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ABOUT THE COVER

Mike Poole’s concept of a “generic” display optimized to communicate flight data to analysts for all aircraft types rather than replicate cockpit instruments that are aircraft specific and designed to communicate data to a pilot to fly an aircraft. Shown is an example of a way to communicate flight data for the purposes of understanding a sequence of events from flight data. Computer real estate is much smaller than an aircraft cockpit, and many recorder parameters that are useful to an investigation are not presented to the pilot in the cockpit. Further, data limitations are such that even though a realistic cockpit display looks authentic, the representation is rarely what was actually presented to the pilot, giving the potential for a misleading analysis (see “Flight Data: Then, Now, and Coming Soon,” page 4). Source M. Poole
Two ISASI Stalwarts Fly West

By Frank Del Gandio, President

I am very saddened to report that we, as a society, and aviation as a whole, have lost two very dedicated and long-term influential men: Olof Fritsch (LM0550) and William Scott (LM3437). Olof passed away on Dec. 15, 2013, at the age of 83 in Montreal, Canada. Bill passed away on Oct. 28, 2013, at the age of 82, in Gaborone, Botswana.

Olof, like many of us, selected aviation as a career very early in life. At age 19 he joined the Swedish Air Force. After migrating to Canada in 1957, he joined the Royal Canadian Air Force, which included service as an instructor pilot, check pilot, and lastly aircraft accident investigator. In 1973, concurrent with a move to Montreal, he joined ICAO as chief of the Accident Investigation and Prevention Section and served in that position for 18 years. He served as the ISASI international councillor for 14 years and as president for 4 years.

Olof, the ISASI 1990 Jerome F. Lederer Award winner, was a guiding light of ISASI for nearly all of the 41 years of his membership, which began in 1972. During his initial years, he was a Canadian SASI member, filling the post of vice president until 1979, when he was elected ISASI’s international councillor; a post he held for 14 years, buttressed by a 4-year run as ISASI president. Many of the society’s established procedures are the result of his work. Olof blended his ICAO role and international councillor roll in a positive manner. During the 1980s, he contributed important efforts as a lecturer and course administrator in conjunction with accident-prevention training programs in Argentina, China, Finland, the Soviet Union, and Sweden, among others. He actively participated in Nordic Accident Investigation Commission meetings. ICAO’s most important aviation safety document, the Accident Prevention Manual, which was published in 1984, can also be attributed to Olof, along with other works, and his excellent ability to capture the most important elements in aviation safety work.

At the May 1998 International Council meeting, Olof declared his intention to retire from the council but remain as a society member. The following sentiment that he expressed to the members came from the heart and marks his character: “These days, my grandchildren (and others) refer to me as the O.G., or the Old Guy. So here is a short message from the O.G. after 22 years on the ISASI Council: ‘OK you guys, you are on your own.’ Over the years, I saw ISASI grow in stature and importance, complementing much of what was being done in ICAO, culminating with ISASI’s participation at the ICAO 1992 divisional meeting. ISASI is a fine organization, with good people. We should cherish it.” I know how delighted he was when ISASI finally gained ICAO observer status in May 2013.

A member of his family said in notifying ISASI of his passing, “His time at ISASI was truly the pinnacle of his aviation career, and he talked often of your organization. A huge loss for us all.” Indeed it is.

Bill Scott became an ISASI member in 1992. By then he was already an air safety advocate in his home area of Gaborone, Botswana, where he operated his business, Problem Solvers Ltd, Botswana. Bill both attended and presented papers at ISASI’s annual seminars, which is where I first met him. While our face-to-face meetings were rare, he kept in contact via e-mail, passing along air safety progress in his area.

He had many admirers in the industry who travelled in his area. D.B. “Don” Todd is one of them. Here is how Don characterized Bill: “He was a fine man of substance in his private and professional working life. He was a very keen safety adviser to many aviators over the years. I served as safety inspector of DCA of Botswana in Gaborone (1984–87) and was there when Bill came in to obtain his CPL conversion. He later owned and was still flying his C210 as of 2013, holding a CAA medical until his late age and remained as a PPL and Cessna 150–210 examiner (among other types) for the CAAB. He managed a successful business called Problem Solvers in Gaborone, and it was such that he had an enlightened answer for almost any business and aviation question asked of him or task that needed to be done. He was well liked in Botswana by the local population being as he was an ethical and religious-hearted man.”

