FORUM

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Air Safety Through Investigation
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ABOUT THE COVER

NASA announced on Dec. 9, 2020, that 18 astronauts were selected to train for the Artemis missions designed to return humans to the lunar surface. As commercial space missions are on the rise in the United States and other nations, the question for ISASI: Do we need a space annex to provide international space safety procedures and investigation authority similar to Annex 13 here on Earth? (See page 4.) Fused photo of a super moon by Gary DiNunno.

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AIR SAFETY INVESTIGATORS
INCORPORATED AUGUST 31, 1964

REHABILITATING PARKED AIRCRAFT FOR FLIGHT

> "IT'S GOING TO TAKE A LOT OF PEOPLE AND A LOT OF TIME TO GET THINGS GOING AGAIN. AND IF YOU'VE GOT LESS PEOPLE, IT'S GOING TO TAKE MORE TIME." — *STEPH SMITH*

I wish everyone a good and safe new year. As 2021 began, we're still facing individual and air safety professional difficulties throughout the world—both trying to stay healthy during the pandemic and surviving the resulting economic turmoil that's wrecked national economies and left many people permanently unemployed or temporarily furloughed. There's hope now for a better future as vaccines and improved medical treatments move from their development stage to initial distribution and eventually become widespread. Recovery for global health and the revival of the aviation industry will still require years of coordination, cooperation, and careful observation.

In my last "President's View" and in my video on ISASI's website, I mentioned remaining vigilant about safety issues as mothballed aircraft are returned to service. Last December, Kathy Scott, a CNN reporter, provided some interesting interviews with a manager of a site in Alice Springs, Australia, where unused aircraft are stored, and a certified aircraft engineer and the commercial director of an aviation services company. Scott observed that more than two-thirds of the world's commercial aircraft were grounded in 2020, and some 31 percent are still in storage. The Asia Pacific Aircraft Storage (APAS) facility still has twice its usual number of jets, now about 150, and has increased its capacity to more than 200, said APAS managing director Tom Vincent, who expects demand to rise in 2021. Vincent observed that getting these aircraft back on the line requires an extensive program prescribed by the maintenance manual provided by each manufacturer before a certificate of release to service can be signed.

Scott also learned there are a myriad of usual problems that must be resolved in these rehabilitation programs. There's more than just removing engine protectors and tape covering every hole, port, or probe, according to Licensed B1 aircraft engineer Steph Smith. For example, bugs (wasps have a way of nesting in hard-to-reach places), water, or debris can invade aircraft systems. Smith estimated that getting a widebody aircraft ready for flight takes about 100 staff-hours, and a narrowbody aircraft takes about 40—depending on the size of the aircraft and the length of storage time.

She commented that engineers have to do a series of engine runs in accordance with the aircraft maintenance manual. "These are done to ensure the engines are still performing as expected and that the long-term storage hasn't caused any detrimental effects to any of the systems that wouldn't be obvious just by looking at them," said Smith. But Scott stressed that it will take a considerable amount of time to get everything flying again given the volume of maintenance work that needs to be done and the number of engineers who've been laid off during the pandemic. "It's going to take a lot of people and a lot of time to get things going again," Smith remarked. "And if you'e got less people, it's going to take more time."

"With some of the newer aircraft, these tests need to be followed in the exact order and to the exact second, otherwise it can fail the test and set you back a few hours," she observed.

"Once the maintenance work packs are cleared and certified, the engineer can then sign the aircraft off as airworthy. They're the final signature that says, 'I'm happy that everything has been done correctly. I'm now releasing the aircraft to service.' That final signature is what the captain will see to then sign the logbook for the aircraft," noted Smith.

Mike Cone, commercial director of eCube, an aviation services company, told Scott that engineers must religiously follow procedure when reactivating an aircraft. Cone also observed that only companies approved by national airworthiness authorites can perform this maintenance. He said no aircraft stored at eCube facitities in Spain and the United Kingdom have returned to the flightline (at the time of this CNN interview).

Cone speculated that the "more marketable" aircraft such as the Airbus A320 and the B-737 will return to passenger flight and that other aircraft may undergo passenger to cargo conversions. Vincent suggested that newer aircraft will leave his facility first as demand returns. Smith commented that the "greener" more sustainable aircraft types will survive this downturn. ◆

Frank Del Gandio
ISASI President

Joseph M. Sedor

DO WE NEED AN ANNEX 13 FOR COMMERCIAL SPACE ACCIDENTS?

By Joseph M. Sedor, Chief, Major Investigations, the NTSB

(Adapted with permission from the author's technical paper Do We Need an Annex 13 for Commercial Space Accident Investigations? *presented during ISASI 2019, Sept. 3–5, 2019, in The Hague, the Netherlands. The theme for ISASI 2019 was "Future Safety: Has the Past Become Irrelevant?" The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

The growth of the U.S. commercial space industry has accelerated over the last several years; FAA-licensed commercial launches have increased from four in 2010 to 33 in 2018. This increase was partly the result of policy changes after the retirement of the space shuttle that have required NASA to use commercial launch/reentry systems for International Space Station resupply and astronaut transfer. Therefore, commercial space launches and reentries will likely continue to increase, which will inevitably result in more mishaps.

Over the last 25 years, the NTSB's Office of Aviation Safety (OAS) has been developing technical expertise and building relationships with stakeholders involved in this emerging mode of transportation to ensure that the NTSB and stakeholders are prepared to investigate any commercial space accident or incident. Although there are similarities between commercial space and aviation investigations, the industry structure, technologies, national security laws, and international treaties that govern space operations dictate that the investigations will be considerably different. Ultimately, these differences will also drive how states interact during an international accident or incident investigation.

The NTSB has been leading or supporting commercial space accident investigations for more than 25 years and has conducted two major space vehicle investigations. In 1993, the NTSB investigated the procedural anomaly that occurred during the launch of an Orbital Sciences Corporation Pegasus expendable launch vehicle. The investigation found safety issues related to command, control, and communications responsibility; launch crew fatigue; launch interphone procedures; efficiency of launch constraints; and the lack of common launch documents. In its final report, the NTSB issued 17 safety recommendations to the Department of Transportation, NASA, and Orbital Sciences.

In 2014, the NTSB investigated the accident of the SpaceShipTwo reusable suborbital spaceplane that broke up during a rocket-powered test flight, killing the copilot. The NTSB identified safety issues regarding the lack of human factors guidance for commercial space operators, the efficacy and timing of the preapplication consultation process, limited interactions during the experimental permit evaluation process, deficiencies in the evaluation of hazard analyses, and the need to improve the lessons learned database. The NTSB issued a total of 10 recommendations to the FAA's Office of Commercial Space Transportation and the Commercial Spaceflight Federation.

In addition to these NTSB-led investigations, NTSB investigators have assisted in multiple spacecraft accident investigations. Throughout the seven-month *Columbia* space shuttle investigation in 2003, more than 40 NTSB investigators assisted both the *Columbia* Accident Investigation Board and NASA with ballistic analysis, debris recovery, wreckage examination, and vehicle reconstruction. Several NTSB investigators also assisted NASA in 2004 with the investigation of the *Genesis* sample-return capsule that crashed into the Utah desert. NTSB investigators documented the accident scene, organized the wreckage recovery, and examined the vehicle's wiring harness for evidence of micrometeorite impact damage.

More recently, NTSB investigators have observed or taken part in several operator-led mishap investigations, including the October 2014 Orbital Science (ATK) Antares engine failure shortly after liftoff; the June 2015 launch failure of the SpaceX CRS-7 mission; the September 2016 pad explosion of the SpaceX Falcon 9 with the Amos-6 communications satellite; and the April 2019 SpaceX Dragon explosion that occurred during a ground test. This "on-the-job training" has provided NTSB investigators with significant and critical experience in the commercial space industry, which has helped the OAS to prepare to lead the investigations of future commercial space accidents and incidents.

Commercial Space Transportation Department

The space industry has historically been led by the government and military, so the commercial sector is relatively young, especially when compared to the aviation industry. The U.S. commercial space industry officially launched in 1984 when the Commercial Space Launch Act (Space Act) was signed into law. The Space Act created the Office of Commercial Space Transportation (AST) in the Department of Transportation, and in 1995, AST was moved within the FAA. The mission of the FAA AST is to ensure protection of the public and property; protect national security and foreign policy interests of the United States; and to encourage, facilitate, and promote U.S. commercial space transportation. As part of its oversight responsibilities, the FAA AST issues licenses and experimental permits for commercial launches and reentries of orbital and suborbital rockets. However, unlike the FAA's aviation regulatory goal of providing the safest system in the world, the U.S. Congress has charged the AST to primarily focus on protection of the public—and not "mission assuredness."

This is not to say that the U.S. Congress does not want a safe commercial space industry. The Space Act, which was most recently amended in 2015, states that the FAA AST should "encourage, facilitate, and promote the continuous improvement of the safety of launch vehicles designed to carry humans." However, Congress also does not want to discourage industry development since human space flight is still inherently risky. So the Space Act includes a provision for a "learning period," which limits any regulation "restricting or prohibiting design features or operating practices" unless resulting from an accident that caused a serious injury or fatality to a person on board, or from a serious incident that almost caused a serious injury or fatality. This learning period, also known as the human space flight regulation moratorium, is currently in effect until October 2023.

This is quite different from aviation regulations that have developed over the years to cover almost all aspects of an aircraft design and operational rules to ensure and improve the safety of passengers and crew. Unlike aviation regulations, AST regulations refer to any person aboard a commercial space vehicle who is not a crewmember as a "space flight participant" and not a "passenger." In addition, these space flight participants are required to acknowledge the risks by signing an "informed consent" that identifies the risks or probable loss during each phase of launch/reentry and the safety record of the launch/reentry vehicle type (describing the launch/reentry failures, if any). The launch/reentry operator must also purchase a specific amount of liability insurance, determined by AST for each launch, to cover any third-party loss (injury, death, property damage, etc.), which can be up to $500,000,000. Since this liability amount might be insufficient for an exceedingly "bad day," the Space Act also requires the federal government to indemnify launch/reentry companies for claims that exceed their required insurance coverage, which could be up to $3 billion (in 2016 dollars).

NTSB Relationship with Commercial Space

NTSB involvement with the commercial space industry is similar to the aviation industry. The NTSB investigates any launch/reentry accidents and certain incidents, and that authority is derived from the NTSB's general authority under 49 Code of Federal Regulations (CFR) 1131(a)(1)(F), which states that the NTSB shall investigate "any other accident related to the transportation of individuals or property when [the accident is] catastrophic." Although this statement is not as clear as 49 CFR 1131 (a)(1)(A), which states that the NTSB shall investigate all "aircraft accidents," the NTSB's interpretation of this statute is reasonable and is accepted by the commercial space industry.

The process to clearly specify the NTSB's authority to investigate commercial space accidents has begun; however, statutory changes are seldom fast. In addition to the NTSB statutory authority, the NTSB also entered into a memorandum of agreement (MOA) with the FAA in 2000 to ensure both agencies understand when the NTSB would initiate an investigation of a nonmanned commercial launch accident. The MOA defines an accident that the NTSB would investigate as a mishap when any portion of a commercial space vehicle or payload impacts outside the impact limit lines; a fatality or serious injury to a person not associated with the launch activities; or damage greater than $25,000 to property not associated with the launch activities. This agreement was initiated during a time when human space flight and commercial reentry operations were not anticipated for many years; thus, although the MOA is still in effect, it is out of date and does not address those operations. Work on updating this outdated MOA is ongoing. In addition to this MOA, the NTSB has an MOA with the FAA and the U.S. Air Force that defines the relationship between all three agencies during space investigations and describes the participation and information exchange procedures.

Although NTSB regulations do not contain specific definitions related to commercial space mishaps, 14 CFR 401.5 contains definitions for commercial space launch and reentry accidents or incidents that assist the OAS in determining whether to initiate an investigation. A launch accident is when there is a fatality or serious injury to a space flight participant or crewmember; a fatality or serious injury to any person who is not associated with the flight; impact of launch vehicle, its payload, or any component outside the impact limit lines (for expendable) or outside a designated landing site (for reusable); or damage to third-party property greater than $25,000. A reentry accident occurs when the reentry vehicle, its payload, or any component impacts outside a designated reentry site; a fatality or serious injury to a space flight participant or crewmember or a person not associated with the reentry; or damage to third-party property greater than $25,000.

In addition, for those mishaps that do not rise to the level of an accident, the regulation also contains definitions for launch and reentry incidents to better define what mishaps the NTSB would likely investigate. A launch/reentry incident is an unplanned event during the launch or reentry that would involve a malfunction of a flight safety system or safety-critical system or a failure of the license's or permittee's safety organization, design, or operations. The FAA AST has recently proposed to modify these definitions to more closely align with those used by the military and NASA by having four "classes" of mishap events rather than just accidents and incidents. The NTSB will likely issue its own definitions along these lines in the next few years.

As indicated by these definitions, it is clear that it takes a more serious mishap to constitute a commercial space accident; an event involving an aircraft is classified as an accident if there is substantial damage to the aircraft of serious injury to a person. Loss of the space vehicle alone does not automatically necessitate an NTSB investigation. However, now that the industry is moving toward human spaceflight, should a mishap occur, the NTSB would investigate it if there is a fatality or serious injury.

As previously discussed, the NTSB has been engaged with the space industry for the last 25 years through our commercial space program within the OAS. The program has matured along with the industry to ensure that the NTSB is prepared to investigate any future space vehicle accident or incident. The goals of the NTSB's commercial space program are to develop the specialized investigative processes and procedures necessary to investigate this emergent mode of transportation, build critical relationships with industry stakeholders, and ensure that NTSB investigators have the specialized knowledge necessary to lead commercial space investigations.

Aviation and Commercial Space Industries Differ

Although there are some similarities with aviation, there are distinct and unique aspects of commercial space investigations that necessitate they be investigated as its own distinct mode of transportation. As with all modes of transportation, the NTSB will use the party system to investigate commercial space accidents/incidents. The overall structure will be similar to major aviation investigations but will likely have fewer parties to the investigation since most of the rocket and vehicle components will be produced by the launch operator. In addition, the OAS's goal for completion of major aviation accident reports is to issue a final report within 12–18 months, which is acceptable in the aviation industry since normal operations generally continue throughout that timeframe. However, for every launch or reentry accident to a space vehicle, the vehicle and/or range is grounded until at least the initial causes are determined. Therefore, the OAS's investigative process will likely have to be accelerated, although even targeting 8–12 months for a final report may be too long. To address this issue, NTSB staff is evaluating the possibility of modified procedures to release preliminary analytical findings (prior to the final report) to allow the resumption of launches or reentries.

Probably the most significant difference between an aviation and space investigation will be in the transparency of the investigation. Normally, the NTSB releases factual data through press conferences (while on scene), press releases (post on scene), and then via the public docket, which contains all relevant factual information NTSB investigators collected during the investigation. The NTSB even has the authority to release confidential commercial information (proprietary data)—which is normally protected—to support the conclusions, safety recommendations, or the probable cause of an accident.

However, the space industry has regulations (export control policies) in place to safeguard critical defense-related technologies in order to protect U.S. national security and foreign policy objectives: the International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR). The NTSB is not exempt from these regulations and cannot release data that is subject to ITAR or EAR, even if it is directly related to the probable cause. Thus these regulations would impact the NTSB's ability to release information on space accidents.

