers and goods safety.

Teamwork beyond the state and a single service provider

The value of teamwork outside the organization should also be considered through the concept of sharing organizational investigations with competitors. While it is common for service providers to regularly review published reports produced by state-run investigations, airlines in particular have traditionally kept their own internal reports closely guarded for commercial reasons.

Competitor investigation reports relating to commonly used aircraft, airports, contractors, and systems are extremely useful for internal learnings and change, often without the expense of conducting an internal investigation. States can assist this by providing a neutral platform for information sharing.

In recent years, the Qantas Group and Virgin Australia have made the first tentative steps in sharing reports. To date, this has been limited to a noncommercially sensitive severe weather event occurring at a common regional airport with a shared ground handling contractor (Qantas Group 2015) that was outside the scope of the state. Data and draft reports were shared and discussed. The results were consistent findings and actions to address common risks, as well as formation of useful business relationships between safety departments for future events.

Further talks have continued between the two airlines and other operators within Australia on the sharing of information and investigation processes by forming an airline investigation working group. These are small steps but important ones, as the state could benefit from these budding interservice provider relationships by leading joint investigations into similar occurrences with input from not just service providers, but potentially manufacturers, airports, air traffic control organizations, and so on.

Case Study: QantasLink Tail Strike Organizational Investigation

Source: Australian Transport Safety Bureau

The occurrences

On Dec. 5 and 11, 2013, QantasLink, the regional airline for the Qantas Group, experienced two separate Bombardier Dash 8-Q400 (Q400) tail strikes in Brisbane (registration VH-QOT) and Roma (registration VH-QOS) in Queensland, Australia. Both aircraft sustained minor abrasion damage to the underside fuselage and buckling of internal structures in the area of the tail strike sensor. There were no injuries to passengers or crew.

The two occurrences had numerous commonalities, including

1. The pilot flying was a trainee first officer under line training, supervised by a training captain operating as pilot monitoring;
2. The undesired aircraft state that led to the tail strike occurred in the last 50 feet of the landing; and
3. The pilot flying did not adequately manage the engine power levers during the flare, which contributed to the declining energy state—causing them to inadvertently pitch up to control the descent rate, which exceeded maximum pitch angles.

QantasLink immediately launched an internal investigation in response to the first occurrence. Upon being notified of the second occurrence, a decision was made to conduct one in-depth internal investigation to examine possible contributing systemic and organizational factors. This investigation was conducted simultaneously with the state's (Australian Transport Safety Bureau [ATSB]) investigation.

The Qantas Group adheres to a just culture when conducting investigations and inquires. There was a strong focus on organizational factors and how the system let down the crew, rather than punitive action taken against individuals. A just culture recognizes that the majority of human actions that are unsafe are not deliberate. A just culture encourages an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information, but gross negligence, willful violations, and destructive acts are not tolerated.

Limited resources led to the allocation of one lead investigator who was supported by numerous subject-matter experts. The investigation took several months and revealed surprising results that extended well beyond pitch attitudes and aircraft handling skills. This generated significant change within the organization.

The aircraft

Due to the design and length of the fuselage of the Q400, there is a relatively small margin between a normal flare angle and a tail strike angle (AAIB 2017). The aircraft can experience tail contact on landing at pitch attitudes from as low as 6.9 degrees. While the Q400 has a "touched runway" sensor to indicate when tail contact has occurred, it does not have a warning system to alert flightcrew members that they have exceeded a pitch attitude limitation.

Flight data revealed that VH-QOT registered a pitch attitude of 7.5 degrees, and VH-QOS registered a pitch attitude of 8.4 degrees.

Data

The investigation revealed that approximately five months prior to the tail strikes, as part of its regular flight data review process, QantasLink had identified an emerging trend in high-pitch attitudes during landing.

In response, a focused analysis was commenced and remained ongoing at the time of the occurrences. The analysis revealed that the trend directly related to high-pitch attitude landings being conducted by first officers under training. The QantasLink Trainee Program immediately became the main area of focus of the investigation.

QantasLink Training Program

At the time of the occurrences, trainee first officers were required to complete the following training prior to commencing line operations:

- The QantasLink induction program.
- Q400 ground courses, including viewing a Bombardier pitch-awareness video.
- Q400 endorsement program composed of four fixed-base procedural training sessions and 12 full flight simulator training sessions.
- Between 75 and 100 hours of line training on revenue flights under the supervision of a training captain, followed by a check-to-line assessment.

Time frames

Investigation interviews were broadened to include a larger group of trainee first officers to seek feedback on their experience with the training program. Most trainees advised that their simulator and ground training was sporadic due to a combination of simulator unserviceability and rostering. Analysis of trainee rosters supported this assertion, with large gaps between training sessions noted for numerous trainees.

Allowing for days off and rest, endorsement training should typically take between 20 and 30 days to complete (ATSB 2016). The rosters of two trainees involved in the tail strikes revealed their ground school took a total of 50 days and 55 days. Such sporadic training may not provide trainees with adequate opportunity to consolidate and retain newly learned skills (ATSB 2016).

Syllabus and techniques taught

Training at the time included minimal normal landings but did not include any specific training to address the risk of tail strike. The ATSB's investigation identified that "varied emphasis on the appropriate handling technique and pitch attitude awareness during first officer training did not ensure consistent application of an appropriate landing technique in the Dash 8-400 aircraft." Trainees also revealed during interviews that they felt that landing techniques taught varied between training captains both in the simulator and during line training.

In response, QantasLink made numerous changes to its training program, including

- changes to training captain selection criteria and training;
- amendments to training captain proficiency lesson plans to include pitch attitude monitoring, dedicated

- training to raise awareness of potential candidate errors, and intervention/recovery training;
- implementation of a pitch attitude monitoring and landing recovery training session as part of cyclic simulator training and proficiency program; and
- implementation of a new rostering protocol that required additional training events if a first officer's training was disrupted by a period of more than seven days.

Lack of guidance

Bombardier provided landing guidance in its Q400 aircraft operating and flight manuals. Normal landings could be conducted with any combination of Flap 15 or Flap 35 and a propeller revolutions per minute setting of 850 or 1,020. A preferred or optimal landing configuration was not specified. The selected landing configuration was at the discretion of the captain.