Ollie Moakofi, CEO of the Botswana CAAB, recalled Bill like this: “He came to Botswana in the mid-1980s as a professional aviation consultant and started solving peoples’ problems in many ways. He was a mature person with loads of wisdom, especially as an aviator and air safety investigator. Having started his flying career in the U.S., Bill taught many people in Botswana to fly up to PPL level. He also owned his own aircraft, a Cessna C210, that he used to fly around southern Africa on his personal business…. He was also one of the founding members of the Botswana Chapter of Aircraft Owners and Pilot Association (AOPA). Bill had devoted his entire life to the good cause of aviation. As a flight instructor and Civil Aviation Authority of Botswana’s designated flight exam- (Continued on page 30)
Flight Data: Then, Now, and Coming Soon

The author discusses past, present, and future trends in flight data analysis and flight animation that are particularly relevant for the next generation of accident investigators.

By Michael Poole, CEO Plane Sciences, Inc.

(Adapted with permission from the author’s paper entitled Flight Data: Then, Now, And Coming Soon presented at the ISASI 2013 seminar held in Vancouver, B.C., Canada, on Aug. 19–22, 2013, that carried the theme “Preparing the Next Generation of Investigators.” The full presentation, including cited references to support the points made, can be found on the ISASI website at www.isasi.org under the tag “ISASI 2013 Technical Papers.”—Editor)

E v erything in life evolves, and these days technology evolution is accelerating at an unbelievable rate. About five years ago, my then 15-year-old son saw an old LP record album. He looked at me perplexed and exclaimed, “Dad, what kind of CD is that?” The next generation of accident investigators may well have no idea what an LP record is; they have little idea what it was like without cell phones and e-mail, which was not that long ago for many of us today. With new technology, and all of its wonder, comes the problem of continuity of expertise that was gained when things were done “the old-fashioned way,” which is sometimes lost in the technology and automation.

This is often the case in accident investigation when it comes to flight data as recovery and analysis processes are becoming increasingly automated. I am 100% in favor of automation; I am an engineer after all! However, it is important for those using the automation to understand the underlying principles and limitations of the internal processes to maximize the potential of getting it right. To quote the NTSB, “…the flight data analysis process is fraught with the opportunity for error.” This is still the case today and for the foreseeable future despite the advances in replay and analysis software, but there is promise.

Flight recorders then and now

The earliest flight recorder was the five-parameter foil flight recorder. In these earlier days, flight recorders had only a few parameters, and the recorder specialist’s job was to get the data off the box. It was not easy and often required innovative techniques. The FDR and CVR installed on Swiss Air 111 that crashed in 1998 were both tape-based recorders that were recovered from the ocean.

The tape was extracted from the recorder and immersed in water and then cleaned in an assembly-line-like process in order to play back on an open reel tape deck. Tape-based recorders ruled throughout the late 60s, 70s, 80s, and 90s. Owing to the cumbersome nature of getting the data off the units, they were used pretty much only for accident investigation, the initial reason they were installed.

Today, we by and large have solid-state flight recorders (both voice and data), and it is not uncommon to have thousands of parameters. This trend will no doubt continue with the data-rich architecture of aircraft today and the increasing data architectures of tomorrow. Data are increasingly used for accident prevention programs (FOQA), and both the U.S. ASIAS (Aviation Safety Information Analysis & Sharing) and IATA FDX (Flight Data Exchange) programs have significant data sharing initiatives whereby they process flight data with a high-level broad-interest event set and treat all contributing airlines as one big airline.

Data are readily retrievable on solid-state crash-survivable recorders (new solid-state FDRs are now “quick access,” and many aircraft also have longer duration separate quick-access recorders that literally fit into the palm of your hand (see Figure 1) and record much longer durations than the 25-hour FDR. Recorders are also capable of wireless download on the ground through 80211 (Bluetooth) or cell phone bands.

Today, we are seeing increased use of telemetry to communicate events diagnosed on board, and the event is accompanied by snapshots of flight data. This is sent from the aircraft to the ground via satellite and is valuable when immediacy is needed. Satcom is still mostly driven for maintenance purposes so that the airline has the right part ready and waiting at the gate to minimize aircraft downtime. From time to time, people wonder why all data are not telemetered to the ground so that there is no need for an FDR on board the aircraft. However, telemetry will not be replacing onboard recorders in the foreseeable future for many reasons, which is beyond the scope of this article.