As a result, the OAS has developed an internal procedure to work with the U.S. Department of State and Department of Commerce to review all factual data/reports and the final report before public release. This extensive review process will inevitably delay the release of factual information until the end of the investigation rather than being released as soon as possible (typically about six months into the investigation for major investigations). The ITAR/EAR review will also likely result in extensive redactions to the factual reports contained in the public docket. Even more significantly, on a highly technical accident, portions of the final report may also have to be redacted, and, in extreme cases, the NTSB may be required to hold the final board meeting in a closed session in order to discuss data that is ITAR-/EAR-restricted. For an agency that normally prides itself on openness and transparency, these restrictions on the release of data will be a challenge, and an appropriate public/media education effort will be necessary to communicate why the restrictions are essential.

Any commercial space orbital launch or reentry accident could become an "international" accident depending on the trajectory of the launch/reentry. Space operations are governed by an international treaty entitled the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space," commonly referred to as the Outer Space Treaty. This treaty has driven much of the U.S. space regulation structure. Although the treaty does not directly address accident investigation, it does address the responsibilities of each state in the event of a mishap. If a launch or reentry vehicle impacts in another state's territory, that state has two responsibilities: render "all possible assistance" to any persons on board and to "safely and promptly" return persons and the vehicle or components.

Article VII of the Outer Space Treaty declares that the state that authorized the launch or reentry is "internationally liable" for damage caused by the vehicle or components to any persons or property. This type of liability-focused language likely stemmed from the fact that when the treaty was originally developed in 1967 all the space operations were one-of-a-kind rockets operated by state governments. The Outer Space Treaty does encourage international cooperation multiple times throughout the treaty; for example, Article X says that states should afford an opportunity to other states to observe launches and reentries. Cooperation, of course, is essential for conducting international investigations, but a state's specific rights and responsibilities also need to be defined for any future international investigative treaty.

ICAO Annex 13 has provided the basic structure for international aviation investigations for more than 50 years, detailing the cooperation necessary as well as a state's rights and responsibilities during an investigation. However, the standards and recommended practices in Annex 13 are not directly applicable to the unique aspects of the commercial space industry (as discussed in this paper). One of the more significant differences between space and aviation is that launch operators are typically the manufacturer and operator of their vehicle, unlike aviation where there are separate manufacturers and separate operators around the world.

Accordingly, using Annex 13 terminology, the state that authorized the launch would be the state of registry, design, manufacture, and operator, and the state where the vehicle or components impacted would be the state of occurrence Although the state of occurrence would have a considerable need to understand the facts, conditions, and circumstances of the accident, it would be nearly impossible for the state of occurrence to conduct a thorough investigation of the mishap, since the expertise resides entirely with the launch operator—especially since the operator would likely be prohibited by law (due to export regulations) to transfer information.

Likewise, the ITAR and EAR national security regulations would also make it difficult for the state of occurrence to send observers to a state of the operator-led investigation. Furthermore, if there are no distinct operators of the accident launch or reentry vehicle in the state of occurrence, there would be no safety reason for them to conduct an investigation since any lessons learned would likely only affect the state conducting the launch (any broad/universal safety findings would be released by the launching state).

In Conclusion

Given the domestic and international regulatory environment, the national security laws, and the unique technical structure of the industry, I do not believe that—at this time—a formal "commercial space Annex 13" is necessary. However, informal international cooperation will be vital to ensuring that safety investigators are prepared to meet the technical and organizational challenges of investigating commercial space vehicle accidents. The existing Annex 13 aviation accident investigation authorities and professional organizations—such as ISASI—will serve as excellent resources in building these relationships. The collaborative efforts between state authorities will help the investigative community refine the specific processes and procedures for investigating commercial space accidents, discover or develop training opportunities, gain understanding of various regulatory structures, and observe commercial space operations. At some point in the future, a more formal safety structure may be needed as the commercial space industry grows and matures (point-to-point service, etc.). However, until that time, the spirit of international cooperation, which has been cultivated by Annex 13, will help ensure that the investigative community is prepared to assist this emerging mode of transportation to improve safety following any commercial space mishap. ◆

Joseph M. Sedor, chief of major investigations for the NTSB, delivers his technical presentation during ISASI 2019.

Video-Based Flight Data Reconstruction

By Dr. Marcus Bauer, Managing Director, iwiation

(Adapted with permission from the author's technical paper Video-Based Flight Data Reconstruction of the Amazon Prime Air B-767 Accident, Trinity Bay, U.S.A., 2019*, submtted for ISASI 2020 in Montréal, Qué., Canada. ISASI 2020 was postponed until 2021 due to COVID-19 restrictions. The full technical paper can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Dr. Marcus Bauer

Introduction

The sole objective of an investigation into an aircraft accident or incident conducted under the provisions of Annex 13 shall be the prevention of accidents and incidents. The purpose of this paper is to encourage an additional investigation means to the existing procedures, practices, and techniques that can be used in aircraft accident investigations.

The investigation of air accidents is based on available data and information to determine the root cause. Flight recorder data, radar data, and wreckage analysis can provide important information. However, in some air accidents, some if not all of these sources of information may not be available to investigators. In recent years, more and more video footage is available, either from witnesses who recorded the accident with their mobile phones or videos recorded by security cameras. This information can be used to reconstruct flight data, aircraft attitude, descent rate, and ground speed.

Thesis

This paper represents the potential and the implementation of using video information to reconstruct the flight history and the flight path in detail. The consistency of the reconstructed information will be explained as well as how it has been validated.

The Methodology

In the frame of my doctoral thesis, the reconstruction methodology iwi® was developed in 2009, based on eyewitness reports in the field of aircraft accident investigation. The development has been based on the overview of existing applications and the existing problematic to recalculate a flight path and thus the flight history without flight data recorder (FDR) data or radar information. The physiology and psychology of an eyewitness have been evaluated; however, the method can also process video information to approximate flight data.

The methodology has been applied already and successfully in several investigations, using video information in examples such as

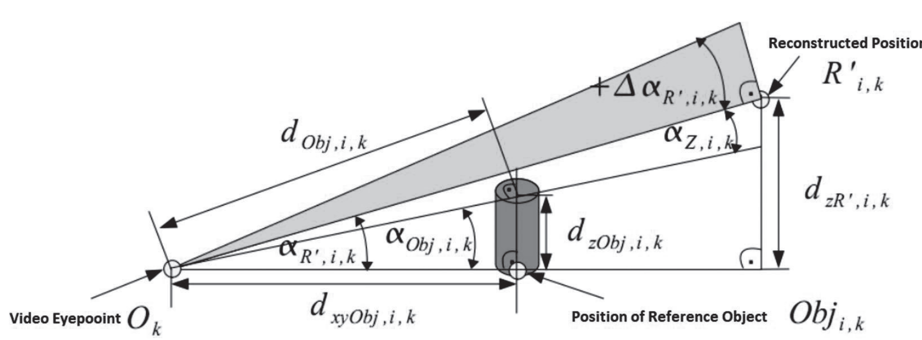
- AS350 Mid-Air Accident, La Rioja, Argentina, BEA, 2015,
- EC145 Accident, Hautes-Pyrénées, France, BEA-É, 2016, and
- Gazelle Mid-Air Accident, Carcès, France, BEA-É, 2018.

The iwi method allows to approximate flight path as well as aircraft attitude and ground speed. The accuracy of the reconstructed data is influenced by multiple technical factors.

In order to reconstruct the elevation, the following factors must be considered and computed for the error calculation as the observed value versus the true value of a measurement:

> **"Flight data that is reconstructed based on video information is applicable!"**

Figure 1. Angular deviation in elevation depending on reference object, eyepoint (left), position of reference object (middle), and observed object location (right).



- Δd_xyGPS: Video location accuracy (latitude and longitude) in meters.
- Δd_zGPS: Video location accuracy (altitude) in meters.
- Δd_xyZPos: Location accuracy of reference objects (latitude and longitude) in meters.
- Δd_zZPos: Location accuracy of reference objects (altitude) in meters.
- Ratio of the recorded object resolution in pixel and object size in meters.

With reference to Figure 1, the formula considers different errors. To place the video informationin in 3-D, a reference object (Obj) as well as the observer (O) location are required. By knowing the positions of "O" and "Obj," the minima and maxima altitude of the aircraft can be calculated by the formula below. The default error tunnel (grey cone) is the result of an aproximated model, showing the possible area where the altitude of the observed object was located. The error tunnel dimension is based on the known errors, such as the camera's position accuracy, as well as the video resolution. Another influencing factor of the default tunnel's size is the distance between the observer and the reference point, as a small miss-positioning of the observer resulting in a variation of the observed object's height. As the variation gets larger, the closer the reference object is relative to the position (latitude/longitue) to the observer.

Formula 1 is used with its derivations to calculate the elevation error based on the reconstructed distance to the object.

In azimuth, the following factors must be considered for error calculation:

- Video location accuracy (latitude and longitude) in meters.
- Location accuracy of reference objects (latitude and longitude) in meters.
- Ratio of the recorded object resolution in pixel and object size in meters

Figure 2 illustrates the formula for the calculation of the observed object's (R) position in latitude and longitude. The observer (O) requires (you are here) as well a reference point (Obj), which indicates the reference to the observed object's position. By knowing the exact position of "O" and "Obj," the exact position in longitude and latitude can be provided by the formula shown hereinafter.

Formula 2 is used with its derivations to calculate the azimuth error based on the

$$\sigma^2_{zObj} = 2 \cdot \Delta d^2_{zGPS} + \Delta d^2_{zZPos}$$
$$\sigma^2_{zObj} = \sigma^2_{xyObj} = 2 \cdot \Delta d^2_{zGPS} + \Delta d^2_{zZPos}$$
$$\Delta\alpha_{R',i,k} = \sqrt{(\frac{\partial\alpha_{Obj,i,k}}{\partial d_{zObj,i,k}})^2 \cdot \sigma^2_{zObj} + (\frac{\partial\alpha_{Obj,i,k}}{\partial d_{xyObj,i,k}})^2 \cdot \sigma^2_{xyObj} + \Delta\alpha^2_Z + \Delta\alpha^2_{FotoObj,i,k}}$$
$$d_{z4,i,k} = \cos(\alpha_{R',i,k}) \cdot \tan(\Delta\alpha_{R',i,k}) \cdot d_{R',i,k}$$
$$d_{z5,i,k} = \tan(\alpha_{R',i,k} + \Delta\alpha_{R',i,k}) \cdot \tan(\alpha_{R',i,k}) \cdot d_{z4,i,k}$$
$$\Delta R'_{z,i,k} = |d_{z4,i,k}| + |d_{z5,i,k}|$$

Formula 1

$$\sigma^2_{xObj} = \sigma^2_{yObj} = 2 \cdot \Delta d^2_{xyGPS}$$
$$\Delta\beta_{Obj,i,k} = \sqrt{(\frac{\partial\beta_{Obj,i,k}}{\partial d_{yObj,i,k}})^2 \cdot \sigma^2_{yObj} + (\frac{\partial\beta_{Obj,i,k}}{\partial d_{xObj,i,k}})^2 \cdot \sigma^2_{xObj} + \Delta\beta^2_{FotoObj,i,k}}$$
$$\Delta R'_{xy,i,k} = \sqrt{(\tan(|\Delta\beta_{Obj,i,k}|) \cdot (d_{xyR',i,k} - d_{xyObj,i,k}))^2 + (\tan(|\Delta\beta_Z| + |\Delta\beta_{WGS84}|) \cdot d_{xyR',i,k})^2}$$

Formula 2

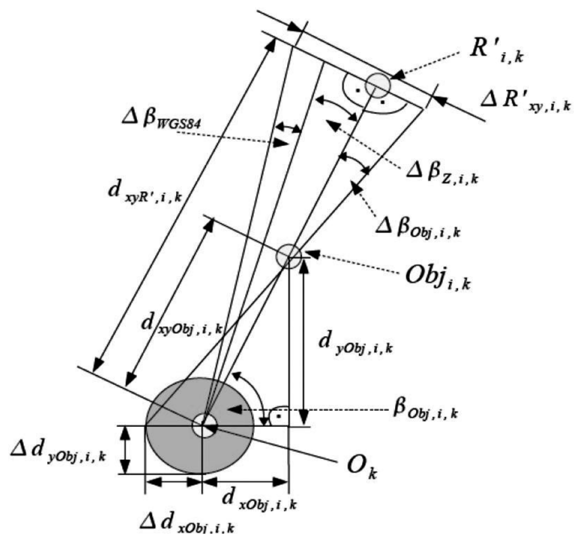


Figure 2. Geometry for calculating the error in azimuth, from witness/camera location via Obj. (reference object) to reconstructed aircraft location (R).

Figure 3. Aerial view of main debris field looking northwest.

Figure 4. Surveillance camera video.

Figure 5. Surveillance camera video.

Figure 6. Camera location shown in Google Earth.

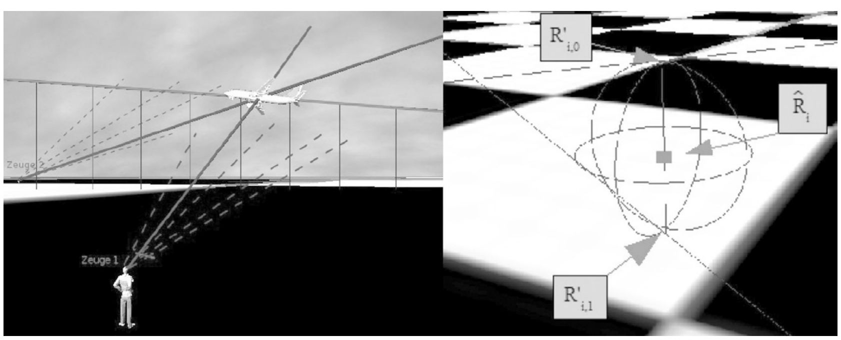


Figure 7. Lines of sight of witness statement (left) and reconstructed location with error (right).

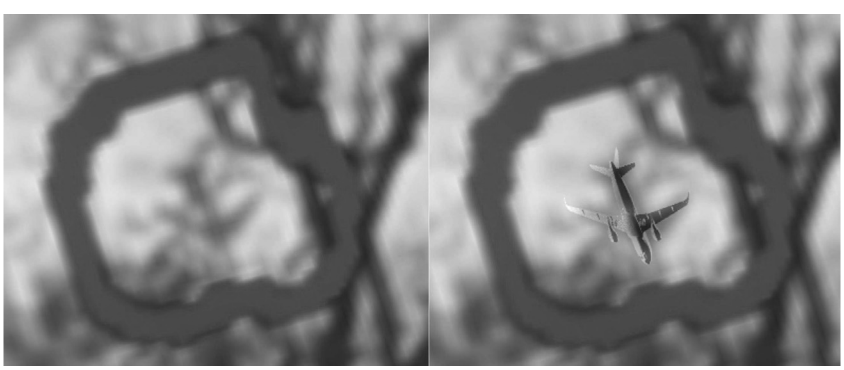


Figure 8. Single frame of video showing the B-767 behind trees (left) and with overlay of 3-D object (right).

reconstructed distance to the object:

The Evaluation Case

On Feb. 23, 2019, the Amazon Prime Air cargo aircraft that was operated by Atlas Air flew from Miami, Florida, to Houston, Texas, and during the arrival phase the Boeing 767-375BCF entered a rapid descent from 6,200 feet and impacted into a marshy bay area around 40 miles away from Houston's George Bush Intercontinental Airport (see Figure 3, page 9).