At the time of the occurrences, QantasLink did not provide any landing configuration guidance or information in addition to that provided by Bombardier, nor was a preferred or optimal landing configuration specified.

In response, QantasLink communicated and incorporated the following into its operations manuals:

- Additional information and guidance on landing techniques covering the approach, flare, and appropriate use of engine power;
- Cautioning that reducing power to idle close to the ground or in the flare may cause a sudden and unexpected increase in drag, along with a reduction of lift;
- Cautioning that should a higher-than-normal descent rate be experienced during the landing phase, the temptation to control this descent rate by pitching up must be avoided;
- A requirement that all flight crews were to review the Bombardier pitch-awareness video by a set date;
- A reminder to flight crews of the standard pitch-awareness calls and associated actions; and
- Guidance for bounced and skipped landing recovery.

Further, Bombardier reviewed its landing guidance and pitch-awareness video and communicated to all Q400 operators via a Flight Operations Service letter that included the following:

- Reminders of the intent of the pitch-awareness video;
- While some Q400 tail strikes have occurred due to unstable approaches, all Q400 tail strikes occur as a result of not respecting the aircraft flight manual caution of six degrees during the landing flare; and
- Management of the absolute pitch attitude during the landing flare to less than six degrees at touchdown, as well as increasing power to reduce the sink rate, will help flight crews avoid tail strikes.

Analysis revealed that in the 12 months following the introduction of the QantasLink and Bombardier safety measures, the number of high-pitch attitudes during landing reduced significantly. To date, there has not been another tail strike in the QantasLink fleet of Q400s or other Dash 8 variants.

While this case study is a good news story, resulting in underlying risks being identified and treated, potentially the investigation process could have taken a different approach: a meeting of minds and exchange of valuable safety data and expertise. A joint investigation between the service provider (QantasLink), the state (ATSB), and the manufacturer (Bombardier) could have reaped the benefits of additional resourcing and a broader range of expertise, mentoring, and immediate access to data that may have led to a swiftly released joint report with recommendations relevant to all Q400 operators worldwide.

Summary

The GASP objectives call for states to put in place robust and sustainable safety oversight systems and to progressively evolve them into more sophisticated means of managing safety. These objectives align with ICAO's requirements for the implementation of SSPs by states and SMSs by service providers. The GASP suggests that international organizations work with their members to ensure congruence between SSP and SMS indicators. States need to actively engage service providers in the development of SMS SPIs.

In this context, the role of the state is evolving to include the establishment and achievement of safety performance targets as well as effective oversight of its service providers' SMSs, including service provider safety investigations. The ultimate aim is to improve the safety performance of the aviation industry for the betterment of all those in the world who rely on aviation transport services.

The QantasLink case study is an excellent example of how cooperation between states and service providers can work when funds, time, resources, and interest are available to invest. We should take this opportunity to improve safety in states and across the world. It is not about us. It is about the travelers.

Aviation safety has made enormous gains over the past 50 years. Much of the gain can be attributed to accident and incident investigation authorities (AIIAs). We are now faced with an even greater challenge. An athlete will tell you that the last little amount is the hardest to achieve. Everything that has made aviation a successful industry up until now continues to be relevant. We must remain vigilant. In addition, we have to work together to root out the last vestiges of unsafe performance. This will require unprecedented cooperation, adaptability, and focus.

Many state AIIAs have been performing the same important role for decades. To change to a new way of operating will require commitment, implementation planning, agreed-upon targets, and objectives. In some instances, cooperation and assistance will be from other similar bodies or an implementation partner.

The future of aviation safety is bright. The future of all contributors to aviation safety is even brighter. The information age has endowed us with the tools and knowledge to achieve ICAO's vision of no fatalities. We look forward to working together to make the vision a reality. ◆

AIRCRAFT SYSTEMS COMPLEXITY AND SOFTWARE INVESTIGATION

By Paulo Soares Oliveira Filho, Air Safety Investigations Manager, Embraer Air Safety Department

Paulo Soares Olivera Filho

(Adapted with permission from the author's technical paper titled The Growing Level of Aircraft Systems Complexity and Software Investigation *presented during ISASI 2018, Oct. 30–Nov. 1, 2018, in Dubai, the United Arab Emirates. The theme for ISASI 2018 was "The future of Aircraft Accident Investigation." The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Introduction

Aircraft design continues advancing human-machine interface concepts in order to improve safety and facilitate the operation from the flight crew perspective. These advances also provide overall operational performance improvements for airlines. Most of these enhancements are obtained by using highly integrated onboard systems with intense usage of software that controls the majority of functions, including those considered safety critical.

However, improvements for pilots and airlines do not mean an easier life for aeronautical investigators when a deep examination of aircraft internal components and their interfaces is in order. Any factual evidence that could lead to scenarios involving possible system flaws will require a great effort of understanding about how the machine works internally.

At the same time, even for those cases in which no clue of aircraft malfunction is in view, with the objective to analyze aspects of the human-machine interface, investigators possibly will need to verify how information displayed to the pilots is generated and processed. This perspective can also be associated with general and executive aircraft designed or modified to receive a glass cockpit.

Likewise, occurrences involving the automation aspect can require a comparison between the pilot's mental model on how the aircraft functions work and how the machine actually works. Again, we have a situation that calls for an adequate level of comprehension regarding onboard systems.

The NASA study on flight software complexity offers an interesting definition for complexity: "how hard something is to understand or verify…."

In this way, as the complexity of onboard systems grows, the challenge of investigators grows as well.

This paper aims to approach three major aspects:

- The reality of the growing aircraft systems complexity with intense usage of software.
- In the light of constant incoming technologies, the importance to revisit some aircraft systems concepts frequently adopted in the investigation process.
- An invitation for envisioning preparation measures to cope with complexity. In this way, a little contribution is offered on the topic—"a practical approach for investigation on complex aircraft systems." This topic is intended to only be an example of initiative in terms of guidance material and recommended practices that can be written to expand the set of references for investigators.