Datamap issues

As an investigation group, it is worthwhile for us to appreciate the issues surrounding datamap evolution as it relates to flight data. What is a datamap? Flight data, regardless of what recorder type, are a stream of binary 1s and 0s. They are not feet, not degrees, not knots. A software process converts the binary data to engineering units.

To convert binary data into meaningful engineering units requires stripping out the correct “word” or bits that constitute a word, doing the math of binary to decimal; two to the zero, two to the one, two to the two, etc., to get a decimal value and then applying a formula to get engineering units. In Figure 2, the parameter in question is stored in a 12-bit word. Twelve bits of 0s equals 0, and 12 bits of 1s equals 4,095. Any combination of 1s and 0s in between will yield values from 0 to 4,095. To convert to say airspeed,
Mike Poole is a professional aerospace engineer with a current pilot’s license and is recognized as an expert in the field of flight data analysis. He represented Canada as the national expert panel member to the International Civil Aviation Organization’s Flight Recorder Panel. He started in the field of aircraft accident investigation in 1977 and worked for more than 20 years with the Transportation Safety Board of Canada. For the last 15 years of his career at the TSB, he was the head of the flight recorder and performance laboratory, which he developed for the board. He was the Flight Recorder Group chairman on all major accidents in Canada as well as several international accidents. In 1985 he was responsible for initiating and driving the development of the Recovery Analysis & Presentation System (RAPS) for flight data analysis, which he successfully commercialized from the TSB in late 2001 to Flightscape. Mike co-founded Flightscape, which he sold to CAE in 2007. He left CAE in 2013 to go back to his entrepreneurial roots and started an aviation subject-matter-expert company called Plane Sciences in May 2013.

The first job of an investigator—then, now, and for the near future—is to obtain/build/import and validate the datamap. This is easier said than done, and there are many competing pressures. In the earliest days when I was at the Transportation Safety Board of Canada, we used to publish the data datamap as an appendix to the engineering report. Of note,
Figure 3

![Diagram of data sources](image)

we also used to publish all of the flight data related to the accident flight. In these early days, the parameter list was small enough that it was simply not an issue space wise. We did this out of what we thought to be thoroughness and to defend the report findings. No one ever raised an issue. In those days, flight data were handled only by a small number of governments around the world, about five in the 1980s. Most airlines only handled the data for annual maintenance readout purposes.

It is worthwhile spending some time on datamaps due to their importance and in the context of then, now, and coming soon and the next generation of accident investigators. In 1988, when the first Airbus A320 crashed, a significant controversy arose in part due to problems with the datamap. This resulted in the credibility of the readout being put in question by groups with apparent stature and credibility. The aircraft hit trees during an unscheduled flyby at an airshow, and the flight data were central to the investigation. Investigation authorities are under intense pressure to produce the data but at the same time must configure the replay system with the correct datamap.

You can only imagine the intense pressure to read out and make the data available to the investigating team being in direct competition with taking one’s time to program the map and test/validate it. In the case of the A320 accident, the pilot association went to great lengths to discredit the readout, and the news media pursued conspiracy theories that hampered the official investigation to the point that a court was convened to address the validity of the flight recorders. Some people began to incorrectly suspect that the government had tried to orchestrate a cover-up and had replaced the accident flight recorders with flight recorders with data showing false information.

People outside of the authority, with credibility when examining the flight data provided by the authorities, did not understand the datamap process. If they had, they would have accepted that the readout produced by the authorities was authentic and had not been tampered with.

Many airlines today are using flight data for FOQA now, and more and more governments have flight data analysis tools. This has increased the commercial marketplace for replay tools that was for many years a very small niche area. The somewhat unfortunate side effect that has surfaced is that there is an increased view that the documentation for the datamap is proprietary, and many aircraft manufacturers stamp proprietary on the documentation.

The secret decoder ring is indeed becoming a secret! This is contrary to EUROCAE guidance (EUROCAE became the world standard for guidance material for flight recorders, and most of the major boards and recorder manufacturers in the late 1980s and 90s participated heavily). When we started seeing hints of “proprietary” concerns at EUROCAE meetings in the early 1990s, we developed guidance material that essentially states that all of the documentation to read out the recorder, including the datamap, should be readily made available. This was in part to allow investigators to engineer special recovery techniques since this is normally not a specialty nor commercially viable for recorder manufacturers to do.