Two security cameras captured the last 5 seconds of the aircraft in a steep, generally wings-level attitude until impact with the swamp. For our own interest, the iwi® methodology was applied to validate the latest methodology developments, reconstructing flight path, aircraft attitude, and ground speed based on the available video information. The results were shared with the NTSB before the black box could be recovered.

Flight Data Reconstruction and Data Comparison

Two video recordings were available from two different locations. They were used to create panoramic images with aircraft positions and video time stamps. The video distortion was corrected using the dedicated lens correction profile (see Figures 4 and 5).

The resolution of the video influences the data reconstruction accuracy as well as the precision of the time stamp information. Video frames at every second were selected to ensure maximum accuracy. The security camera recording frequency was approximately one frame per second.

The GPS location of both cameras was identified, as shown in Figure 6, using Google Street View, as well as the location of reference objects like buildings and trees, as shown in the video. The location accuracy was defined with +/- 16 feet in latitude/longitude and altitude. The reference objects were used to place the image information within the 3-D environment. All data collected was imported into the reconstruction software called Immersive Witness Analyzer, which sets all lines of sight considering reference objects. The software estimates the reconstructed flight path considering potential error information using the specified and decribed formulas.

To estimate the aircraft's attitude at different locations along the flight path, a 3-D model of a B-767 was placed and adjusted with respect to the video image frame rate.

The left image in Figure 7 shows the lines of sight from the perspectives of two security cameras. The intersection of both lines ap-

Figure 9. Attitude error +/-10 degrees visualized (blue/cyan), heading (left), pitch (middle), roll (right).

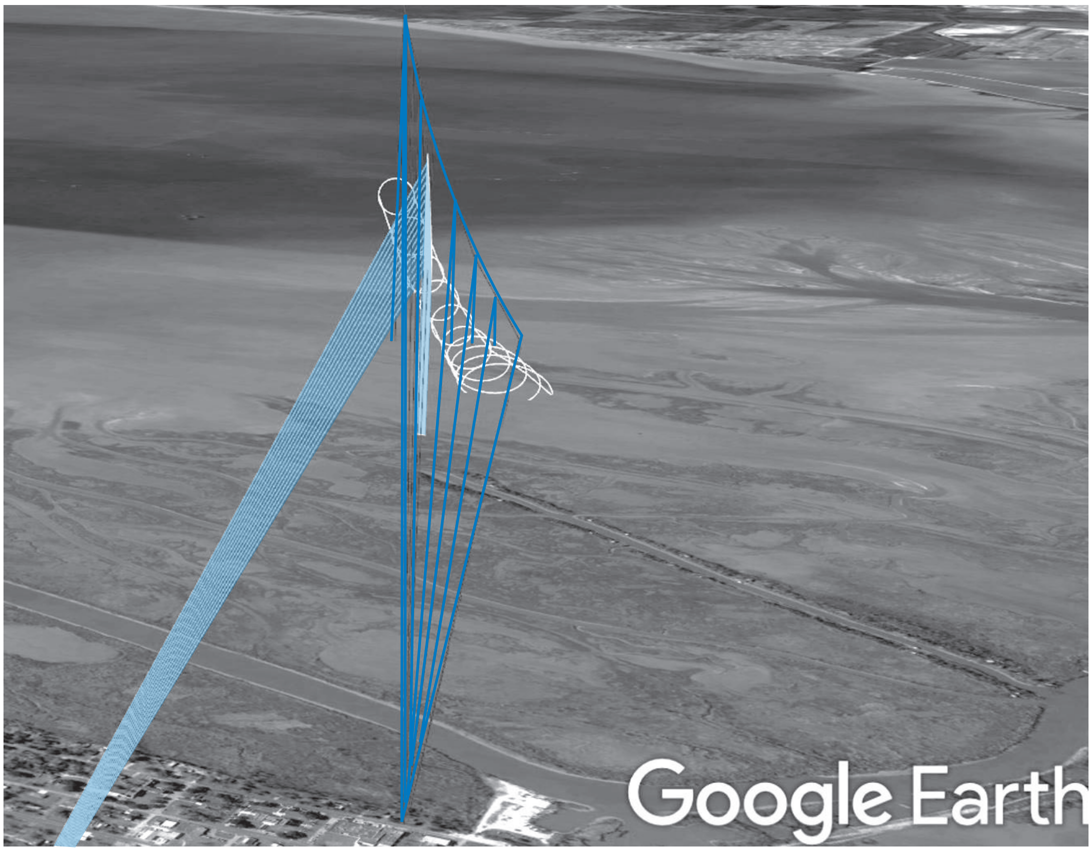


Figure 10. Illustration of the reconstructed flight path with error tunnel (white circles) that shows the line of sight from the first observing camera (light blue) and second observing camera (dark blue).

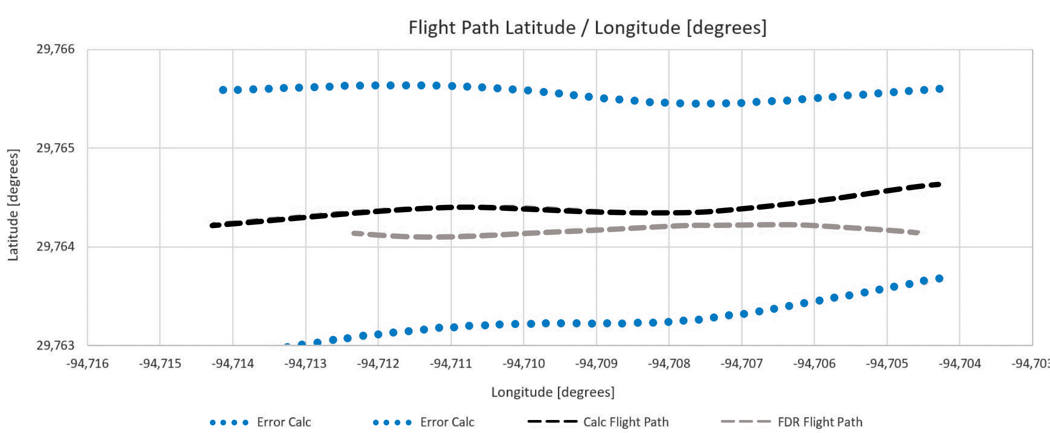


Figure 11. Reconstructed flight path (black), FDR flight path (grey), and error tunnel (blue).

proximates the position of one position of the observed object as shown in the right image. In this case, the B-767's position (intersection of both lines of sight) was located, considering the potential errors.

The images in Figure 8 show one single frame of the video. The left image shows the outline of the aircraft behind trees. To determine the attitude of the aircraft, a 3-D model of a B-767 was placed in the 3-D software application at the reconstructed position and the attitudes of the aircraft such as heading, pitch, and roll were adjusted until the objects fitted best to the outline in the image. The accuracy for attitude reconstruction depends on the resolution of the frame. However the potential error can be up to +/- 10 degrees based on experience.

To better explain the reason for the experienced size of the error in attitude, Figure 9 shows the visual differences. The modified values for +/-10 degrees are visualized in blue and cyan and overlayed. Based on the experience of several reconstructions and video data, a good fit could be determined within the maximum error of +/-10 degrees for all three axis.

The reconstructed flight path was compared to the original FDR data (shown in Figure 12, page 12) that was recovered from the B-767 wreckage. Figure 11 shows in latitude and longitude the flight path that could be reconstructed in black. The original flight path (grey) is close to the reconstructed path (black) and within the error tunnel (blue).

To better compare the difference between both, the extrapolated flight path from the video method and the recorded flight path from the FDR, the distance was calculated in feet and shown along the time in Figure 13. The solid blue line describes the difference in latitude and longitude in feet between the reconstructed position and the recorded FDR data. The graph with dotted blue line shows the maximum possible distance, known as error tunnel, based on the formulas. The achieved accuracy of the reconstructed flight path was in a range of between 50 and 150 feet, finally within the error tunnel (see Figure 13).

Figure 14 shows the reconstructed altitude (light blue) of the airplane and the recorded FDR altitude data (light grey). The reconstructed altitude is within the error tunnel shown in dark grey, dotted blue, with the exception of the beginning from 0.0 to 0.25 seconds, when the aircraft was shown only partially in the first frame. This may have resulted in a larger error in the early portion of the calculation. Finally, the difference in calculated verses FDR recorded altitude was between 32.7 and 171.9 feet.

Since the video could be synchronized with the time base, using the video frame time stamps, a reconstruction of the ground speed and descent rate was possible.

Based on the calculated decent rate (black) in feet/minute, Figure 16 shows that the aircraft reduced its descent rate from -39.800 feet/minute to -15.000 feet/minute. The recorded FDR data showed that the B-767 reduced its decend rate from -28.000 feet/minute to -18.240 feet/minute within 2 seconds. The difference between the reconstructed data and recorded FDR data showed in the beginning quite a large difference up to 10,000 feet/minute. This was possibly due to the fact that the aircraft was only partially visible in the video and that the recording rate of the security camera was a relatively low one frame per second, as shown in Figure 15.

Since the video could be synchronized with the time base, using the video frame time stamps, a reconstruction of the ground speed and descent rate was possible.

Based on the calculated decent rate (black) in feet/minute, Figure 16 shows

Figure 12. Recovered black box (left) and ADS-B flight path data (right).

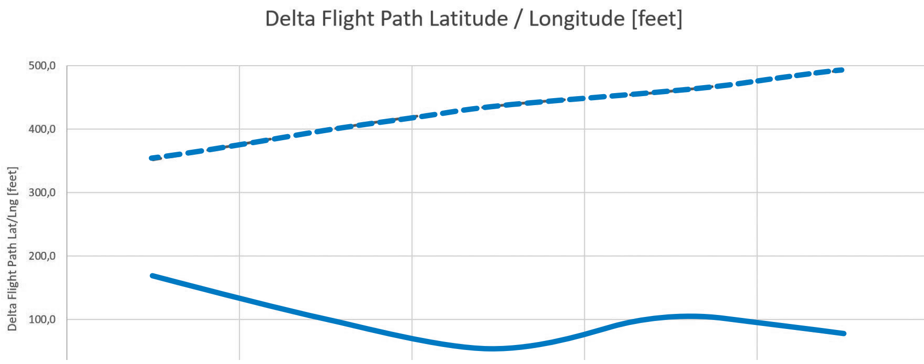


Figure 13. Distance in feet between reconstructed and recorded FDR (blue) and error tunnel (dotted blue).

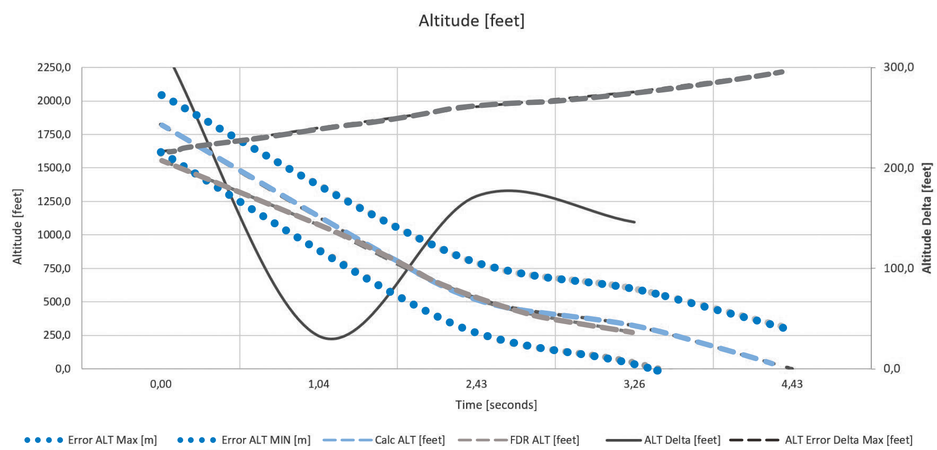


Figure 14. Reconstructed altitude (light blue), FDR altitude (light grey), error tunnel (dark grey, blue dotted), and difference (blue).

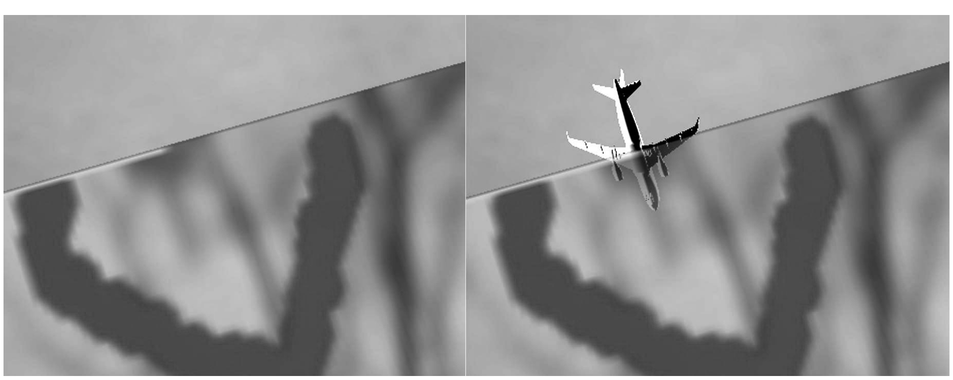


Figure 15. First frame of video showing aircaft only partially.

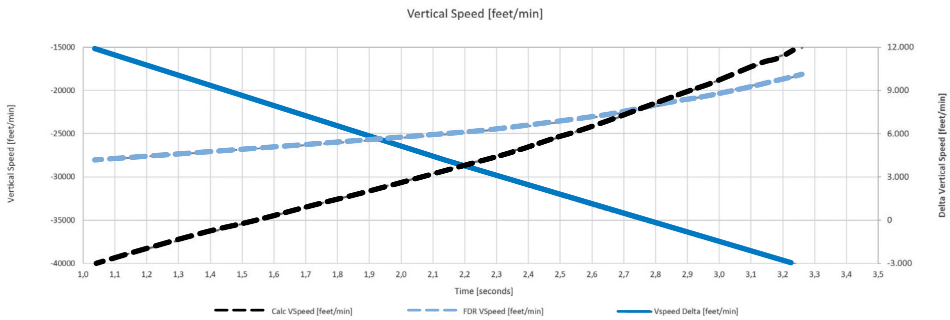


Figure 16. Calculated vertical speed (black), recorded FDR vertical speed (light blue), and difference value (blue).

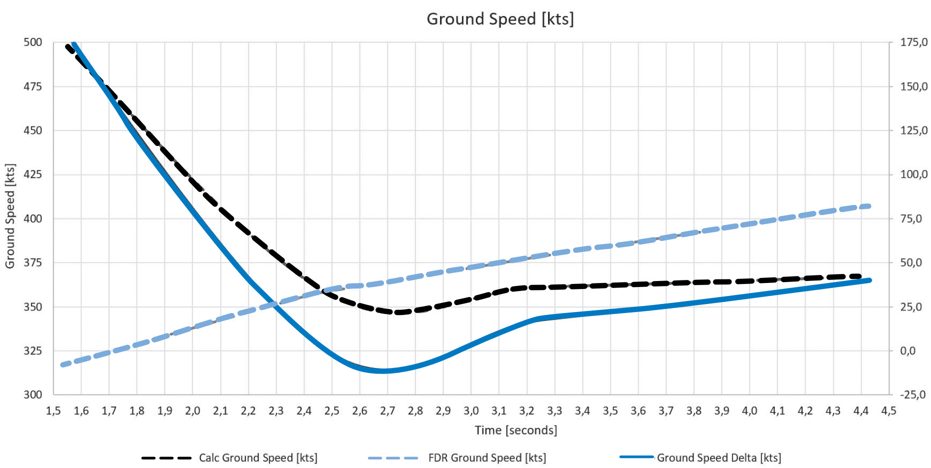


Figure 17. Calculated ground speed (black), FDR ground speed (light blue), and difference value (blue).