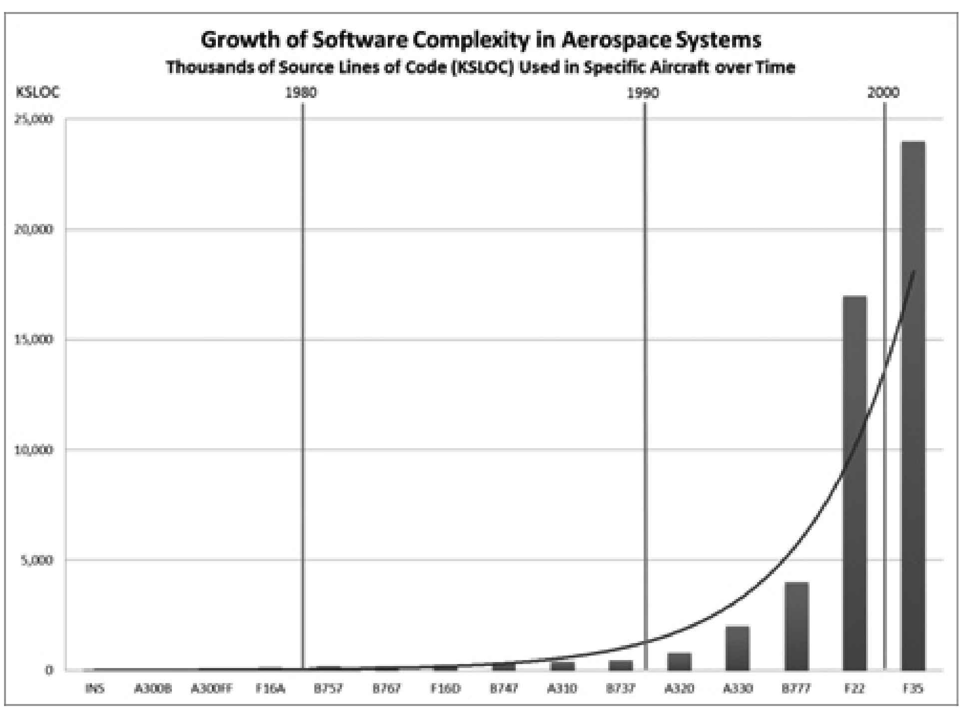
Uncovering hidden complexity

Aviation history has shown an increasing demand for improved onboard functionalities. Among the reasons for this demand, it is possible to list safety enhancements, performance improvements, and security issues. The following text is a good expression of this reality:

"Associated with the enhanced capability afforded by the technology, and as driven by the competitive pressures of the civil transport aircraft market, the functionality of avionics systems has continued to escalate."—Cary R. Spitzer, Editor, *Digital Avionics Handbook*

A direct observation of the cockpit panels on different aircraft generations shows indubitable growth of onboard resources to the pilots. However, this assertion better applies to airplanes preglass cockpit. Since the beginning of the glass cockpit fever, it is not so visually evident the amount of complexity behind the systems not directly associated with the panels. As an example, it is possible to mention the

Figure 1: Growing software complexity in aerospace systems.



functionality called "autobrake," which frequently corresponds to a single switch in the cockpit panels. Of course, the autobrake switch could never give us an idea of how many lines of software code and how many interfaces with other systems are necessary to make this functionality come true.

In short, nowadays the real dimension of complexity growth on modern aircraft is quite hidden inside the onboard computers but pops out whenever deep analysis is required.

Industry discussions about parameters and methods to measure software complexity are in place. For the purpose of this paper, the parameter of software size can help us.

As more onboard system functionalities are progressively being implemented, the size of software, measured in terms of source lines of code, is believed to double every four years. That trend has been observed for at least five decades as seen in Figure 1 (see page 23).

Revisiting (or updating) some relevant concepts

"Interactive complexity" can be understood as more intense interlacement among systems. To safely integrate such systems containing new technologies, the industry and authorities have developed new concepts and occasionally have revised some legacy ones.

As a consequence, investigators need to revisit some definitions to establish a firm foundation to build analysis, conclusions, and effective recommendations.

Updating, or even only revisiting, some legacy concepts and terminologies regarding aircraft systems will allow being better prepared for present and future complex investigations. Certainly, it is not the intent of this presentation to try to identify all of these concepts. Instead, some examples have been selected to be explored here only for illustrative purposes.

Reviewing failure, fault, and error concepts

The classic investigator's initial approach with respect to aircraft systems is to identify the existence of any failure that could be associated with the sequence of events that resulted in the mishap. There is nothing wrong with this mindset; however, a full understanding of the term "failure" (as used by the engineers who designed the aircraft) is in order. Additionally, the term "fault" can possibly be perceived as an equivalent to "failure" by people not involved long term in aircraft design and maintenance. The term failure comes from the pure mechanical systems era, when a function became inoperative or degraded frequently due to some jammed or broken part. In the software era, this term needs to be revisited.

It is worth mentioning that the classic failure concept is not applicable to software as it has no physical properties. Instead, certain software can be found in an undesired condition, which occurs when the specific logic path that contains an error is executed. It means that an error may exist inside software but will never cause any consequence as long as it is not executed by the processor. In this way, the error itself is not an event but a state. However, it has a potential to ultimately cause the associated system to be inoperative or no longer function as intended (according to the specifications).

An attempt to organize a compilation of failure, fault, and error definitions in a simple way can be found in Figure 2.

From the definitions, the term fault can be applied both to software and hardware. Aircraft systems design techniques can be used to detect faults and manage them in order to maintain the system fully functional or partially functional.

The role and challenge of integration

Investigations of highly integrated systems require adequate tools, methods, and the availability of a representative integration laboratory. Most of the times, it is not enough to perform tests/analysis of components separately. Figure 3 illustrates the evolution of avionics architectures and the increase of integration.

High integration means a greater number of interactions among parts, components, and functionalities. During investigations, it is essential to distinguish a system's misbehavior caused by a single component anomaly and those that have root cause in the interactions between components tightly coupled.

Further reflection in these aspects leads us to consider that the investigation effort applied to understand and test the parts separately is required to be equivalent to the effort to understand, analyze, and test the onboard systems as a whole, whenever possible. A further reflection could be to ask ourselves how to investigate interactions inside software. Or even, how to investigate software at all.