Despite EUROCAE’s guidance, like my son who never saw an LP record, there are many new players in the flight recorder field that were not part of the deliberations. Datamap documentation is perhaps one area in which we took many steps forward and then one step backward with the notion that how the data are programmed against the ARINC 717 standard should be a secret and difficult to obtain.

ARINC (a standards organization) has developed FRED—Flight Recorder Electronic Documentation Standard, also known as A647A. A647A started out in the Transportation Safety Board of Canada as the FRCS or Flight Recorder Configuration Standard as a result of Boeing sending me a “book” for the documentation of one of its aircraft datamaps in the late 1980s. We had to manually type in the information, which was very time consuming and error prone. FRCS and now FRED is simply an electronic format/standard for the datamap documentation in order to easily import and/or exchange datamaps between ground stations. While we solved the problem of hand typing the datamap in and the errors associated with this method, there is now a view by some that datamaps should be proprietary so you can’t get them so easily anymore.

With the advent of the solid-state recorder, EUROCAE decided that since the FDU defines the datamap, why not have the FDU write the datamap to the FDR during each cold start? Indeed, the new B-787 is the first aircraft in the world in which the FDU writes the datamap to the FDR on power up. This means we are moving toward plug and play and in theory with a process that is much less “fraught with the opportunity for error.” The ground station reads the FRED (datamap file) from the FDR, and this is exactly what happens with the B-787, although there are still issues with FRED that cause the process to fall short of plug and play. But plug and play is on the horizon. Recording FRED to the recorder should eliminate the proprietary issue as FRED is an open standard, and anyone who can download the FDR will have the datamap. But for all the B-787s out there, there are tons of other aircraft where it will continue to be a concern until we can get some clear FAA, EASA, etc., regulations.

In summary, datamaps are key to the FDR analysis process. In my opinion, the documentation should not be secret or proprietary. It is understandable that if someone has to interpret the documentation and spend weeks building a datamap, it has value. However, if the documentation is in FRED and is plug and play, there is no longer a need for people to spend effort to configure their ground station; the working file and the documentation are one in the same!

Most airlines today can view flight data in engineering units in literally minutes owing to FOQA and having preconfigured...
the datamaps for their recorders. The investigation authorities have to do this configuration work in the aftermath of an accident, which means delays in disseminating the flight data. The time has come for the industry to solve this problem as with today's technology it is simply unacceptable for the investigation authority to take days or weeks to produce the flight data.

Theoretically the fix is simple. There needs to be ONE validated and tested datamap for each unique acquisition unit output attached to the aircraft records and in the FRED format, and FRED needs some minor extensions to support full plug and play. While understandable in the past, today investigators need to spend their time analyzing the flight data instead of spending their time generating the flight data. The datamaps used for FOQA should be accurate and validated. FOQA in many ways is more important than accident investigation. It is time for the airlines and the authorities to work together and solve this problem so that all flight data users benefit from an accurate process from binary to engineering units data. If you are authorized to access the flight data, the datamap should never be the holdup. Make flight data proprietary, not the datamaps.

When we get to the point that all FDAUs generate the map based on their programming, the first job of the investigator of obtaining and validating the maps should all but disappear, allowing the investigation team to focus on data interpretation. Like my son who saw the LP and wondered what kind of CD it was, some investigator of the future will see a datamap file and wonder what the heck it is used for! Unfortunately today datamaps remain a substantial problem and result in unnecessary delays in data production by the authorities in the aftermath of an accident.

Flight animation
Flight animation is based heavily on flight data and has undergone significant development and prominence since it was first introduced in the mid 1980s.

The wireframe animation (see Figure 4) is one that I did in 1985 in which two aircraft experienced a risk of collision. We used to call this a “near-miss,” but a near-miss is a hit in fact so we changed it to “risk of collision.” I think this was the first animation on a mini-computer in the world.

In those days, there were no paint schemes on the aircraft, instrumentation was simple both on the aircraft and in the animation, and we did not have terrain or weather modeling. Software and computers to do this were expensive. The wireframe animation you see here was done on an HP mini-computer that we paid $80,000 for in 1985. To develop an animation was a very manual process that meant that you really had to know what you were doing.