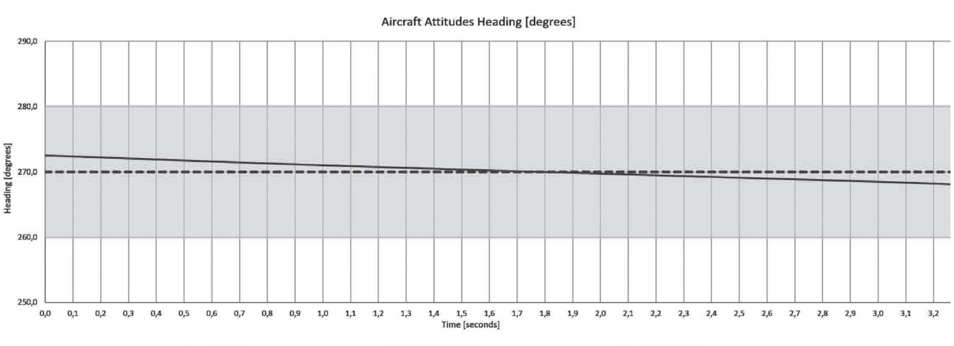


Figure 18. Reconstructed heading attitude (dotted lines) and recorded FDR heading (full line).

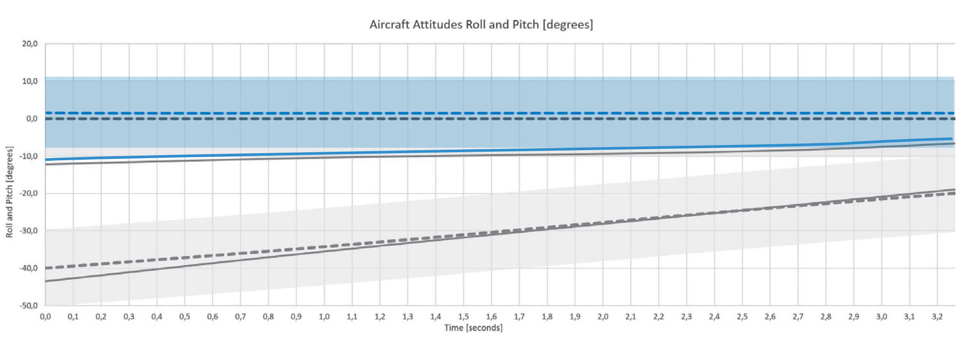


Figure 19. Reconstructed pitch/roll data (dotted lines) and recorded FDR data (full lines).

> **"Flight data that is reconstructed based on video information is applicable!"**

that the aircraft reduced its descent rate from -39.800 feet/minute to -15.000 feet/minute. The recorded FDR data showed that the B-767 reduced its decend rate from -28.000 feet/minute to -18.240 feet/minute within 2 seconds. The difference between the reconstructed data and recorded FDR data showed in the beginning quite a large difference up to 10,000 feet/minute. This was possibly due to the fact that the aircraft was only partially visible in the video and that the recording rate of the security camera was a relatively low one frame per second, as shown in Figure 15.

Figures 18 and 19 show the reconstructed attitude data for heading (dotted lines), roll (blue), and pitch (dotted lines). The calculated data is shown as dotted lines. The heading, pitch, and roll values fit very well with an offset of less than +/- 10 degrees.

Conclusion

The reconstruction of flight data based on video information is capable, and the data is applicable. The accuracy of the reconstructed data depends on the location accuracy of the video source position and reference objects, as well as on the frame rate of the video and its resolution. Further, the attitude data could be reconstructed very well within the experienced accuracy.

The more video sources that are avialable, the better the approximated positions can be calculated and cross-checked.

In parallel to the increase of digital data, more and more video footage is available. The capability of this method can support to reconstruct data, based on video information, but also the combination of recorded data and video information can provide additional important details. ◆

Why Did the Helicopter Collide With Trees?

Investigating the Causes from Analysis of Images and Sounds

By Koji Fukuda, Deputy Investigator for Aircraft Accidents, Japan Transport Safety Board

Currently, 75 helicopters are operated by 55 local governments in Japan for the purpose of firefighting and disaster prevention. For similar purposes, there are other services such as emergency medical service (EMS), police, the Coast Guard, and the Self Defense Force. The firefighting disaster prevention helicopters are operated under guidelines made by each local government independently. They are single-pilot operations even though they are medium-sized helicopters of about 5 tons. The pilots are not required to have instrument flight licenses. And crews are not transferred among other local government teams. This case is an example of a firefighting and disaster prevention helicopter accident in which all nine people were killed. The helicopter was not equipped with a recording device such as a black box, so the investigation required considerable effort to determine what occurred and why it happened.

There was a mysterious video taken on the aircraft that seems to show that when approaching trees, the helicopter collided with the trees without avoidance. To get a real sense of the accident, investigators were required to conduct a drone investigation and to analyze the images and sounds recorded in the video in various novel ways.

Summary of the Accident

On Sunday, March 5, 2017, a mid-sized rescue helicopter, a Bell 412, operated by the Nagano Fire and Disaster Prevention Aviation Center took off from Matsumoto Airport to go to rescue training and collided with trees and crashed into the mountain's slope while flying toward the training site near the summit at 13:33. There were nine persons on board the helicopter, including a captain and eight others, and all of them suffered fatal injuries. The helicopter was destroyed, but there was no outbreak of fire.

Onsite Investigation

The three investigators went to the site the next day. The accident site was on a snowy mountain, and the roads leading to the site were not cleared. The large rescue vehicle had reached near the site. Our rental car had studless tires, so I thought it was fine, but it was useless. I had to push the car many times on a road like an inclined ice rink that was hard to walk.

Lesson 1: Select a four-wheel-drive car on snowy roads. Not enough with studless tires.

Drone Investigation

This JTSB accident investigation was the first time the agency used a drone to collect onsite data. The drone was used not only to take photographs from above the crash site, but also allowed the investigators to create one fine 2-D image (Ortho Mosaic) or 3-D images by analyzing the image data taken continuously and the data of the position and the altitude of the drone.

Lesson 2: The effectiveness of the drone for accident investigation is not just to obtain aerial photos.

Location Survey (Laser Range Finder and GPS Receiver)

The position and height of the cut trees could be measured easily and clearly by using a laser range finder (TruePulse 360, Laser Technology) and a GPS receiver (MMCX: Mobile Mapper CX, Magellan Navigation). As described in the report, these tools enabled the investigators to see more details of the accident site than what was available from the drone investigation.

Lesson 3: Easy location survey with laser and GPS. (Of course, you need tools and training.)

(Adapted with permission from the author's technical paper Why Did the Helicopter Collide with Trees? Approach the Causes from Analysis of Images and Sounds *presented during ISASI 2019, Sept. 3–5, 2019, in The Hague, the Netherlands. The theme for ISASI 2019 was "Future Safety: Has the Past Become Irrelevant?" The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Image Analysis of Video Taken on the Helicopter

Since the helicopter was not equipped with a recording device such as a black box, it was difficult to determine fact information. However, the camera attached to the rescuer's helmet was taking a video of the situation from the middle of flight until the accident. The video shows that the weather at the time did not interfere with the flight.

The helicopter gradually approached the mountain surface covered with trees at a constant attitude and speed and crashed into trees. That the helicopter was flying normally and then, without an avoidance maneuver, collided with trees as it gradually approached is highly unusual. What happened? Nothing happened. Why did the pilot fail to avoid? This was a shocking question that I had to keep asking until the end of the investigation.

Estimating the position and altitude of the helicopter over time by analyzing still images with the video stopped and then estimating the flight path by linking the images was possible. We knew that the helicopter took off from the airport, headed northeast while climbing above the city, entered the airspace above the mountains, and turned right. It is highly probable that it headed toward Mt. Hachibuse in continuing roughly level flight at a speed of about 100 knots. The helicopter's altitude above ground level (AGL) became lower gradually, and the tree-covered mountainside was looming ahead. The helicopter collided with trees while maintaining attitude and speed.

The helicopter leveled off at about 1,740 meters. It is somewhat likely that this was because the helicopter was trying to ensure the safety altitude of 150 meters or higher from the destination, the helipad, with an elevation of about 1,580 meters. It is highly probable that while maintaining the maximum safety altitude, the helicopter took neither the avoidance route at a constant altitude by directly heading for the helipad nor the avoidance route by climbing. Instead, it continued to fly toward Mt. Hachibuse at a constant altitude after turning right. Its AGL became lower while flying into and over the mountains region, and the helicopter approached the ground. It is highly probable that the helicopter flew into an uncontrollable condition as it crashed its fuselage and main rotor blade (MRB) into trees over a distance of approximately 40 meters. It is highly probable that the helicopter turned upside down and collided with an approximately 40-degree slope from its nose. It is also highly probable that it was four seconds later after the helicopter collided with trees when the video recording stopped with the impact of the helicopter crashing into the ground.

Lesson 4: Analysis of flight tracks from video taken on the helicopter.

Detailed Investigation of the Helicopter

From the scattering of debris from the accident site, it was estimated that the helicopter hit a tree and became uncontrollable and crashed. The investigation of the details of the airframe was conducted in June when the snow melted and the debris was salvaged from the mountain, and no anomalies of the airframe and engine were found from the debris.

Voice Analysis of Video Taken on the Helicopter

An alarm sound and sounds indicating abnormality of the helicopter were not recorded until it collided with trees. A sheet recorded by a mechanic sitting in the left seat was found, which revealed that the crew of the helicopter had been performing engine performance tests after takeoff.

Furthermore, by combining and analyzing this one sheet and the in-flight video and audio, the in-flight situation became clearer. At first, I had no idea what the crewmembers were talking about, but it became clear that they were checking the engine, and the content of the conversation became more understandable. Furthermore, by analyzing the engine noise, it was possible to estimate the throttle and engine N2 governor operation status during engine check, which supported the fact that an engine check was performed.

An analysis of the audio recorded by the video camera found that a spectrum of approximately 22 Hz was recorded at a constant frequency from the beginning of the video until 4.0 seconds before the audio recording stopped. Assuming that the sound was generated by the MRB, this would be equivalent to approximately 330 rpms. The 100% number of MRB revolutions is 324 rpms.

An audio spectrum of approximately 3,300 Hz and an audio spectrum of approximately 3,400 Hz were transmitted at a constant frequency, respectively. However, immediately after the voice of "minus two," in the former case, the frequency increased by approximately 200 Hz, while in the latter, the frequency decreased by approximately 200 Hz. Those frequencies returned to original frequencies, and they were constantly transmitted again, immediately after the voice saying, "I return it."

Koji Fukuda

It is highly probable that there were no abnormalities in the helicopter's engines from the time of takeoff until transition to level flight. As the engine had been operating when the helicopter crashed, it is highly probable that the MRB had been rotating at constant rpm until the helicopter collided with trees. It is highly probable that the helicopter was conducting engine data checks enroute from takeoff. When the helicopter commenced turning right above the mountains, it is probable that engine checks had been completed. It is highly probable that the mechanic was conducting engine checks, concentrating on the flight instruments, and hardly watched outside. And it is somewhat likely that his attention was focused on addressing the engine data check records even after the engine checks were completed, but this could not be specified.

Since the engine check was finished 2 minutes before the collision with trees, it was difficult to link the relationship with the collision.

Lesson 5: Analysis of human voices requires understanding what the person is doing.

Lesson 6: We can understand the situation of the engine by analyzing the sound.

Captain's Helmet Visor

From the fact that the captain's helmet visor had an impact mark near the center and approximately half of its right side was missing, although the visor cover was not broken, it is probable that the visor received an impact from the right side while in a lowered state. From the fact that the captain's visor was raised at the time of takeoff, it is probable that the captain lowered his visor while in flight. The captain's right upper arm moved 1 minute and 30 seconds before the collision with trees. It is somewhat likely that it was because turning right at that time would have the helicopter face the direction close to the sun, and the captain lowered his helmet visor to ward off the glare of the sun; however, this could not be specified.

With the visor lowered, the outside view was clear and not too bright, and the instrument indicators were readable. Therefore, it is probable that the use of the visor had no effect on flying the helicopter. However, with the visor lowered, the opening state of eyes and the facial expressions were not recognized from outside.

Verification by Same Type Helicopter

1) Position of the mechanic's right hand

When the CP lever was moved up to the same position as at the time of climbing, and the right hand was extended to the ITT trim switch, almost the same composition as in the image of video camera (-4 minutes and 5 seconds) was reproduced.

2) View from the cockpit

The inspection was conducted after parking the same type of helicopter with a magnetic heading of 150 degrees, the same heading as at the time of accident. It was conducted at about 13:40 on April 10, 2018; however, the pilot's face was not exposed to direct sunshine. The pilot's view was not blocked, and it was possible for him to recognize visually the obstacles lying ahead in keeping the piloting posture, when either only glancing at the instruments without moving his head or facing the instruments and looking at them. However, when the body was bent forward and the head was lowered a little, the glare shield blocked the forward view (the horizon). Therefore, it seems that when the obstacles lying ahead are approaching, the approaching obstacles may not be recognized visually. With the posture of the mechanic mentioned above (1), the forward view was blocked because the position of the head was lowered.

When looking at the pilot's face with the visor lowered, the opening state of eyes and his facial expressions were not recognized.

3) Different views with and without visor

The different views with and without the visor that is attached to the helmet was confirmed. Without the visor, the contrast between outside and inside the helicopter was clear, and when looking outside, it seemed that the view was too bright. Immediately looking at the instruments inside the helicopter, it was not to say that anything could not be seen but eyes seemed tired. With the visor lowered, the outside view was clear and not too bright. Immediately looking at the instruments inside the helicopter, it seemed a little dim, but the instrument indicators were readable.

Lesson 7: Verification will require new discoveries or proofs of certainty.

ELT

The helicopter was equipped with an emergency locator transmitter (ELT) with switches (G switches) designed to automatically activate with impact from six directions. When an examination was conducted by an agent of the manufacturer following the accident, it was found that the ELT had not activated in this accident. The examination after the accident revealed that the G switches that should activate with impact from the front, left, above, and rear were stuck because the bulb-shaped parts inside the ELT were rigidly fixed.

Because the ELT is an important piece of equipment whose activation or nonactivation when an accident occurs can affect human survival, inspection of items established by the manufacturer must be carried out and certainly within the time period set by the manufacturer. Therefore, the contents contained in the manufacturer's maintenance manual, including that pertaining to functional inspection of G switches, must be clearly stated in the ELT system maintenance manual of the certified workplace, and the person who conducts an inspection or maintenance must leave records of that inspection or maintenance. Even when a G switch satisfies technical requirements at the time of its manufacture, it may deviate from those requirements by becoming stuck or degraded with the passage of time. Therefore, it is important to make periodic inspections of ELT G switches mandatory.

The JTSB recognizes this as an important issue because there are many accidents in which the ELT signal was not transmitted due to the problems with the ELT and installation and operation methods of the antenna, and ELT problems hinder early detection of survivors,

Lesson 8: The ELT is important for saving lives.