Before jumping into the swamp of failures and faults

The strategy proposed is to first apply full effort to understand aircraft systems in normal conditions and after that start to approach occasional faults or failures.

The question here could be what is the

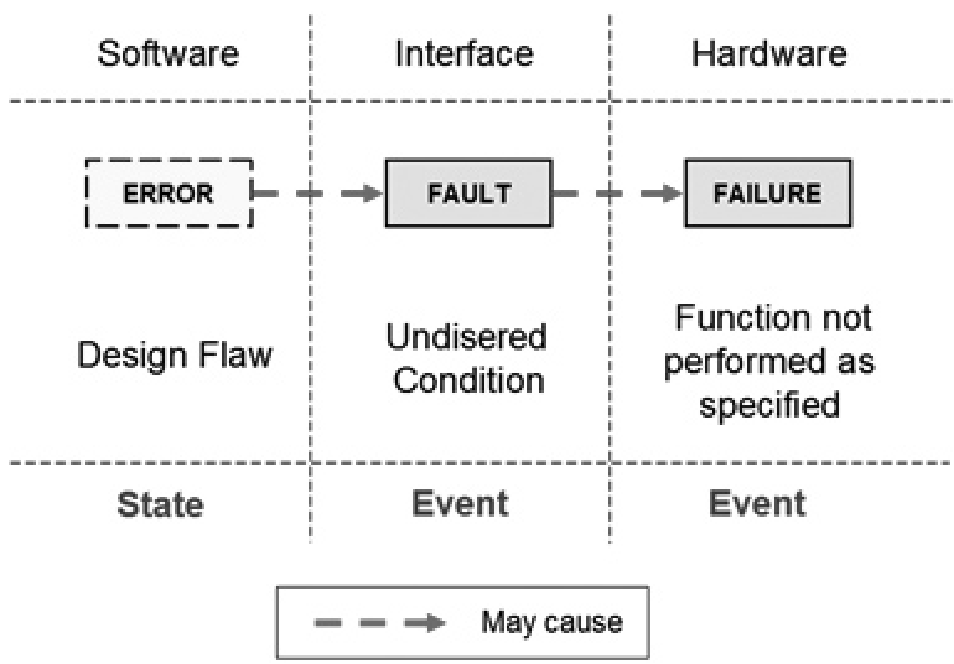


Figure 2. Representation of error, fault, and failure.

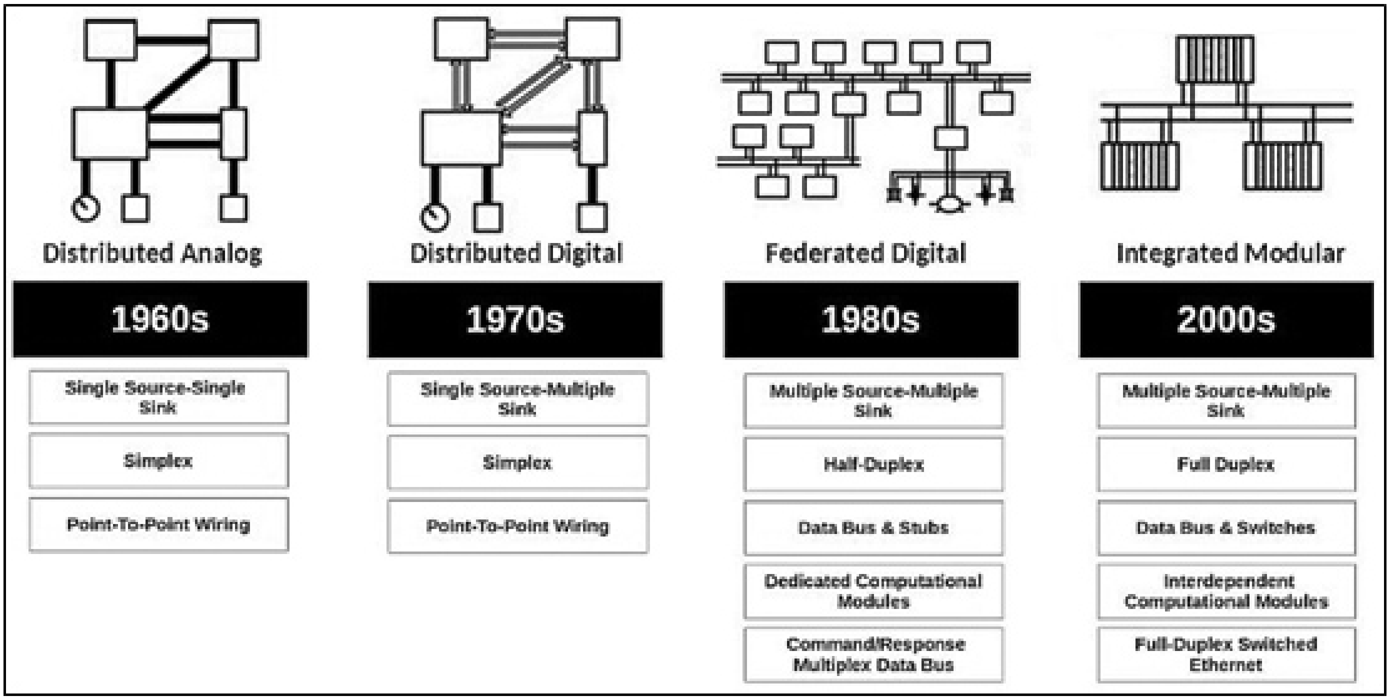


Figure 3: Growing level of integration in avionics architectures.

normal way to operate the system and what is the expected outcome? Normal way refers to the operation of the aircraft in accordance with the approved procedures specified in the manuals. It includes respecting the approved operational aircraft limits/envelope. In this way, the aircraft manuals can be considered an extension of the aircraft.

After all factual information has been collected from the accident site, it can be a big and natural temptation for investigators to focus first on the eventual evidence of failures. However, understanding the system's normal operation first will avoid difficulties, and possible delays, in the effort to discover the failure mechanism.

You can invest some days to understand the normal operation and then some days the failure or jump directly to the failure and eventually spend a month to fully understand how and why the failure occurred, including its surrounding aspects. This is because complex systems include different modes of operations, protections, alerts, fault management strategies, and application of fail-operational/fail-safe concepts that only make sense if seen from the perspective of normal operation and human-machine interface philosophy.