Figure 5 is from an A310 that hit a mountain in Kathmandu. The animation we did at the time (around 1990) had a very simple terrain profile by subtracting pressure altitude from radio altitude, which is the line you see under the flight path. The instrumentation was very simple compared to the primary flight displays and other avionics displays in today’s cockpits.

Animation today is photorealistic and getting more so all the time—approaching Hollywood realism quality and with very inexpensive, readily accessible software compared to not long ago. Google Earth and Xplane, for example, provide access to very well-developed terrain and weather modeling. Despite all of these impressive visuals, core flight data have not changed all that much, and there are still many challenges with flight animation related to the quality and quantity of the data.

The following is just one example of many that will give you an idea of the data challenges we still face, often masked by automated animation systems. These issues are not going away anytime soon despite the impressive visuals of animation software, so we need to be ever careful because “seeing is believing.” In this example (see Figure 6), the pressure altitude is shown for a typical landing. Pressure altitude has a characteristic drop in ground effect during landing as well as during rotation on takeoff. If you used pressure altitude as the height parameter in your flight animation, the aircraft will dip below the runway.

The radio altitude (RALT) data are shown in gray. The problem with using RALT for height above the ground is that terrain profile and/or buildings affect the data. The dip shown on approach is either a hill or building the aircraft is flying over,
trend to try to replicate the cockpit displays using flight data. While this is understandable and I am not saying we should not do it, there are issues as investigators that you should be aware of. The first is that a lot of recorded data are not shown to the pilot in the cockpit.

When investigating an event, a replica of the cockpit may, therefore, not always be the best way to figure out what happened. There is also a big real estate problem. Computer screens, unless you connect a bunch together, are much smaller than most airplane cockpits. Instruments in the aircraft are designed so a pilot can fly the aircraft with the space available in your field of view in a cockpit. I submit to you that there is a difference in designing a display to fly an aircraft and designing a display to communicate flight data to understand what happened, especially considering that you have much less real estate for the latter (see Figure 7).

Additionally, data sample rate, resolution, availability, and the fact that there is a lot of processing within the avionics, such as filtering, that is hard if not impossible to replicate in software are all such that the display you are looking at may be different from what the pilot might have been seeing. There is a danger here that a pilot will be second-guessed after the fact incorrectly as the recreated display can be misleading.

Putting the case around instruments, 3-D representations of throttles, knobs, and buttons all increase the realism of the display and the wow factor, but at the end of the day they take up valuable space that could be used to communicate more information. No matter what aircraft you are looking at, there are a fair number of parameters that transcend all types. I think it is useful for the industry to come up with “generic” displays optimized to communicate flight data rather than replicate instruments that were optimized to fly an aircraft.

Figure 8 is an example of what I mean. I did this very quickly (less than an hour) in PowerPoint just to give you some ideas regarding the ways to communicate flight data for the purposes of understanding a sequence of events from flight data. On the left you see AOA and flight path angle coupled with pitch attitude. Instead of a big attitude indicator, we have not an actual drop in flying height because we see no drop in the pressure altitude. What most animation system do, in the interests of getting an automatic animation that looks reasonable, is to splice in the radio altitude data into the pressure altitude data at 50 feet. The white line is the pressure altitude to 50 feet and then the radio alt from 50 feet down. This will result in a reasonable height profile for an animation.

However, this assumes that the aircraft is above the runway elevation at 50 feet. If, for example, the aircraft lands short and there is a valley before the runway threshold, this method will not work as the valley will result in an increase in height that will show the aircraft rising when it did not, as shown in the white line in the figure.

As with all methods, they work for many cases but not for all cases. The challenge is always to use processes that do not mask real aircraft behavior or introduce artifacts that are not representative of real aircraft behavior. When the issue is subtle, it is hard to know and easy to be misled. I could show you dozens more examples of data issues much more complex than this, but this example gives you the idea.

Animations are an artifact of the data process and affected by all kinds of data issues that are a function of the source data, quality, quantity, resolution, datamap, and math. The good news: the trend is to record high-resolution position data and much higher sample rates with aircraft like the new B-787 and A350 so eventually these problems will go away, but not in my lifetime owing to the tons of aircraft today where we face these issues.