Flight Recorder

For aircraft that are required to fly within small safety margins in activities involving lifesaving and similar operations, the installation and utilization of a flight recorder can prove useful in better understanding the characteristics and flight operations by regularly analyzing and evaluating the flight conditions in ordinary flight operations. If an incident or an accident occurs, it will contribute significantly to precisely identifying its causes and developing recurrence prevention measures. Accordingly, equipping such helicopter with flight recorders is considered a high priority, and it is desired to study for its realization and promotion with the cooperation of relevant parties.

Lesson 9: A flight recorder is important for accident investigation.

Not Taking Avoidance Maneuver

It is somewhat likely that there were no abnormalities in the helicopter until it collided with trees. It is somewhat likely that during the time from when the helicopter turned right above the mountains until when the captain's right upper arm moved, at least there was nothing wrong with the captain's condition like loss of consciousness.

Voices were not recorded after a rescuer said, "Right rear clear" until the helicopter collided with trees. From this fact, it is somewhat likely that all members on board had not responded to the approaching danger. However, there is a possibility that the extension microphone of the video camera might have come off the helmet, but this could not be specified.

It is certain that the captain was under treatment for particular diseases, and he was taking the prescribed medicines. However, it could not be clarified whether the captain was subject to influence of those previous diseases, which would hinder the performance of aviation duties or not, and whether the captain took those prescribed medicines during the flight and he was affected by those medicines or not.

Regarding the helicopter's not taking avoidance maneuver, it is somewhat likely that the captain could not recognize the dangerous situation and did not take any avoidance maneuver because he was in a state where the arousal level was lowered with microsleep, and so on, because of fatigue and time difference. However, it was not possible to clarify whether he actually fell into such a state.

The captain should keep watch so as not to collide with other objects. If, for some reason, he could not keep watch, it is highly probable that it was necessary for him to have instructed the mechanic to temporarily keep watch for him.

If the mechanic did not question the captain about the flight route and the altitude, it is somewhat likely that his attention was focused on the instruments and the log papers, and therefore he did not keep sufficient outside watch; however, this could not be specified.

If the rescuers in the cabin did not question the captain about the flight route and the altitude, it is somewhat likely that they thought that the highly experienced captain and the mechanic were grasping the outside situation and keeping forward watch. Or perhaps that they got used to low-altitude flight so much that their sensitivity to the danger became lower due to rescue mission and training; however, this could not be specified.

It is important for conducting safe helicopter operations that all crewmembers display

CRM skills under the appropriate leadership of the captain. It is probable that the mechanics can be actively used as cooperative resources to realize safe helicopter operations in the flight operations at the center. Therefore, it is desired that the center will endeavor to establish CRM appropriately based on the center's flight operations.

Lesson 10: Safety of CRM and two-person operation.

Probable Causes

It is highly probable that the accident occurred because the helicopter did not take avoidance maneuver even while getting closer to the ground.

Regarding the helicopter's not taking an avoidance maneuver even when getting closer to the ground while flying in a mountainous region, it is somewhat likely that the captain could not recognize the dangerous situation because the captain was in a state where the arousal level was lowered; however, it was not possible to clarify whether he actually fell into such a state.

Other Identified Safety Matters

It is highly probable that the captain had a past medical history and a surgical history and he was under treatment with medication. However, it is certain that he had obtained the aviation medical certificate without making a self-report on his medical information. In the examination for the aviation medical certificate, it is difficult to make an appropriate judgment on whether to conform to the standards of aviation medical examination unless applicants declare their medical history and information accurately. Applicants for the aviation medical examinations must accurately make a self-report on their medical information to apply for the aviation medical certification. Regarding this matter, the JTSB said to the Ministry of Land, Infrastructure, Transport, and Tourism that it is necessary that the Civil Aviation Bureau thoroughly instruct aircrews to accurately make a self-report on their medical information to apply for the aviation medical certification. If nonconformity is suspected, they must not engage in the performance of aviation duties and must receive instructions from the designated aviation medical examiners and others, even if their aviation medical certificate is still within the validity period.

In this accident, the captain of the helicopter in operation by one pilot was taking photos during the flight at such a low altitude that shall not be allowable from the aspect of safety, and it is probable that there might have some cases where keeping outside watch was not conducted appropriately. The center conducts flight operations by one pilot (the captain) in accordance with the regulations. However, it is desired that the center study using a two-pilot crew when possible.

Lessons

- *Lesson 1: Select a four-wheel-drive car on snowy roads. Not enough with studless tires.*
- *Lesson 2: The effectiveness of the drone is not just aerial photo.*
- *Lesson 3: Easy location survey with laser and GPS. (Of course, you need tools and training.)*
- *Lesson 4: Analysis of flight tracks from video taken on the helicopter.*
- *Lesson 5: Analysis of human voices requires understanding what the person is doing.*
- *Lesson 6: We can understand the situation of the engine by analyzing the sound.*
- *Lesson 7: Verification will be new discoveries or proofs of certainty.*
- *Lesson 8: The ELT is important for saving lives.*
- *Lesson 9: A flight recorder is important for accident investigation.*
- *Lesson 10: Safety of CRM and two-person operation.*

Summary

In March 2017, a rescue helicopter operated by the Nagano Fire and Disaster Prevention Aviation Center took off from Matsumoto Airport and collided with trees and crashed into the mountain's slope while flying toward the training site. In August 2018, 1.5 years later, another accident involving a firefighting and disaster prevention helicopter occurred and killed nine people in the neighboring prefecture. This is still under investigation, but it has become a major social problem in Japan due to the two accidents with a number of victims happening in two consecutive years. I do not yet know whether the two accidents had something in common, but it would be disappointing to think that if the 2017 accident investigation report was published in July instead of October, it would have had a deterrent effect.

Last Lesson: Report should be published as soon as possible. ◆

Competency-Based Education:

A Framework for a More Efficient and Safer Aviation Industry

By Dr. Flavio A.C. Mendonca, Ph.D., Assistant Professor; Dr. Julius Keller, Ph.D., Assistant Professor; and Dr. Brian Dillman, Ph.D., Associate Professor, Aviation and Transportation Technology, Purdue University

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(Adapted with permission from the authors' technical paper Competency-Based Education: A Framework for a More Efficient and Safer Aviation Industry *presented during ISASI 2019, Sept. 3–5, 2019, in The Hague, the Netherlands. The theme for ISASI 2019 was "Future Safety: Has the Past Become Irrelevant?" The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

Aircraft design and reliability as well as pilots' education and training have steadily and significantly improved in the last 20 years. Nevertheless, high-profile accidents still occur, even when the aircraft and related systems are operating adequately. Controlled flight into terrain, runway incursion accidents, and loss of control in flight are examples of mishaps in which inadequate decision-making, poor leadership, and ineffective communication are frequently cited as contributing factors. Conversely, the investigation of accidents (e.g., US Airways Flight 1549, in the U.S. on Jan. 15, 2009) and serious incidents (e.g., TAM Linhas Aereas Flight 3756 in Brazil on June 17, 2011) have shown that flight crews must be flexible and adaptable, think outside the box, and communicate effectively to cope with situations well beyond their individual expertise.

Conventional flight training requirements generally consider only the so-called "technical skills" and knowledge. Interestingly, pilot competencies in important areas such as leadership, teamwork, resilience, and decision-making are not explicitly addressed. The aviation system is reliable but complex. Thus, it is unrealistic to foresee all possible aircraft accident scenarios. Furthermore, there are many organizational variables that could have a detrimental impact in the flight deck of an aircraft.

To further improve flight training, the global aviation industry is moving toward evidence-based training (EBT). EBT provides rigorous assessment and assurance of pilot competencies throughout their training, regardless of the accumulated flight hours. EBT programs must identify, develop, and evaluate the competencies required to operate safely, effectively, and efficiently in a commercial air transport environment. Moreover, EBT needs to address the most relevant threats according to evidence collected in aircraft mishaps, flight operations, and training.

There is some emergent empirical evidence showing that high-quality education and flight training have a greater impact on efficiency and safety than just the total flight hours accumulated by entry-level pilots. Advanced qualification programs are utilized in Part 121 operations. A similar model with the development and assessment of defined competencies can lead to better education and flight training outcomes in collegiate aviation. In keeping with this transition to a competency-based educational model and given an understanding of the benefits of an EBT program for aviation safety and efficiency, the Purdue School of Aviation and Transportation Technology is redesigning its professional flight program. The benefits of this program will include

- establishing advanced training processes that will enhance the acquisition of knowledge, skills, and abilities by the future professional pilot workforce that meet or exceed safety standards;
- amplifying the quality of education and flight training over flight hours; and
- developing empirical data to inform decision-makers such as program leaders and regulators.

The goal of this transformation process is to develop a competency-based program that will attend to academic and regulatory requirements and that are in alignment with the major aviation stakeholders' standards and recommendations. It is important to note that a competency-based degree will require graduates to demonstrate proficiency in competencies that are valued by the aviation and aerospace industries. Therefore, this will be beneficial for both the graduates as well as the industry.

Aircraft Accident Investigation Process

Human errors have been implicated in more than 80% of aircraft accidents. However, those errors should be viewed from a systemic perspective since expressions such as procedural violations, human errors, and/or poor CRM will have limited value in preventing future mishaps. Latent conditions arising in the managerial and organizational sectors frequently facilitates a breach (or breaches) of the complex aviation system's inherent safety defenses. In simpler terms, latent conditions often permit or even motivate unsafe acts by the flight crew (and other aviation professionals).

According to ICAO, the accident investigation process is comprised of three phases: data collection, data analysis, and presentation of findings. The data collection process should focus on obtaining data relevant to the accident, which will include human factors. The data analysis should be concurrently conducted with the data collection process. The analysis of data frequently triggers additional needs that require further data collection. During those two phases investigators should scrutinize whether errors and/or violations by the pilots suggest deficiencies in necessary knowledge, abilities, and skills for efficient and safe job performance. Moreover, investigators should assess if identified flaws in pilot competencies result from training inadequacies.

When the active failures and latent conditions have been identified, the safety investigators should elaborate safety recommendations to prevent the reoccurrence of similar accidents. It is important to note that safety recommendations will generally address any possible combination of three factors: training, technology, and regulations.

The following section highlights the investigative process and outcomes for the selected accidents.

Pilot Competencies and Aviation Safety

The global aviation industry is moving toward EBT and rigorous assessment and assurance of pilot competencies throughout their training, regardless of the accumulated flight hours. The aim of the EBT program is to identify, develop, and evaluate the competencies required to operate safely, effectively, and efficiently in a commercial air transport environment while addressing the most relevant threats according to evidence collected in aircraft mishaps, flight operations, and training.

In 2009, Colgan Air Flight 3407, a Bombardier DHC-8-400, crashed during an instrument approach to Buffalo Niagara International Airport in Buffalo, New York, killing two pilots, two flight attendants, 45 passengers, and a person on the ground. The NTSB identified several issues associated with the pilots' decision-making, teamwork, and communication processes. The report emphasized poor leadership by the captain as a factor in this mishap. The board members suggested that leadership training for upgrading captains could both standardize and reinforce the leadership competency of a pilot-in-command during air carrier operations. Lastly, the board issued two safety recommendations covering leadership training for upgrading captains at 14 Code of Federal Regulations Part 91K, 121, and 135 operators.

The Colgan accident became a major catalyst of significant changes in the U.S. aviation industry, mostly focusing on flight crew training and qualifications. The Airline Safety and Federal Aviation Administration Extension Act (Public Law 111-216), passed in 2010, requires pilots to hold an airline transport pilot (ATP) certificate in order to be hired by a U.S. air carrier. In order to possess an ATP certificate, pilots must be 23 years old and have at least 1,500 flight hours. This rule, however, allows some age and flight-hour reductions for specific military and FAA-approved post-secondary academic experiences. Currently, this law has created major challenges for airlines to find and hire qualified pilots. Notwithstanding, accidents that occurred prior and after Public Law 111-216 have suggested that flight hours are not a good predictor of pilot's performance.

In another example, an Airbus A300-600, operating as UPS Flight 1354, crashed short in August 2013 during a nonprecision approach to Runway 18 at Birmingham-Shuttlesworth International Airport in Birmingham, Alabama. The aircraft was damaged beyond repair by impact forces and a postcrash fire. Both flightcrew members were killed as a result. The board highlighted several issues associated with poor decision-making and communication processes by the flightcrew members and inadequate leadership by the captain. The final report indicated several safety recommendations in which some called for improved communication processes by flight crews.

The FAA has mandated CRM for Part 121 operators since 1998. The CRM training provided by air carriers generally includes concepts such as leadership, communication, decision-making, and threat-and-error management. CRM training has enhanced aviation safety and efficiency. Nevertheless, aircraft accidents and incidents in which inadequate CRM processes are identified as contributing factors still occur. There is no empirical evidence to support the claim that more flight hours will make a pilot safer and/or more efficient. For example, the captain and the first officer of Colgan Air Flight 3407 had 3,379 and 2,244 total flying time, respectively. Similarly, the captain and the first officer of UPS Flight 1354 had 6,406 and 4,721 flight hours, respectively.

Aircraft design and reliability as well as flight education and training have steadily and significantly improved in the last 20 years. Nevertheless, high-profile accidents still occur, even when the aircraft and related systems are operating adequately along with experienced pilots. For instance, controlled flight into terrain, runway incursions, and loss of control in flight are mishaps in which inadequate decision-making, poor leadership and/or teamwork, and ineffective communication processes are frequently cited as contributing factors. Interestingly, pilots involved in the mentioned accidents were arguably experienced.

Conversely, the investigation of accidents, for example, US Airways Flight

1549 in the U.S. on Jan. 15, 2009, and serious incidents indicated that flight crews have to be flexible and adaptable, think outside the box, work as a team, and communicate effectively in order to cope with situations well beyond their individual expertise. Such abilities could reduce the risk, probability, and/or severity of accidents.

The investigation of aircraft accidents and incidents, an important reactive component of the elements contained in the safety management systems framework, allows the identification of the latent conditions and active failures contributing to the mishap. In addition, such a process often uncovers other deficiencies and hazards that, although not a causal factor to the mishap, could become a contributing factor in future safety occurrences if not effectively addressed. This process can support top-management (e.g., new and/or updated safety processes) and even state (e.g., new policies to promote safety) decisions regarding the development of mitigation strategies and corresponding effective allocation of frequently limited resources.

Therefore, in a "safety management environment, the accident investigation process has a distinct role, being an essential process that deploys when safety defenses, barriers, and checks and counterbalances in the system have failed." Nevertheless, findings of a well-conducted aircraft accident (or incident) investigation process will be transferred throughout the organization so that everybody will be aware of hazards and associated risks within specific areas of operation. Additionally, findings will lead to new or updated safety training so that personnel have the skills, knowledge, and abilities to perform their duties efficiently and safely. Safety promotion efforts are paramount to advancing desired outcomes.

Safety Management Systems (SMS)

SMS is a "formal, top-down business-like approach to managing safety risks. It includes systematic procedures, practices, and policies for the management of safety (including safety risk management, safety policy, safety assurance, and safety promotion)." It is a tool that establishes processes to identify hazards and mitigate the associated risks with

A slide shown during the authors' ISASI 2019 presentation.

a significant enhancement in aviation safety. It translates the organization's safety concerns into effective actions to mitigate hazards.