Two U.S. Federal Aviation Administration (FAA) system definitions:

- Fail-operational: A characteristic design that permits continued operation in spite of the occurrence of a discrete malfunction.
- Fail-safe: A characteristic of a system whereby any malfunction affecting the system safety will cause the system to revert to a state that is known to be within acceptable risk parameters.

Software versus hardware

Essentially, software is an organized sequence of instructions to be executed by a processor. Instructions could be defined as ideas on "how to do." Therefore, software is invisible, intangible, and abstract.

As previously mentioned, software has no physical properties, and there are no physical laws underlying software behavior. Therefore, there are no physical constraints on software complexity. You can write a software code as complex as you wish.

These aspects demonstrate that the differences between hardware/mechanical and software cannot be disregarded. Table 1 (see page 26) is a proposal for mapping these main differences based on two books: *Safeware—System Safety* and *Computers and Software Safety and Reliability.*

Hardware/mechanical parts may exhibit progressive malfunctions due to wear but without full interruption of operation. However, since there are no wear-out phenomena, software errors typically occur suddenly without previous clues or warnings.

Unlike hardware, the cause of failures in firmware using embedded software is always systematic, not random.

The system's interaction with the environment

The last line of Table 1 brings us an important aspect that needs to be explored. The hardware of an onboard computer is subjected to different external foreseen threats, as illustrated in Figure 4 (see page 27).

Any engineering measure to protect equipment against adverse external factors will always assume an envelope in terms of maximum and minimum values. Of course, it is impossible to design a component that resists, for example, an infinite high temperature. A certain value certainly needs to be defined by industry and authorities as adequate in terms of an acceptable level of safety.

As the realities of equipment operation under actual environmental conditions are better understood, the engineering mitigation measures for these stresses are constantly being improved. A challenge for the investigator is that some of these threats are not measured or even if they are measured sometimes it is assumed that the value is not recorded. A good example is electromagnetic interference, which can be produced by diverse sourc-

Hardware/Mechanical	Software
Subjected to wear out.	There is no wear out.
Some failures are due to wear, fatigue, overload or manufacturing issues.	The classic concept of failure is not applicable. A "fault" occurs when the logic path that contains an error is executed.
Reliability is time related and can be quantified.	Reliability is not time dependent, and it is difficult to be quantified. Traditional reliability measures don't apply.
Failure rates are somewhat predictable according to known patterns.	It is not consensus that failure rates can be directly associated to software.
Possible inspection or measurement.	It is not possible to perform direct visual inspection.
Preventive maintenance can be applied.	There is no equivalent to preventive maintenance for software.
Subjected to manufacturing variability.	Software can be replicated perfectly.
Hardware interfaces are tangible.	Software interfaces are conceptual.
A hardware or a mechanical device can exist without software.	There is no software without hardware. Pure software is useless; software exists only as part of a system. The software interface with aircraft happens only through the system's hardware.

Table 1: Differences Between Hardware/Mechanical and Software

es, including lightning strikes.

However, as we live in the information age, every day new sources of data become available to the public. In recent years, meteorological science has evolved in such a way that it is possible to obtain real-time lightning maps on the Internet (e.g., www.lightningmaps.org).

New and reliable data sources are becoming available faster than an investigator can be aware. This aspect reinforces the value of sharing information, techniques, tips, and tricks throughout the investigators' community. Additionally, it is essential to also share the assessment of how trusty a certain Internet source is.

A practical approach for investigation of complex aircraft systems

This step-by-step approach must not be considered as definitive or seen as a formal manufacturer procedure, far from it. As mentioned before, it is only a little contribution to illustrate the idea that some additional guidance material and recommended practices can be developed to be included in the investigator's toolbox.

Survival in a complex environment requires well-established references and guidance, otherwise the investigator may end up lost in a sea of information. The following practices can be useful for investigators on the path to determine failure mechanisms.

Step 1. Obtaining all information regarding the aircraft configuration

Since the majority of the system's behavior is determined by software, it is essential to obtain the information about the software version of all involved components. For highly integrated airborne systems, there is usually a so-called "top level system part number" or software version (load) of the entire avionics suite, which most of the time can be retrieved by accessing the central maintenance computers or maintenance logs.

For distributed federated or avionics architectures, the only way is to verify the version of each component on ID plates. If the aircraft was totally destroyed, the maintenance records are the source from which to get this information.

Units that compose a distributed/federated avionics suite can be upgraded individually. However, situations are not rare in which the airframe manufacturer developed and certified a software upgrade of a certain component together with the upgrade of other unit(s). This can also be the case for hardware upgrades. In this situation, the upgrade is made involving a group of components in accordance with the service bulletin issued by the manufacturer.

Operators need to pay close attention to what the approved configurations are in terms of component software/hardware versions. In other words, components that are individually airworthy (e.g., FAA Form 8130) will not necessarily compose an airworthy configuration in the aircraft.

Intermixing components in a nonapproved configuration may cause unpredicted consequences in terms of misbehavior, malfunctions, and failures. The adverse effects may appear not necessarily during startup but maybe only during flight. If no proper hardware/software configuration analysis is performed, the investigation will likely become jammed or entangled in the net of conflicting information.

Step 2. Collecting and analyzing onboard recorded data

It is well known that crash recorders are not the only possible source of onboard recorded data. From the late 1980s, the majority of onboard electronic units and modules have internal nonvolatile memories (NVMs) that may record fault/failure codes for maintenance purposes. The data retrieved from the central maintenance computer is a top priority. NVM usually concentrates status information from a set of components. In highly integrated systems, the interpretation of the presence/absence of fault/failure codes in the NVM is very dependent on the hardware/software versions. It is recommended that the interpretation of the fault/failure codes logs is done meticulously, in teamwork, involving investigation authorities, component manufacturer, airframe manufacturer, and the operator's representative.

Regarding the crash recorders, it is recommended that the analysis of the flight data recorder (FDR) be done by the same team that worked on NVMs to ensure the right correlation between the FDR data and NVM data.