**Cockpit displays**

As investigators, it is also worthwhile exploring the current
put two rings around the aircraft. Trend arrows can be used to show altitude and turn rates. Wind speed and direction are often very important, recorded yet not shown in the cockpit and so on. I will be spending some time on this idea over the coming year and hope to come up with what I am going to call the “validate the animation quality template,” which also doubles as an investigative template that reduces the potential to second-guess what the pilot saw yet communicates the data so that we can better understand what happened.

Just as you have to validate the datamap, you need to validate the animation before people go off and make conclusions based on it. I used to put this on all TSB animation I did: “Any conclusions based on this animation should be thoroughly reviewed in light of the manner in which it was produced to let people know that animation is a process with opportunity for error.”

Flight animations today look picture perfect regardless of what the quality of the source data is. So as investigators it is important, now more than ever given the proliferation of automated systems, to understand the underlying principles of the process.

**Coming soon**

We will see more FDR systems recording the datamap to facilitate plug and play, which will ultimately eliminate the proprietary issue surrounding datamaps and allow authorities to focus on data interpretation instead of taking time to produce the data. GPS position/altitude will (like the B-787 and A350) be recorded to high resolution, which will eliminate a ton of flight path problems and aircraft behavior problems to produce more accurate flight animations. Replicating instruments will remain challenging as even on the A350 and B-787 there are not enough data to factually/faithfully reconstruct the displays without substantial math processes and approximations.

FOQA will continue to set the standard of safety, and we will see pilot union barriers continue to reduce as more people appreciate the true value of treating the world as one airline when it comes to safety. Safety authorities should and will eventually play a role in this proactive effort given that their primary mission is to advance safety. In Canada at least, the word “safety” was chosen in naming the investigation authority over the words “accident” or “investigation,” and this was purposeful with the mind that the authority should not limit itself to reactive accident investigation. Most investigation authorities perform safety studies from time to time. The time has come to do safety studies with flight data.

I also think you will see FOQA programs that link events to the most common solution that made the problem reduce or go away so that as an industry we can leverage the lessons learned from each other. This is commonly referred to as artificial intelligence, and this is a great potential evolution of the IATA FDX and U.S. ASIAS data-sharing programs.

The diagram in Figure 9 is my vision of the future to the flow and use of flight data. Much of this is already materializing in various small ways.

Following the data flow from the top left and going counterclockwise: Flight data are downloaded from the aircraft wirelessly on the ground after the flight. The data go to a “flight data center(s),” and flight data centers are ideally linked. The events are put into a FOQA database as is the case now at each airline (not linked). Simulator training facilities (as well as other stakeholders for specific purposes) should have access to the flight data centers to facilitate evidence-based training in both the simulator itself or in the brief/debrief environment. Simulator sessions should use the flight data from the simulator to assess the flight crew performance and automatically find events rather than sole reliance on the instructor pilot. This is slowly becoming known as Simulator Operations Quality Assurance (SOQA). The SOQA database can be compared to the FOQA database to identify differences in the way aircraft are being flown in daily operations to that of simulator training. The future should bring a generation of
simulators that can also accept the flight data as an input for occasional complex diagnosis, especially in cases in which the human-machine interface is under analysis.

On the ground after the flight, a report can be generated on the crews’ electronic flight bag or iPad for an instant for their eyes only debrief. I call this cockpit FOQA, and I think it has enormous potential to advance safety by putting the results directly back into the hands of the people most able to effect change.

In the air, diagnostic-driven reports will come to the data centers (as happens now and has for many years) via siticom. What may come soon is that in extreme cases the flight data could be transmitted in real time to the ground both forward and backward in time until the aircraft lands safely. This could be either through a crew action PAN PAN PAN we have smoke in the cockpit or through an onboard diagnostic (unusual attitude in the case of AF447) or through a ground-based request (you are no longer on radar or in communication) with the theory being that the number of aircraft in distress at any one time should be zero... or maybe one.

For single-pilot commercial operations in smaller aircraft, with telemetry it is possible to have a virtual copilot on the ground monitoring many flights and helping out when required. Consider this a form of advanced flight following. With telemetry and military drone technology, it is also possible to have operation control of commercial aircraft from the ground in the future.

It is probably not a big leap of faith to consider a one-man cockpit for large commercial aircraft where, in the event the pilot is incapacitated, the ground takes over operational control.

I realize this is very controversial, but one thing I have learned is that what we often think is ridiculous and impossible today becomes the reality of the future. Military fighter operations, which are highly demanding, are currently one-man operations. The cockpit of the future may well be one pilot with a “virtual” copilot on the ground monitoring the flight data who can monitor many flights at the same time with technology that is literally around the corner.