The benefits of an effective SMS include compliance with regulatory requirements, improved productivity and morale, a healthy safety culture, best use of the resources available, and more business opportunities leading to a competitive advantage. Most importantly, a robust SMS will reduce the risk (probability and/or severity) of aircraft accidents. SMS comprises four key components: safety policy and objectives, safety risk management, safety assurance, and safety promotion. Part of safety promotion is the process of training and education.

Often, conventional flight training requirements generally consider only the so-called "technical skills" and knowledge. Yet, pilot competencies in important areas, such as leadership, teamwork, resilience, and decision-making, are frequently not explicitly addressed. The aviation system is reliable but complex. Thus, it is unrealistic to foresee all possible aircraft accident scenarios. After all, there are many organizational variables that could have a detrimental impact in the flight deck of an aircraft.

Nevertheless, empirical evidence indicated that high-quality education and flight training have a more positive impact on aviation safety and efficiency than accumulated flight hours. A competency-based education program could provide pilots with technical and nontechnical competencies needed to safely and efficiently operate in a highly complex social-technical system. Developing a competency-based training program can be daunting. The following section outlines the development within a collegiate aviation flight training program.

Competency Development in Collegiate Aviation

By 2036, the aviation sector will need 554,304 new pilots, 106,800 new air traffic controllers, and 1.3 million aircraft maintenance personnel. Boeing's Pilot and Technician Outlook forecasts there is a need for 790,000 new pilots, 665,900 new technicians, and 923,179 new cabin crewmembers by 2037. However, focusing on U.S.-based demand versus supply, it is estimated that the demand is about three times the supply. As a result of this massive gap in supply, there is a severe pilot shortage across the nation, and this issue has garnered attention from the mainstream news media. As a result, most of the national and global conversations are focused on quantity rather than quality of the workforce. However, educators and researchers in several industries have advocated competency-based education for decades to focus on quality.

In the aviation industry, ICAO and

IATA have recognized the need to develop and evaluate the performance of flight crews according to a set of competencies. Interestingly, both ICAO and IATA encourage operators to identify and develop their own competency system and related behavioral indicators, encompassing the nontechnical and technical knowledge, skills, and attitudes to operate efficiently, effectively, and safely in the aviation industry. Early efforts to use a competency-based approach to develop the knowledge requirements, establish assessment tools, and run preliminary tests support the notion that a competency-based approach could (a) identify weaknesses in pilot candidates and (b) enable hiring airlines and training providers to improve the success rate in the initial training, thereby simultaneously addressing both quality and quantity aspects of pilot training.

ICAO defines competency as a "combination of knowledge, skills, and attitudes required to perform a task to the prescribed standard." According to the U.S. Department of Education, a competency-based program leads to better student engagement because the content is relevant and tailored to each student's unique needs. Other benefits of a competency-based program include more efficient use of technology, identification of target interventions to meet specific learning needs of students, increased productivity and reduced costs, and the incorporation of active learning strategies into the curriculum. Thus, development and assessment of defined competencies can lead to better education and flight training outcomes. In order to develop competencies, a rigorous process needs to be partaken.

Figure 1. Conceptual model of professional flight competencies.

A consensus modeling approach was utilized to facilitate the process of developing the competencies described herein. Consensus decision-making refers to all members of a group agreeing on the chosen tasks, in this case competencies. A high level of participation between both the faculty and industry representatives, all leaders in their respective areas, was obtained. The first task of the faculty was to conduct a thorough literature review and identify 10 competencies. Once the 10 competencies were identified, focus groups and discussion were completed. These groups were a mix of faculty, flight instructors, limited-term lecturers, and industry representatives.

Additionally, a session was held with faculty from the other majors: aviation management, aeronautical engineering technology, and unmanned aircraft systems to provide another external perspective. The goal of the faculty was to write the competencies so that assessment in the classroom, flight, and simulators was feasible. Lastly, an outside representative from a university that focuses on abilities-based curriculum was sought. Some competencies were combined (e.g., intercultural and teamwork), leading to six pilot competencies in technical and nontechnical areas. The expert concurred with the selected and defined competencies after revisions. The results section outlines the unanimously selected competencies, description and rationale, and broad outline of the assessment strategies.

Both technical and nontechnical competencies were identified through extensive literature review and external review. The six program competencies are as follows:

- Technical excellence,
- Communications,
- Leadership,
- Decision-making,
- Resilience, and
- Teamwork.

The professional flight degree program seeks to develop these competencies within an integrated, high-consequence, and meaningful educational environment. Figure 1 illustrates how technical excellence is at the center of what we do. However, all competencies are connected and influence each other.

Each competency will be mapped to specific learning experiences within the flight program, and it will be developed at one of three levels of proficiency: Emerging (Level 1), Developing (Level 2), or Proficient (Level 3). Thus, over the length of the professional flight degree program, each student will progressively develop their competencies from emerging through proficient levels. Finally, at the conclusion of the program, all graduates will be expected to achieve proficiency across all the competencies.

This competency-assessment is grounded in Bloom's taxonomy to include psychomotor, cognitive, affective, and interpersonal aspects. Bloom's taxonomy will be used to describe instructional objectives in the professional flight degree program educational documents, conduct objectives-based assessments on the professional flight degree program students' achievement, and for aligning curriculum and assessment. The three suggested proficiency-level descriptors for the professional flight degree program are as follows:

Level 1–Emerging: Students within this category demonstrate airmen certification standards for the appropriate certificates and ratings, learning basic and some advanced aviation knowledge and skills for immediate needs, as well as beginning to employ appropriate academic and discipline-specific characteristics.

Level 2–Developing: Students within this category are challenged to reflect upon strengths and weaknesses pertaining to the airmen certification standards, increase their aviation knowledge and skills in an increasingly greater number of situations, and learn a wider variety of professional attributes.

Level 3–Proficient: Students within this category shows appropriate knowledge, skills, and abilities for operating transport-category aircraft, exhibit lifelong learning habits, and demonstrate the ability to conduct themselves in accordance with discipline professional standards.

A competency-based collegiate professional flight degree program could yield the following advantages: (a) significantly enhance aviation safety; (b) establish advanced training processes that will enhance the acquisition of knowledge, skills, and abilities; (c) meet or exceed personnel safety standards; and (d) emphasize quality of education and flight training over flight hours.

Discussion and Conclusions

The aviation industry plays a major role in global economic activity and development. "One of the key elements to maintaining the performance of civil aviation is to ensure safe, secure, efficient, and sustainable operations at the global, regional, and national levels." According to Airbus, safety efforts have steadily reduced the rate of aircraft accidents since 1960. During the last two decades, there has been a 70% and 95% reduction in the hull losses and fatal accident rates, respectively. Such achievements can be largely attributed to new technologies (e.g., traffic collision avoidance system), effective safety regulations and policies (e.g., SMS), and continuous improvements in safety training (e.g., CRM).

The global air traffic is expected to double every 15 years. The fleet growth rate is overwhelming, with the industry delivering approximately 2,000 aircraft per year. More flights will most likely increase the number of accidents unless the aviation industry challenges itself with more ambitious approaches to reduce the accident rate. The current and expected growth of the aviation industry associated with the mandatory retirement age for the baby-boom generation has created a demand for pilots all over the world that exceeds supply. Thus, it is expected that new pilots will often become air carrier captains at a younger age and with less flight experience than in the last decades.

Moreover, with increasing substantial changes in operational and/or organizational complexity, rapid advances in aircraft technology, single-pilot commercial operations, and fewer predictable hazardous conditions, training must reflect the relevant needs of professional pilots. A flight competence-based degree approach could provide the aviation industry effective opportunities to address several issues afflicting the industry. Most importantly, it could provide pilots with the knowledge, skills, and abilities to respond effectively to unanticipated hazards and threats that could (will?) arise during flight operations. A competency-based flight program represents a paradigm shift in flight crew training. Such an approach is focused on developing and/or strengthening competencies that are fundamental to operate effectively, efficiently, and safely in an extremely complex social system while addressing hazards and associated risks identified during the investigation of aircraft accidents, incidents, and flight operations. As bonus benefits it will

- provide empirical data that could assist in expediting the development of performance and expertise among new pilots;
- develop empirical data that could assist aviation stakeholders, especially policy makers, in assessing the effectiveness of the "1,500 hour rule";
- provide opportunities for research;
- optimize the safety training (e.g., CRM) of pilots; and
- significantly enhance aviation safety.

The organization of the proficiency-level descriptors represents professional flight skills development across a continuous spectrum of increasing proficiency, starting with basic competencies professional flight students possess when they enter the program and concluding with the lifelong learning in which all aviation professionals engage. The three levels represent three stages of development, describing expectations for knowledge and skills at each level as the breadth of capabilities expands and concepts transition from ideas to practice.

As the development of the hybrid competency-based education model to be employed in the program progresses, program faculty will develop the related student learning outcomes based on the competencies presented, using the suggested proficiency-level descriptors to delineate the outcomes into measurable categories. Associated competencies will then be measured for the three levels (developing, emerging, and proficient) of student achievement. Each competency will need to be mapped to the proper course for evaluation. Formative and summative assessments must be developed along with appropriate rubrics. Testing and research processes will have to be conducted to ensure reliability and validity. Additionally, a robust data management plan will have to be developed for continuous improvement efforts.

The development of competencies based on empirical data will provide the faculty another means of assessment within the classroom and flight courses. This data will allow for more precision in understanding student progress as well as the program overall. Furthermore, in the future, there may be opportunities for the development of a true competency-based education program in aviation. The processes explained in this study to determine and assess the professional flight program competencies, as well as the corresponding student learning outcomes using the proficiency-levels descriptors, will lead to a more comprehensive and consistent learning process across the courses that comprise the professional flight program curriculum.

Practical Implications

The core competencies will be fully integrated within different forms of pilot training (e.g., core courses, flight simulator) so that students can develop their technical and nontechnical competencies. In addition, training will include challenges and the context of flight activities flight crews face during regular flight operations. Strategies used to develop, strengthen, and assess the identified competencies will be based on course needs identified at an industry level. Those needs will be determined by analyzing large datasets that will include data from flight operations quality assurance and line operations safety audits programs and from the investigations of aircraft accidents and incidents.

Nevertheless, it is also important to consider situations in which flight crews' competencies contributed to effective crew performance and to the successful management of challenging situations. Most importantly, we truly understand that feedback from ISASI is paramount for this flight competence-based approach to achieve one of the most expected and desired outcomes—safety enhancement. ◆

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ANALYZING LARGE AND COMPLEX IMAGE COLLECTIONS

(Adapted with permission from the authors' technical paper Analyzing Large and Complex Image Collections During a Safety Investigation *presented during ISASI 2019, Sept. 3–5, 2019, in The Hague, the Netherlands. The theme for ISASI 2019 was "Future Safety: Has the Past Become Irrelevant?" The full presentation can be found on the ISASI website at www.isasi.org in the Library tab under Technical Presentations.—Editor)*

On July 17, 2014, Flight MH17 crashed due to the detonation of a warhead launched from the eastern part of Ukraine using a Buk missile system. Because the remains of the airplane were located in an area of ongoing armed conflict, it was not possible to secure the physical investigation material, and an extensive investigation could not be conducted at the crash site right away. For this reason, an important part of the investigation by the Dutch Safety Board consisted of the manual analysis of the photos and videos acquired by Ukrainian and Malaysian investigators, the Australian Federal Police, the OCSE, journalists, and local people. In total, approximately 20,000 photos and 3,000 videos were collected.

In this paper, the photo and video analysis performed by the Dutch Safety Board will be described, the lessons learned, and the ways we have sought to improve the efficiency of the analysis of large and complex image collections to support future investigations. Finally, the application developed based on these lessons and a use case to show how the application can be used are also presented.

Image Analysis in the MH17 Crash Investigation

The overarching question of the investigation was what happened to Flight MH17. The main goal of the photo and video analysis was to find which wreckage pieces were found where. Once access was gained to the crash site, having this information made it more efficient to decide which pieces to get and where to get them. Furthermore, it assisted in answering the main question by providing information about the breakup sequence and the state of the wreckage pieces right after the crash.

The analysis started fairly simplistic by filtering out unwanted files (e.g., nonimage files, thumbnails, low flight resolution images) and by sorting images into folders with several categories, such as engines, wings, cockpit, etc. Due to the complexity and large number of images, this quickly became hard to manage. Many images contained multiple objects; many images could not be classified right away, as it was unclear what was actually shown on the image; it was hard to keep track of which images had been seen by the investigators; our PCs and Windows Explorer could not keep up with displaying large folders with many images; and going through all the images one by one was very time consuming.

A software tool called Netclean Analyze (now known as Griffeye Analyze) was suggested by Team High Tech Crime of the Dutch police. This tool allows for quickly browsing through many images by generating thumbnails, and it allows for tagging images with multiple tags, which can subsequently be used to filter. It solved several of the aforementioned problems. However, it was still time consuming, and the interface to tag images was somewhat cumbersome, requiring multiple clicks.

The image and video analysis resulted in several "products" for the investigation team and for the report. First, an overview was created of the whole crash site, subdivided into smaller areas, both based on their location and on the airplane parts that were found there (see Figure 1). Together with the side view (see Figure 2), it gave a quick and clear idea of the general breakup sequence.

Then, for each area a more detailed map was created with the exact location of all the identified wreckage pieces (see Figure 4, page 26). In some cases, it was easy to find the exact location, due to GPS data included with the photo. In most cases, however, no GPS data was available, and satellite imagery and the linking of multiple photos were needed to pinpoint the location. For example, the piece in Figure 3 was found by finding the two houses in the background, one with a green roof, a slight extension to the side, and an extension to the back on the left; and the house with the grey roof on the right.

Figure 1. Overview of wreckage area showing the six smaller sites. (Source of satellite images: Google Earth/Digital Global)

Improving the Image Analysis Process

Where the above explained how the

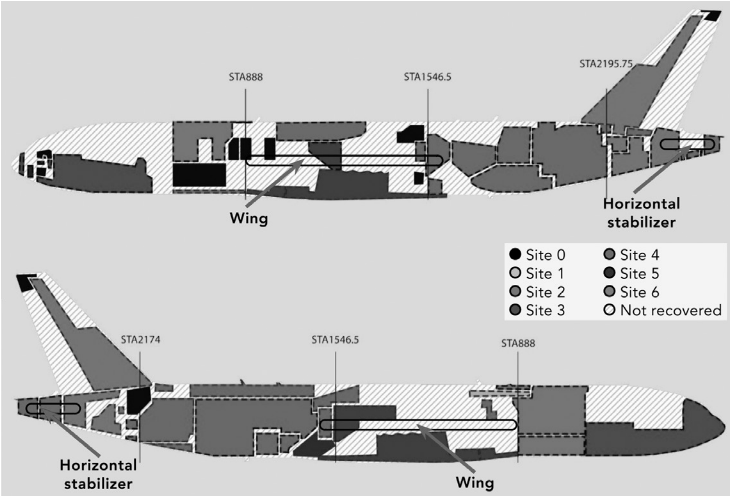

Figure 2. Side view left (top) and right (bottom). Identification of wreckage retrieved from the wreckage sites. (Source: Dutch Safety Board)

actual investigation took place, we now switch to the postanalysis in which we consider methods that could have made the process more efficient and that could form the basis for potential future investigations.