Step 3. Reproducing scenarios in a controlled environment

The third important step is to try to reproduce the aircraft fault/failure condition in a controlled environment. The concept of a controlled environment can be understood as an aircraft integration laboratory, "iron bird," or even the aircraft under investigation—if it has not been significantly damaged in such a way that the repair will not affect the representativeness of the subsystem(s) under investigation. Another aircraft tail number of the same model can be used as a controlled environment, as long as it is free of malfunctions and uses the same software/hardware configurations. Variations can be accepted if an engineering analysis demonstrates that the differences will not affect its representativeness.

Before running any test or analysis, the setup of the controlled environment needs to represent, as close as possible, the conditions of the systems present at the moment of the occurrence.

The majority of in-flight conditions are very difficult to reproduce on actual highly integrated aircraft on the ground. Even an aircraft integration laboratory requires a good pretest planning and hours of setup depending on the specific desired in-flight conditions.

In terms of engineering, it is almost impossible to fully understand the failure mechanism without reproducing it in a controlled environment (CE). No effective engineering effort to design a technical solution or correction is possible without a full comprehension of the failure mechanism.

Note that full flight simulators (FFS) used for pilot training may not be adequate for a CE going deep into aircraft systems for failure investigation. An FFS aims to reproduce the predicted behavior of onboard systems with the focus on cockpit effects and does not necessarily use the same hardware/software of an actual aircraft.

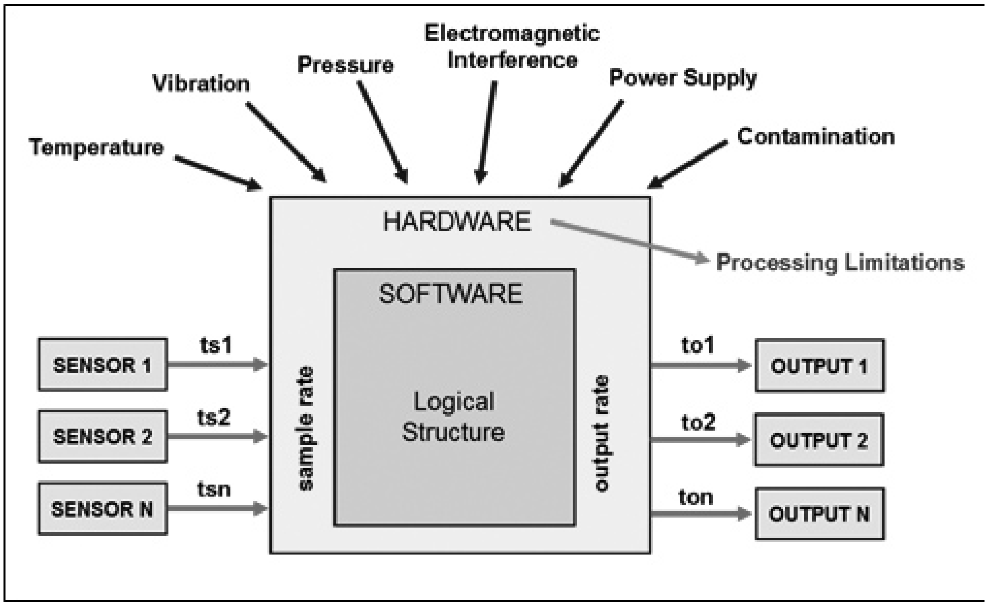


Figure 4. Simplified schematics for hardware and software interface.

Step 4; Software investigations

For the purposes of this paper, "software investigation" refers to the activities performed on aircraft systems to understand their behavior as a result of software design and investigate possible flaws.

It is important to note that in a modern avionics suite, most interactions among parts, components, and functionalities are virtually established at the software level.

The identification of a flaw in the software can be achieved only if the error/malfunction/fault/failure is found or reproduced during the activities performed in the CE. Investigators need to be aware that, even applying the best effort in the CE, unfortunately the situation experienced in the occurrence under investigation may never be reproduced. This is because the software of a highly integrated aircraft uses a lot of input variables and eventually an error becomes evident only in a very specific combination of input values and processing status. About this subject, Leveson states, "Even if the possibility of software error is investigated, subtle errors that cause accidents in well-tested and sometimes long-used systems are not easy to find (or to prove that they may or not exist)." Note that in this excerpt, the author uses "accident" as a general term, not specifically in the context of aeronautical mishap investigation.

Conclusions

- The real dimension of complexity growth on modern aircraft is hidden inside the onboard computers.
- Software is invisible and intangible, and there are no physical laws underlying software behavior. Traditional investigation concepts and techniques do not necessarily apply.
- It is essential to retrieve any information regarding the aircraft configuration in terms of hardware/software versions.
- Components that are individually airworthy (FAA Form 8130) will not necessarily compose an airworthy configuration in the aircraft. Non-approved configurations may cause unpredicted consequences in terms of misbehavior, malfunctions, and failures that can be virtually impossible to investigate in the case of total loss.
- A planned use of an adequate controlled environment is a key factor for the success of investigations involving highly integrated onboard systems.
- Aircraft complexity and the unfolding challenges cannot be eliminated but can be managed through adequate training, specific guidance, clarification, and harmonization of relevant concepts/terminology.
- It is worth sharing in a timely manner indications about new trusty data sources (especially those on the Internet) that can be strategic for the investigators' community. ◆

Mid-Atlantic Regional Chapter Holds Annual Dinner Meeting

Nearly 60 Mid-Atlantic Regional Chapter (MARC) members, ISASI officials, and guests gathered on May 2 in Herndon, Virginia, USA, for the annual MARC dinner and business meeting. Frank Hilldrup, MARC president; Jeff Guzzetti, vice president; and Scott Hubbard, treasurer, welcomed attendees to the event and conducted the chapter's business meeting. Bruce Landsberg, the U.S. National Transportation Safety Board's (NTSB) vice chair, provided the evening's keynote address.

His presentation provided insight into various aspects of the NTSB's modal investigations and Most Wanted List topics. Landsberg's comments touched on human factors and aircraft design, medical fitness, distractions, complacency, and the importance of programs dedicated to flight data monitoring and analysis.