We are living in an increasingly data-rich world with clever applications that exploit the availability of data that we never dreamed off a couple of decades ago. The future for safer aviation through increased use of flight data proactively is promising and ensures that we have more data than we know what to do with in the aftermath of an accident.
Investing in increased investigating capability of O&M factors will lead to greater safety payoff though safety action that addresses the systemic issues that shape human performance.

**Improving Investigation of Organizational And Management Factors**

By Joel Morley and Jon Stuart, Human Performance Division, Transportation Safety Board of Canada

Joel Morley is a senior human performance analyst at the Transportation Safety Board of Canada, a role he filled from 2001 to 2007 and returned to in 2012.

While at the TSB, Joel has participated in numerous investigations in the aviation, rail, and marine modes and trained a large number of investigators in the theory and practice of investigating human performance factors. In addition to the TSB, Joel has experience applying safety management and human factors for a large air navigation service provider and has worked as a researcher and consultant. Joel holds a Ph.D. in applied psychology from Cranfield University.

Jon Stuart is the manager of human factors and macro-analysis at the Transportation Safety Board of Canada. Jon has led the investigation of both human and organizational factors in a number of major and smaller investigations across the aviation, marine, rail, and pipeline modes of transportation. He has previously worked to deliver human factors projects in several safety critical industries. Jon holds a Ph.D. in human factors from Loughborough University.

(Adapted with permission from the authors’ paper entitled Improving our Capability to Investigate for Organizational and Management Factors presented at the ISASI 2013 seminar held in Vancouver, B.C., Canada, on Aug. 19–22, 2013, which carried the theme “Preparing the Next Generation of Investigators.” The full presentation, including cited references to support the points made, can be found on the ISASI website at www.isasi.org under the tag “ISASI 2013 Technical Papers.”—Editor)

It is widely accepted that to improve safety, organizations should focus their efforts on improving the system rather than the individual, that regulators should examine process and performance in addition to compliance, and that effective organizational safety cultures are critical to ensuring that these efforts are successful.

This presents a number of challenges for safety investigators. How do we decide when to investigate for these factors, balancing comprehensiveness and timeliness in investigations? How do we document and analyze the role of these factors in an occurrence? What standard of evidence do we use to prove the existence and influence of factors involving safety management and safety culture? How do we present a compelling argument for change?

To address these challenges, the Transportation Safety Board (TSB) of Canada has developed a number of tools for investigators to use. These include a safety analysis methodology, workshops on investigating human and organizational factors, and a Guide to Investigating for Organizational and Management Factors. First produced in 2002, the guide is now in its second edition. The TSB developed the new edition based on the learning in the intervening 11 years, developments in safety science, and examination of feedback from our board.

The approach taken in revising the guide is described here, as are the challenges identified and the tools provided to TSB investigators to help address the challenges.

Improve system conditions

Studies of how accidents happen in complex systems have convincingly documented that, although human performance is implicated in most occurrences, the key to improving the safety of the system and preventing future occurrences lies in improving the conditions in the system that influence human performance. These studies have led to such influential models that our lexicon has adapted—safety professionals will forever be associated with Swiss cheese!

Given our current understanding of the importance of the system in determining human behavior and the advent of Safety Management Systems (SMS) being recognized as the way forward in improving safety, we will define organizational and management (O&M) factors as latent unsafe conditions (hazards) within the organization that increase the probability of further unsafe conditions or unsafe acts, or that reduce the effectiveness of the organization’s ability to manage safety.

Our challenge as investigators lies in ensuring that occurrence investigations are sufficiently comprehensive to examine the aspects of the system that will likely have the greatest safety payoff, and be sufficiently robust to make a compelling argument for change while balancing the need to ensure timeliness and delivery of investigations within our available resources.

To address this challenge, the TSB provided an updated version of its Guide to Investigating for Organizational and Management Factors to investigators. The guide’s intent is to help structure the inquiries into O&M factors that influence human performance in investigations. The second edition of the guide takes into account the signifi-
significant advances in the implementation of SMS that have occurred throughout the industries we serve, and the significant experience gained by TSB investigators in the 11 years since the first edition was published.