The analysis process of a large image collection generally consists of two phases:

- Exploration, applicable when the investigator is faced with a collection they do not know much about beforehand and wants to discover what is inside and/or how the data is structured. An exploratory session typically takes time and involves a dynamic model of the data, continuously refined as the analyst iteratively gains knowledge.
- Search, applicable when the investigator has a clear idea what they are looking for and queries the system for items relevant to certain attributes. A search session is then a sequence of query-response pairs, and the analyst expects fast response. The data model is static, since the investigator knows exactly what they are looking for, and this can be communicated to the system through a query.

Tasks related to these phases can be placed on an explore-search axis (see Figure 5, page 26), with tasks on the left generally preceding tasks more toward the right, but with a lot of switching back and forth between the different tasks.

- Clustering: Groups images based on similarity to make it easy for the investigator to find structure in the collection and relations between images.
- Browsing: Allows the investigator to quickly and intuitively view the image collection.
- Structuring into categories: Brings relevant structure to the image collection to more easily make sense of the data.
- Finding relevant items: Finds those images that give information that supports hypotheses or answers questions of the investigator.
- Searching additional relevant items: Images of the same object or location but from a different angle can give new information.
- Ranking: Sorts images based on content or metadata.
- Querying item: Searches for a specific image.



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- Querying structure: Uses the created structure to test hypotheses and answer questions.

To improve efficiency, several of these tasks can be (partially) automated using computer vision. Computer vision is the interdisciplinary scientific field of how computers can make sense of digital images or video. It tries to automate tasks that humans can do with their visual systems. Computers nowadays can learn to recognize objects and locations, such as cats, cars, Paris, the beach, etc. However, to do so the computer needs a lot of examples to train on (approximately 1,000 images per object). While this is no problem for everyday objects and locations, airplane crashes and other accident sites are often unique in location and the type and state of objects. State-of-the-art computer vision techniques are thus not yet able to do some of the most difficult parts of the analysis: determining what the object is and where it is located. In combination with the expertise of an investigator, however, it can make several tasks much easier.

To assist the investigator in the analysis, and with the limitations of the current state of the art in computer vision in mind, the following tasks were sought to be automated and developed into an app:

- Cluster images with similar content into groups.
- Query an image, sorting all images based on their similarity with the queried image.
- Query part of an image, sorting all images based on their similarity with the queried part of the image.

Figure 3. Example of finding the location through satellite images. (Source of top image: Rob Stothard; source of bottom image: Google Earth)

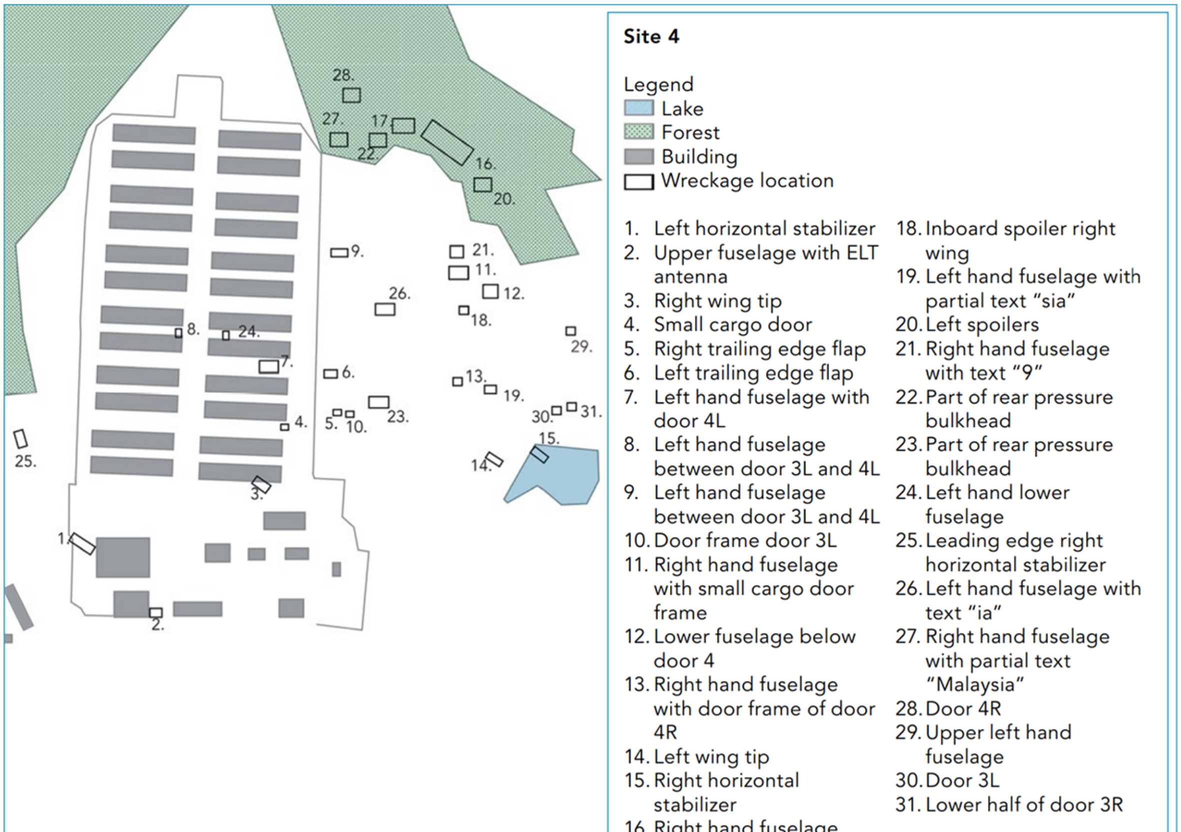

Figure 4. Overview of wreckage site 4 and the location of the wreckage pieces. (Source: Dutch Safety Board)

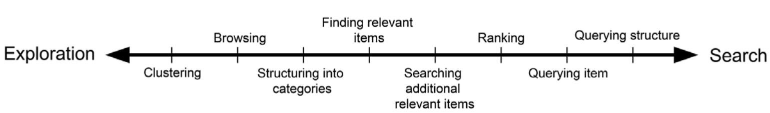

Figure 5. The exploration-search axis with example multimedia analytics (sub)tasks.

Furthermore, the investigator should be able to

- Browse fluidly through the images.
- Place images in user-defined category "buckets" to structure the image collection.
- Retrieve and filter images based on these buckets.
- Gain information about progress made in the structuring of the image collection.

We developed ImEx (Incident Image Explorer) with these tasks and features in mind to assist investigators in investigations with large image collections. To cluster images based on similarity, ImEx makes use of a convolutional neural network. A brief description follows, as a full explanation of neural networks goes beyond the scope of this paper. In short, convolutional neural networks are the current state of the art in computer vision. By making use of large collections of labeled training data, a neural network is trained to discriminate between categories (such as cats, dogs, houses, cars, etc.) by extracting features from images, such as shapes and textures. Features extracted from an image are represented by a value, where a higher value means the feature is present more frequently and more clearly in the image. In the training phase, the neural network learns which features are best to discriminate between categories. By finding these features, it can decide to which category an image belongs.

ImEx works slightly different. As noted, training a neural network requires a lot of training examples, which are usually not available for crash sites or other accident sites. Therefore, rather than classifying images (deciding to which category an image belongs), ImEx only calculates whether images look similar or not. ImEx still makes use of a neural network trained to classify everyday objects and scenes (such as different types of animals, sceneries, intact airplanes, other modes of transportation, instruments, etc.).

The neural network used in ImEx extracts 2,048 features per image. The similarity between two images can then be calculated by correlating the 2,048 features of one image with the 2,048 features of another image. If this correlation is higher than a user-defined threshold, the two images are placed in the same cluster. If other images also correlate higher than this threshold, these images are also placed in the same cluster. This process is repeated until all images are placed in a cluster.

A high threshold will result in many small clusters, whereas a low threshold will result in fewer, but larger clusters. This threshold can be changed by the investigator to suit the task and preferences. A cluster overview can be generated, which shows the most relevant image of each cluster. This enables the investigator to quickly find relevant clusters.

It is then up to the investigator to classify the clusters. In ImEx, the images in a cluster are displayed in a scrollable canvas at the bottom of the screen. The display size of the images can be adjusted. The investigator can create buckets for holding whole clusters or a selection of images in order to structure the image collection. Relevant images or parts of images can be queried to find additional images. By generating buckets, and by adding images to these buckets, the image collection is given structure by the user.

A second window shows the progress of structuring the image collection and a Sankey diagram to show relations between the buckets. Based on images contained in multiple buckets, the Sankey diagram shows a breakdown of each bucket, e.g., upon close inspec-

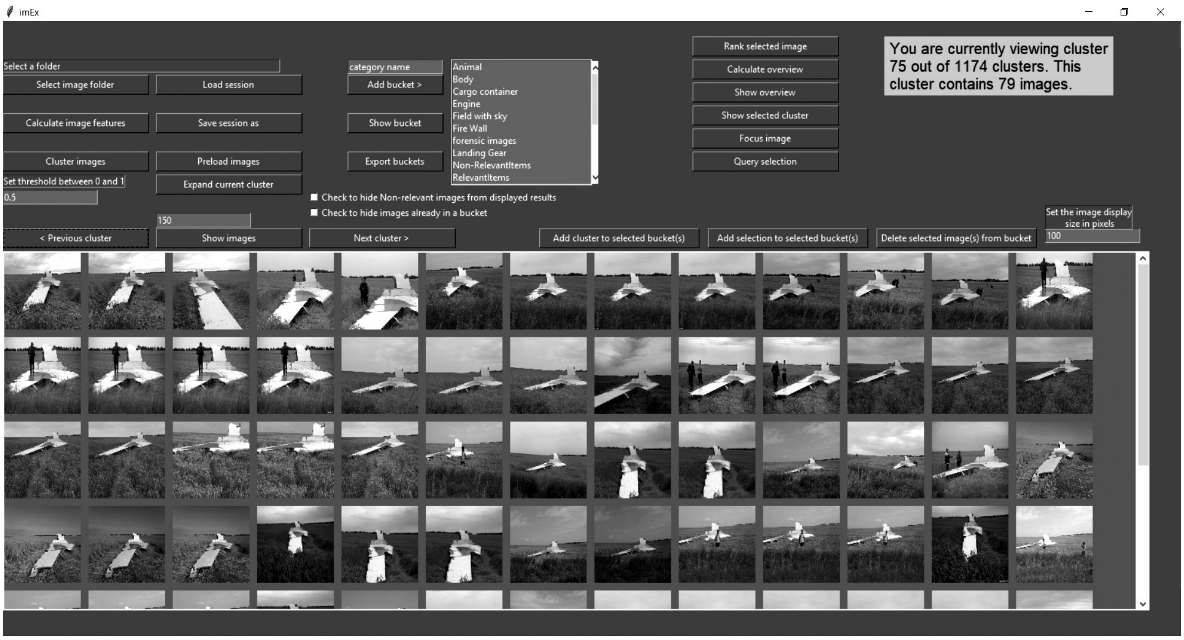

Figure 6. ImEx user interface with example cluster of vertical tail.

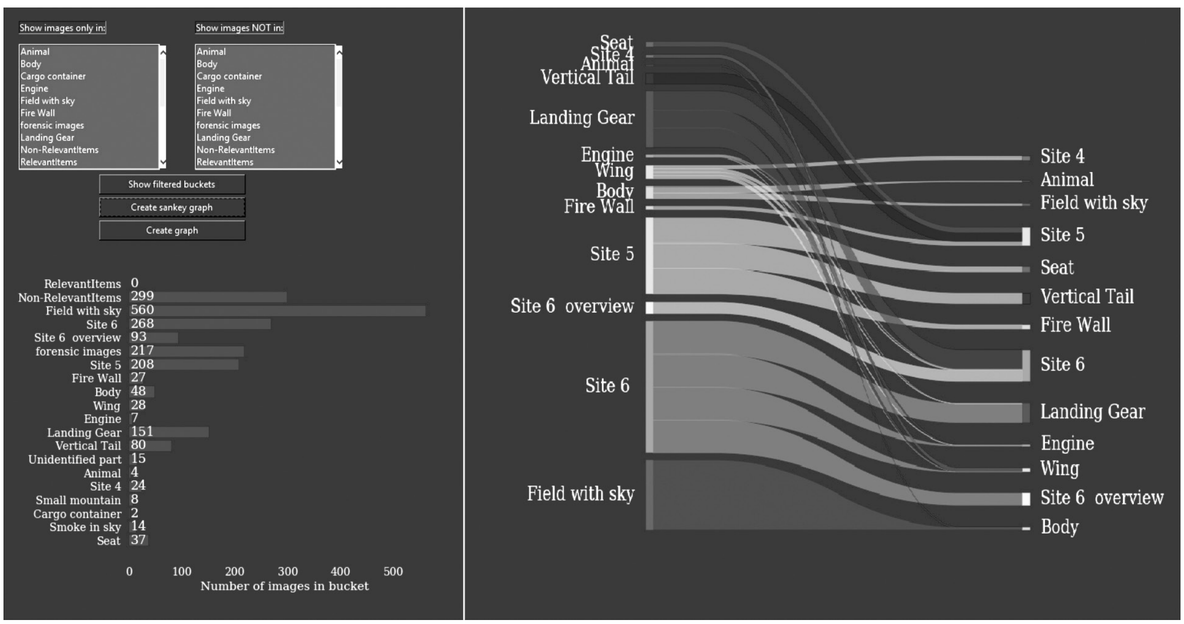

Figure 7. ImEx user interface showing overall progress (left part) and a Sankey diagram showing the progress of the buckets capturing the categorization performed by the investigator (right part).

tion, the Sankey diagram in Figure 7 shows that parts of the wings were located both in site 4 and site 6, because images containing wings were placed in the "wings" bucket, but also in the "site 4" and "site 6" buckets.

Successful Use Case

While the application was developed in light of the Flight MH17 investigation, it is not the only investigation with a large number of photos, as nowadays almost everyone has a camera on their phone with them at all times, and thus crashes and other incidents and their aftermath are sometimes captured by many people. To see how the application generalizes to other cases, the following use case is discussed.

This use case focused mainly on the search part of the exploration-search axis. After a large bonfire during New Year's Eve on the beach got out of hand, the Dutch Safety Board started an investigation. Approximately 4,000 images were collected from citizens, police, and journalists. ImEx was then used to find all images showing the tower of pallets before it was set on fire. By making use of the cluster overview, relevant clusters were quickly identified, allowing for efficient browsing of the image collection. ImEx greatly reduced the time needed to find the relevant images, as only a small part of the image collection needed to be inspected in close detail.

Figure 6 shows the main user interface (note that screenshots may differ from the actual application since development is still ongoing) with descriptive buttons, as well as an explanation canvas on the right, which guides the investigator through the app, and can display a description of the function of each button by right-clicking the button. The figure also shows an example of a cluster generated by ImEx containing 79 images of the vertical tail.

Conclusion

In this paper, an application is presented that was developed after the Flight MH17 investigation showed its necessity. ImEx generates clusters with images containing similar content, based on features extracted with a neural network. This allows the investigator to efficiently explore and search through a large image collection, bring structure to the data by placing images into user-defined buckets, and show the relationships between the buckets through the Sankey diagram. This makes analyzing a large and complex image collection achievable through an efficient and clear process.

The app can be downloaded for free at https://tinyurl.com/imexapplication. ◆

Anthony Brickhouse Receives Prestigious Safety Award

Marcus Costa, chief of ICAO's Accident Investigtion Division, recently noted that it is rather uncommon to come across good news during this surreal pandemic. He wished to publicly congratulate "our distinguished colleague Professor Anthony Brickhouse for being awarded the 2020 Reese Dill Aviation Safety Medal of Honor."