Ron Schleede, ISASI vice president, who had served as MARC president for many years, was the subject of an official tribute by MARC members and officials and ISASI officers who reminisced about sharing accident investigations. Several noted that Ron helped them during their early "tin kicker" years. Ron was given an F-100 model similar to an aircraft he flew while serving in the U.S. Air Force.

Drawings were held for door prizes. Airbus Americas, Inc. Communications Specialist Andrea Twohie provided an Airbus 380 model that went to F/O Ariane Morin (Jazz Aviation). Eclipse Group Inc. Managing Director Steven Saint Amour brought fleece jackets and t-shirts. Jackets went to Brian Poole and Bob Drake. T-shirts went to Stacey Jackson and Darren Gaines. JetBlue's Safety Investigations Manager Andrew Averna donated an A320 model that went to Alan Yurman. Southwest Airlines Senior Manager of Safety Investigations Erin Carroll donated two round-trip tickets that went to Patrick Hempen and Lisa Harter. USC's Thomas Anthony gave a windbreaker that went to ISASI's U.S. National Society President Toby Carroll.

During the meeting, participants donated and pledged $2,826 to the Kapustin scholarship fund, which provides a stipend that allows selected aviation students to attend the annual ISASI seminar and other benefits. (For more information on this ISASI scholarship, go to www.isasi.org/awards.) ◆

Ron Schleede, ISASI vice president, right, receives accolades during the annual MARC dinner and a model of an F-100 in appreciation for his years of service as MARC president.

Bruce Landsberg, the U.S. National Transportation Safety Board's vice chair, delivers the keynote address at the MARC meeting.

Forum Digital-Only Format Begins with this Issue

By the time you receive this print version of *ISASI Forum*, more than 120 ISASI individual and corporate members who requested a digital-only subscription will have received their magazine through e-mail in a page-turning format that provides hyperlinks to www.isasi.org and other sites—offering additional information, more reliable and faster delivery, and size reduction or expansion to enhance readability depending on device choice or eyesight requirements.

If you requested a digital-only subscription and instead received a print version of the magazine, the e-mail address you provided ISASI was *not* valid and you should send a new and valid e-mail address to isasi@erols.com. If you wish to change your subscription either to digital-only or back to print-only, please contact the ISASI office at the same e-mail address. A subscription to both formats is not currently an available option. However, the digital-only version will be posted to the ISASI website library. ◆

ISASI Representatives Attend Fifth ICAO/AIGP Meeting

How is the International Civil Aviation Organization's (ICAO) Annex 13 revised and kept current in the "real world"? ICAO is constantly striving to improve aviation's global strategies regarding safety performance from a wide variety of sources. Formerly, all ICAO member states and interested nongovernment organizations were periodically invited to Accident Investigation Group (AIG) Divisional meetings to discuss and provide input for updates to annexes, manuals, circulars, and other subject material. In the interest of economy and efficiency, ICAO now includes input through technical panels of interested participants.

As an approved international observer organization, ISASI has participated as a member of the ICAO Accident Investigation Panel (AIGP) for the past five years. The participation has included attendance of senior ISASI members at five annual four-day panel meetings in Montreal, Que., Canada, since 2015. The fifth meeting was held April 29–May 2. Bob MacIntosh, ISASI treasurer, and Mark Clitsome, retired director of investigations for the Transportation Safety Board of Canada, represented ISASI. Mark is a valuable addition to the ISASI-ICAO Working Group as he also was the chair of the first three AIGP meetings before retiring.

The AIGP meetings routinely involve approximately 40–45 participants from about 25 countries and other observer organizations. Much of the work of the panel members, besides the meetings in Montreal, involves e-mail exchanges and conference calls. This work has led to significant updates and additions to ICAO standards and recommended practices and guidance materials regarding accident/incident investigation and accident prevention matters. For example, the AIGP/5 Panel work program included discussions on investigator training, the relationship between the accident investigation authority versus the airworthiness authorities' responsibilities, improved guidance regarding the investigation of UAS, protection for flight recorder information being streamed to the ground, feedback on the performance of the Global Aeronautical Distress Safety System (GADSS), and a look at the future of aviation investigations possibly related to cyber-risk intrusions.

ISASI's contributions on the panel are highly appreciated by ICAO and panel members. The Society remains at the forefront of Annex 13 revisions and updates, which are ultimately approved and implemented as standards and recommended practices applicable throughout the global accident investigation community. ◆

Singapore TSIB Hosts Fourth Accident Investigation Forum

Singapore's Transport Safety Investigation Bureau (TSIB)organized the Fourth International Accident Investigation Forum (IAI Forum/4) at the Singapore Aviation Academy on April 10–12. It was attended by 155 participants.

The triennial event was strongly supported by the International Civil Aviation Organization, the European Civil Aviation Conference, the International Society of Air Safety Investigators, the Flight Safety Foundation, and Curt Lewis and Associates.

The participants of the IAI Forum/4 found the event a useful platform for sharing experience and knowledge. The topics covered were diverse and rich in content, and the forum provided an excellent opportunity to network. ◆

Participants of the IAI Forum/4 gather for a group photo.

Virtual Reality in Accident Investigation Training

Caj Frostell, ISASI international councilor, reports that in February the Singapore Aviation Academy introduced a virtual reality (VR) accident site as part of its accident investigation courses. After several years of deliberation as to whether to bring in a small aircraft wreckage for accident site and wreckage examination training, the Singapore Aviation Academy opted for a VR wreckage. One of the advantages cited was that VR could easily involve a modern, large widebody aircraft. Due to space constraints, wreckage would have been limited to a small aircraft.

The VR session modules were composed of three exercises: accident site safety, photography, and evidence collection. VR headsets were available for up to 20 course participants. For courses with more than 20 participants, the participants were divided into two groups, and the course schedule was modified to accommodate two days of VR training, one day for each group. Before putting on the VR headsets, the VR instructor (David Lim of the Transport Safety Investigation Bureau of Singapore) introduced the background to the events leading to the accident involving a large widebody aircraft and the exercise tasking for each of the three modules.