Brickhouse, who serves as ISASI's student chapter and mentoring coordinator and is an Embry-Riddle Aeronautical University associate professor of aerospace and occupational safety and director of the aerospace forensics lab, recently had the honor of delivering a guest lecture virtually for the Reese Dill Aviation Safety Lectureship series of the Aero Club of New England (ACONE). Following the lecture and discussion, Brickhouse was awarded the 2020 Reese Dill Aviation Safety Medal of Honor.

Since 2012, the Reese Dill Aviation Safety Lectureship Series, which honors ACONE member Reese Dill's lifelong commitment to aviation, has featured presentations from renowned professionals in aviation. Other alumni and friends of Embry-Riddle who have had the honor of speaking at the safety lectureship series include David L. McKay, president and chief executive officer of United States Aircraft Insurance Group, and aerobatic pilot Patty Wagstaff.

ACONE is the longest-established aeronautical club in the Americas, founded in 1902, which predates the Wright Brothers' first successful powered flight. Its members include some of the true legends of aviation.

ACONE is also renowned for its "crash course" safety seminars, given in conjunction with the AOPA Air Safety Institute and the FAA. It also manages and awards more than a dozen educational scholarships for pilots and aviation technicians and advocates with federal, state, and local regulators for the advancement of flight. ◆

ISASI Corporate Members Test Flying-V Airliner Design

In June 2019, ISASI corporate members TU Delft and KLM presented to the public their plans for a Flying-V aircraft designed to save 20% on both fuel and emissions due to its unique shape. The scale model and the mock-up of the interior of the Flying-V attracted huge interest, and the story was covered by numerous news media outlets.

Roelof Vos, project leader of Flying-V and assistant professor of flight performance and propulsion, said, "Something we had been working on for years was suddenly in the spotlight." He noted, "The aircraft design of the Flying-V is potentially much more efficient than the traditional 'pipe with wings' design. The concept was received with great enthusiasm, but a lot of hard work will need to be done if the sustainable flying wing is to be ready by 2040."

A patent that appeared in the news media first drew Vos's attention in 2014. Justus Benad, a graduate from TU Berlin, produced a draft design for Airbus—another ISASI corporate member—for a flying wing with seating for 300 passengers. "Most new aircraft concepts aren't radically different from current designs. This one intrigued me," remarked Vos. "It promised a staggering 10% improvement in aerodynamic efficiency and a 2% reduction in takeoff weight compared with a conventional aircraft. My immediate reaction was, as critical researchers, we have to check these claims thoroughly."

Vos also thought that he could improve the draft design: "We gave it an oval fuselage instead of a round pipe, and it became the Delft Flying-V." The aerodynamics research based on this version improved the results even further than the original promising 10%. The prognosis for a lower takeoff weight also turned out to be correct, although this was difficult to calculate for an aircraft that was still only a design on paper. The lower weight is largely due to the unique shape of the aircraft. "Passengers normally sit in the middle of the plane and the wings generate the lift; this force must then be transferred to the cabin. This requires extra construction weight, which is no longer needed in our design."

Work began in the Delft airplane hall of the Faculty of Aerospace Engineering to construct a scale model of the Flying-V with a wingspan of 3 meters. Researcher Malcom Brown is heading the project. His students are actively involved, as they are with other parts of the project. "It's great to see how much students learn from doing something practical like building a model that actually works," Brown said. The model will be used for actual research flights, so we have to be as accurate as possible."

The news media attention may have quieted, but work behind the scenes is still in full swing. "This was an integrated project from the word go; all disciplines are involved. You don't want to complete a fantastic aerodynamic design only to discover that the finished product is far too heavy," observed Vos. "We recently met with experts from across the sector to discuss the challenges they envisaged. We ended up with a list of almost 50 subjects that need further scrutiny."

These varied from highly practical to totally theoretical. "This new aircraft," Vos said, "must be capable of landing and being serviced at existing airports. Imagine if you must change an engine and they're fitted on top of the wings. You can get to them using a crane at Schiphol, but what about at other airports in the world?" And there are more conceptual questions about the dynamic stability of the design. "You need to know precisely how the mass is distributed and how the aerodynamics change at different speeds," explained Vos. "We can measure some of this during the test flights, but a small test model doesn't fly fast enough to be able to draw any definite conclusions. We can try to estimate it using existing methods, but these were designed for the existing models. In order to do this, we need to come up with a clever way of combining the results of various tests and analyses."

Will a Flying-V become a reality in 2040? "Airbus, Schiphol, KLM, and other parties are already very enthusiastic. A consortium will be formed so that we can work more intensively on developing the design with all of these parties," Vos said. But he is still erring on the side of caution. "There's still so much that we don't know about this aircraft; in another five years, we might even come to the conclusion that it's not feasible after all."

In July 2020, a team of researchers, engineers, and a drone pilot from TU Delft traveled to an air base in Germany for a week of test flight, together with a team from Airbus. For the maiden flight of a scale model, Ph.D. candidate Nando van Arnhem was the drone pilot of the project team. He controlled the scaled flight model via radio link. His task was to take off and fly a number of test maneuvers and approaches until the batteries were nearly empty and then land. The goals were to show that the aircraft can perform a sustained flight based on predicted flight mechanical behavior and to obtain an initial dataset of its flight characteristics. And Nando succeeded. The scaled model made a successful maiden flight.

The flight generated a lot of interesting data and knowledge, such as

- rotation on takeoff was performed easily and occurred at a speed of 80 kilometers per hour.
- The plane's thrust was good, and flight speeds and angles were as predicted.
- The aircraft's center of gravity was located slightly more toward the rear than had been calculated in advance.

For the test flight, the team put extra weight into the nose and placed the landing gear a little bit further to the front of the aircraft. If the center of gravity isn't in the right location, the aircraft can become unstable.

During the test week, the team had to repair the antenna to improve the telemetry.

The current design shows "wobbling"—in technical terms, Dutch roll. This makes it difficult to keep the wings level and causes the aircraft to have a somewhat rough landing. Aerodynamic calculations had predicted this behavior, but now that is has been demonstrated in a real flight, the team will be able to adjust the aircraft accordingly.

With the collected data from the first flight, the team will be able to make an aerodynamic model of the scaled flight model. This model makes it possible to calculate exactly in what ways the scale model will need to be adapted. The team will also prepare the aircraft for new flight tests. ◆

A scale model of the Flying-V on the runway during flight testing.

Curran Retires as GCAA Chief Air Accident Investigator

"On behalf of the United Arab Emirates General Civil Aviation Authority [GCAA], we wish Tom Curran a well-deserved retirement from his chief air accident investigator position. There is much to mention about a person who has spent his entire career contributing to aviation safety," said Middle East and North African Society of Air Safety Investigators (MENASASI) President Khalid Walid Al Raisi.

Curran is an experienced airline manager whose career has spanned aeronautical engineering, air safety management, accident investigation, quality systems, and emergency response planning.

In August 2012, he took up the position of senior air accident investigator with the air accident investigation Sector in the GCAA, based in Abu Dhabi. In 2015, Curran was promoted to chief air accident investigator. He has been responsible for leading investigations as the investigator-in-charge, and among many other responsibilities was the creative force and editor of *The Investigator* safety magazine, which has contributed to promoting accident investigation as a primary source for improving air safety.

Curran was the co-founder, with Ismaeil Al Hosani, the former assistant director general-Air Accident Investigation Sector, of MENASASI as a chapter of ISASI. Al Hosani was the first president of MENASASI, and Curran held the position of secretary until recently. He is a committed member of ISASI and was honored to hold the position of chair of the committee responsible for the ISASI annaual seminar that was held in Dubai in 2018.

Curran's experience in the civil aviation industry is well recognized. He joined the staff of the Aer Lingus Air Safety Office in 1990, following 22 years in aeronautical engineering and aviation safety roles. In 2003, he assumed responsibility for the Aer Lingus safety management system and accident prevention and flight safety program as head of air safety, reporting directly to the chief executive and the board on all matters involving air safety management and emergency response planning. Curran has also played a significant part in supporting aviation family assistance since its beginning in the mid-1990s. Family assistance plays a vital part in the humanitarian response to an accident.

On his retirement, Curran would like to offer his very best wishes for the future to all of his friends and colleagues, particularly those at Aer Lingus, the GCAA, MENASASI, ISASI, and various family-assistance organizations

Khalid Walid Al Raisi concluded, "Our ways may part, but our minds will still think the same. We wish him a happy and healthy life, surrounded by his family and friends." ◆

News from Australia

Australian Society (ASASI) President John Guselli reported that, thankfully, 2020 has come to a close. The ASASI membership continued to function despite the massive cutbacks to the industry and the uncertainty of when normal operations will resume again. He noted that vaccines are being distributed, which provide some hope for the future.

Gusellli said that ASASI has been fortunate to see increases in membership. Four student members joined from RMIT University in Melbourne, Victoria. Three full ISASI members joined with ASASI's successful alignment with the Australian Chapter of Women in Aviation (WAI). ASASI offerred two memberships as scholarships to WAI for determination as it saw fit—in line with both organizations' safety objectives. Sophia Miller-Hamor, a safety, risk, and compliance specialist in the Cargo Division of Virgin Australia in Brisbane, and Rhiannon LaRosa, head of aircraft airworthiness and maintenance control for Maroomba Airlines in Perth, western Australia, received the scholarships and are now welcomed as ASASI members. Another WAI member, Leslie McChesney, general manager of Sky360, also joined ASASI and brings with her a wealth of experience.

Guselli expressed congratulations to Ph.D. student Matthew Harris who's attending the University of Southern Queensland for being awarded the inaugural Macarthur Job Scholarship that the Flight Safety Foundation's Basic Aviation Risk Standard Program provides in association with ASASI. Harris was recognized for his paper *New Ideas on How to Implement Lessons Learned from Safety Investigations back into Industry: The Supervisor's Role.* The scholarship provides an allocation up to AUD$2,000 to support travel, accommodations, and registration for the annual Australian and New Zealand Societies' (ANZSASI) seminars held in either Australia or New Zealand.

In another first, Guselli said ASASI held its 2020 annual meeting in a virtual format. The meeting was productive and paves the way for future communication strategies in this manner. In conclusion, he said the Australian and New Zealand Societies continue planning for the ANZSASI seminar scheduled for June 4–6 at the Novotel Gold Cost, Queensland. As a reminder, he asked ISASI members to "save the date" for ISASI 2022 Aug. 20–Sept. 2, 2022, at the Pullman Hotel, King George Square, Brisbane, Australia. ◆

Recent Activity for LASASI

Latin American Society of Air Safety Investigators (LASASI) President Danial Barfani and Vice President Enriqueta Zambonini recognized that 2020 was "a difficult year for all of us, but in LASASI we set out to move forward with the assumed challenge of refounding the Chapter, and we want to share with you the steps we have taken so far.

"We set the basis of identity from the creation of a new logo, we developed a webpage, and we opened social networks. We held our first two virtual meetings to gather the partners, present the statute, and promote the project in the region. We continue to grow and add new members. We conducted a webinar on investigation processes and a presentation of a case study of an emblematic accident in the region, with a participation of more than 70 people. The webinar was a great success.

"We held elections during December. The officers are

- President: Daniel Barafani
- Vice President: Enriqueta Zambonini
- Councelor: Julian Echeverri
- Councelor: Alejandro Oms
- Secretary: Jefferson Fragoso

"We believe in teamwork as the best way to keep developing the Society by a wider view and to boost safety in the region by a joint effort.

"We give thanks for the support from all of the Society chapters and especially the board. Since last year when we had the opportunity to present at the seminar in The Hague and share the idea of the project, we feel very supported.

"We hope that 2021 will be a more prosperous year, where despite the challenges of this difficult and complex context for the world, we can continue to grow professionally...but above all, humanly," Barfani concluded. ◆

MOVING? NEW E-MAIL ACCOUNT?

Do you have a new mailing address? Have you recently changed your e-mail address? Then contact ISASI at isasi@erols.com to ensure that your magazine and other ISASI materials are delivered to you. Please include your previous address with your change request. Members in Canada, New Zealand, and Australia should contact your national society.

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IN MEMORIAM: ESPERISON "MARTY" MARTINEZ

Esperison Martinez, Jr., 86, of Annapolis, Maryland, died on Wednesday, Nov. 4, 2020. He was born in Dodge City, Kansas, on Nov. 15, 1933, and raised in St. Paul, Minnesota. Marty's family collectively prepared this published obituary:

"Cherished for his endless words of wisdom, life lessons, and continuous loving support, he was always the chief family advocate, protector, and champion. He was happiest when gathered together with family and relished lively conversation and meals together. Family, he said, was the most important thing in life, and he lived true to that value, never missing a recital, graduation, or school performance. He will forever be remembered as the world's best husband, father, and grampy.

"Known as Marty in the military and throughout his professional career, he served in the U.S. Navy and U.S. Air Force, retiring from a 20-year military career as chief master sergeant in 1971 after serving honorably in Germany and Thailand. During his military service, he served as a writer for the official Air Force magazine, *Airman*, and as superintendent of the U.S. Armed Forces Radio and Television Network Thailand. He was fortunate to take his young family with him overseas, creating many beautiful memories during his years in Germany and returned there many years later with his expanded family for a memorable trip that included a grampy-executed 'quick trip' to Venice for lunch.

"Having established himself as a talented and highly regarded journalist during his military career, Esperison next wrote for the Air Line Pilots Association magazine for 22 years, serving ultimately as editor-in-chief. After a second retirement, his passion for his profession propelled him into a third career, working as editor of the International Society of Air Safety Investigators' journal for 20 years, in addition to contributing to various community newsletters. Perhaps most importantly, he passed along his wisdom and expertise by serving as chief editor of school papers, presentations, and college applications for his adoring grandchildren."

A private family burial was held at Crownsville Maryland Veterans Cemetery with a celebration of life to follow this summer.

ISASI President Frank Del Gandio relected on the "passing of a great friend": "I first met Marty in 1995, when I was the ISASI secretary. Then ISASI president, Richard Stone, brought him to ISASI when Marty retired from ALPA. Until that time, I did not realize that Marty had been part of my life for the preceding 30–35 years. I enlisted in the military in 1963, and my favorite publication was *Airman*, the official magazine of the U.S. Air Force. I thoroughly enjoyed the articles that were all written or edited by Marty. When I started working for the FAA as an inspector in 1974, one of my fellow workers was a furloughed airline pilot. He always gave me his ALPA magazines. The magazines were full of great airline articles, of which Marty wrote many or edited all of them.

"Marty came to ISASI as the managing editor of *ISASI Forum*. The original *Forum* had a heavy blue paper cover. With the January–March 1997 issue, Marty transformed *Forum* into a 'first class' publication. I continually receive accolades attesting to the quality of the magazine. Marty's ability to write was outstanding. His writing was easy to read, but always technically correct. He obviously passed this ability on to his family, as seen in the obituary that his children and grandchildren wrote.

"As the years rolled by, Marty and his wife, Gladys, became good friends with my wife and myself. After the Munich, Germany, seminar in 2015, the four of us traveled to surrounding European countries, and we enjoyed their company at all ISASI events. Marty retired as *Forum* editor in 2016. He continued to participate until recently in the Society's communications as the editor of *ISASI Update*. Marty was a great coworker and a dear friend. The entire ISASI organization sends our prayers to Gladys and the entire Martinez family." ◆