In the VR module 1 session on site safety assessment, participants were taken to five main locations, and each main location was composed of two to four sublocations. In total, the exercises involved 16 multiple-choice questions in which the participants had to individually identify the hazard types present and another 16 multiple-choice questions in which they had to select the best mitigation measures for each of the hazards present. In the wrap-up session, the instructor reviewed the correct answers to the questions. The VR system documented the answers of each participant, as well as the percentages of correct answers to each question. The educational value of the exercise was clearly in the wrap-up session, and sufficient time was allocated to this session.

In the VR module 2 session on photography, the participants were divided into four groups. Each group was given a specific area to photograph: front of the aircraft, back of the aircraft, left wing, and right wing. The group had to select a suitable general overview location for initial photos and then move closer to specific details in the respective exercise area. In the wrap-up session, the quality of the photos and wreckage chosen to be photographed by the participants were discussed in detail. Once again, the educational value of the module was in the guidance provided in the wrap-up session.

In the VR module 3 session on evidence collection, the participants examined the wreckage and the area surrounding the wreckage to determine what parts should be collected for evidence and/or further examination. The educational value was in the wrap-up session, which provided an opportunity for participants to discuss their selections. The instructor provided further relevant (PowerPoint presentation) guidance to participants.

Whether we deal with an actual (small aircraft) wreckage or a VR scenario of a large transport-category aircraft, the essential educational values are in the design of the tasking, questions, activities, reporting, and discussions for the participants. And most importantly, sufficient time (and relevant supporting educational content) should be allocated to the wrap-up sessions. The VR sessions will be part of the practical exercises in the accident investigation courses at the Singapore Aviation Academy again in February 2020. ◆

Caj Frostell, ISASI international councilor, views a wreckage site using VR goggles.

SERC to Hold Annual Meeting

The Southeastern Regional Chapter (SERC) of the U.S. Society will hold its annual meeting August 2–3 in Atlanta, Georgia, USA. On Friday, August 2, participants will tour the Delta Air Lines Training Center. The following day, presentations at the training center will begin at 8:30 a.m. and include investigating fires and explosions, when you assume…, daylight black holes, and high-load event reporting. The Hilton Atlanta Airport Hotel reservations deadline is July 19. A flyer and registration form are available on the ISASI website at www.isasi.org under the Events Society/Chapter Meetings tab/SERC Meeting. ◆

ADDRESSING THE RISKS OF ERRONEOUS DATA ENTRIES

(Continued from page 13)

The objective of this systemic investigation was to encourage EASA and other certification authorities to consider the big picture of this safety issue. It includes the risk description based on the lessons learned already provided by several SIAs, the exhaustive list of technical features developed by manufacturers, and the levers available to them to extend their use (e.g. promotion, certification, standardization, or mandatory implementation). In this sense, the objectives of the BEA investigation seem to be consistent with the recent transition to an overall risk management.

Of course, it is too early to evaluate the impact of this investigation, but we can say that we have agreed on the following point: The mitigating actions put in place by EASA, while addressing technical solutions, have mostly targeted the reinforcement of procedural barriers to be set up by competent authorities, operators, and training organizations. Although it was intended that these would be supplemented by additional safety benefits arising from industry input, the recurrence of this kind of event should lead aviation authorities to reconsider the prioritization of potential benefits—the implementation of available and proven technical solutions. ◆

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Who's Who: Bell—Above and Beyond Flight

We're pioneers. We were the first to break the sound barrier and to certify a commercial helicopter. We were aboard NASA's first lunar mission and brought advanced tiltrotor systems to the market. Our commercial and military products are familiar to generations of people inside and outside the aviation industry, including Bell helicopters, the Huey, and the V-22 Osprey.

Today, we're defining the future of on-demand mobility and vertical lift.

Bell has made its name known by building aircraft that save lives, and rapidly delivering and retrieving warfighters in extreme, challenging environments.

We've been developing agile machinery built for fast transport and swift movement for decades. But creating the next generation of vertical lift products means thinking above and beyond flight.

Earlier this year at the Consumer Electronics Show (CES), Bell revealed the configuration and full-scale vertical-takeoff-and-landing (VTOL) air taxi vehicle. The air taxi, named Bell Nexus, is powered by a hybrid-electric propulsion system and features Bell's signature powered-lift concept incorporating six tilting ducted fans that are designed to safely and efficiently redefine air travel. Bell Nexus represents the nexus of transport and technology and of comfort and convenience. Nexus captures the long-sought-after vision of quick air travel with a unique in-flight experience, keeping passengers connected to their lives and saving valuable time.

Team Nexus, consisting of Bell, Safran, EPS, Thales, Moog, and Garmin, are collaborating on Bell's VTOL aircraft and on-demand mobility solutions. Bell will lead the design, development, and production of the VTOL systems. Safran will provide the hybrid propulsion and drive systems. EPS will provide the energy storage systems. Thales will provide the flight control computer hardware and software. Moog will develop the flight control actuation systems. Garmin will integrate the avionics and the vehicle management computer.

Alongside the debut of Bell Nexus, Bell featured the Autonomous Pod Transport (APT)—an exciting new venture for Bell. The APT family, which varies in payload capability, can serve many mission sets from medical, law enforcement, and offshore missions to on-demand delivery services. Bell is expanding into a new industry to show the full spectrum of our capabilities and the real-world challenges APT will address.

Bell's future flight controls simulator was a new experience for CES participants this year. Bell is actively collecting data to help shape the future flight controls of aviation. Data from these simulators will be used to determine what actions and interfaces are intuitive to the average potential operator and what prior experiences and abilities contribute to these opinions.

Urban air travel is coming closer to the masses through recent advancements in technology and software. The critical last step is designing a flight control ecosystem that allows individuals to safely and efficiently operate urban air vehicles.

When it comes to developing the world's first air taxi or producing lifesaving commercial and military aircraft, we have the innovative minds and the relentless drive to revolutionize search-and-rescue operations, business travel, and vertical takeoff and lift. And we're just getting started.

Headquartered in Fort Worth, Texas, USA, as a wholly owned subsidiary of Textron Inc., we have strategic locations around the globe. And with nearly one quarter of our workforce having served, helping our military achieve its missions is a passion of ours. Above all, our breakthrough innovations deliver exceptional experiences to our customers—efficiently, reliably, and always with safety at the forefront. ◆