That edition of the guide included two lists that provided high-level guidance in terms of the types of O&M factors that should be considered during an investigation. The first list provided starting points for understanding the organization’s safety philosophy, policies, and procedures and how these translated into actual work practices. The second list identified potential unsafe conditions that should be considered for their potential to impact human performance and reduce safety. While the first edition of the guide was most helpful in the data-collection phase of the investigation, the second edition aims to provide greater structure for the analysis of O&M factors.

How TSB investigates

Before discussing the tools the TSB provides its investigators to investigate O&M factors, an understanding of the approach the TSB takes to investigating in general is helpful. All TSB investigators are taught to employ TSB’s Integrated Safety Investigation Methodology (ISIM).

ISIM analysis begins with depicting what happened in the occurrence as a sequence of events, then progresses to explaining why it happened with the addition of underlying conditions for those events deemed safety significant. This information is represented in a sequence of events, unsafe conditions, and underlying factors diagram (see Figure 1). The methodology progresses to developing an argument for change through the application of risk- and defense-analysis processes. The purpose of structuring the data collection and analysis in this systematic way is to ensure that the argument for change is compelling.

The TSB has had this investigation methodology in place for many years. The intent of the current work is to enhance the process already in place and provide a framework for using it to investigate O&M factors.

Method—consultation and development

The TSB is well known internationally for the high quality of its investigations and is committed to continual improvement. In preparing to develop the updated guide, we wanted to understand what was working well and where there was opportunity for improvement in handling O&M factors in our investigations. Consultations were undertaken with TSB board members, managers, and investigators in all of our modal groups to better understand what has gone well in these investigations, what challenges were faced, and to better understand what tools and approaches were needed to improve the TSB’s capability to systematically investigate these issues.

In addition to these discussions, board comments on draft reports were reviewed, a review of the literature was done, and discussions with investigators in other boards were conducted. The following is a brief summary of the challenges identified that we intend to address through application of the new guide:

-**Scope:** Investigations vary significantly in scope, and it may not always be evident that the decision to include or exclude issues was made explicitly. Given the data collection and analysis required to substantiate O&M issues, pursuing these factors in the investigation will impact the resources required for an investigation.
-**Completeness:** O&M issues may be identified too late in the investigation process, causing the data to support analysis to not be collected.
-**Weak or missing links:** The link between an O&M issue and the safety impact must be clearly demonstrated. Weaknesses in the analysis, including leaps of logic, overuse of labels, and lack of corroboration for opinion or third-party statements, will lessen the argument for change.
-**Potential for hindsight bias:** Given that O&M investigations often revolve around an organization’s response to a given hazard, it is understandable how the risk associated with the hazard would be underestimated post-occur-

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- **Potential for hindsight bias:** Given that O&M investigations often revolve around an organization’s response to a given hazard, it is understandable how the risk associated with the hazard would be underestimated post-occurrence with knowledge of the outcome. It is easy to overestimate what a decision-maker “should have” known in the lead up to the occurrence.
- **Interviewing challenges:** With respect to O&M, it can be challenging to ask questions related to the organization without appearing to be “fishing,” to ask difficult questions of individuals in positions of authority, and to press the interviewee for specifics.
- **Experience with management issues:** Investigators have excellent technical knowledge in their area of specialization, but investigating O&M issues may take them further outside their comfort zone.

These challenges were targeted during the development of the guide and its associated tools. The guide and the toolkit were piloted on various groups within the TSB. Participants were asked to use occurrence investigations with which they were familiar to test the tools and to provide feedback. Ideas and suggestions were incorporated into subsequent drafts of the guide.

O&M factor investigation toolkit

In the TSB’s ISIM framework, analysis is defined as “The process of organizing facts, by using methods, tools, techniques to: a) assist in deciding what additional facts are needed; b) establish consistency, validity, and logic; c) establish sufficient and necessary causal and contributory factors; and d) guide and support inference and judgements (conclusions).”

The tools and frameworks presented in the guide are aimed at addressing the challenges previously described by as-
The tools developed for this guide are one of the items on TSB's Watchlist since "Transport Canada does not always provide effective oversight of aviation companies transitioning to safety management systems, while some companies are not even required to have an SMS since 2005. However, the board has included this item on the Watchlist since "Transport Canada does not always provide effective oversight of aviation companies transitioning to safety management systems, while some companies are not even required to have one." The tools developed for this guide will help the TSB monitor this important Watchlist issue.

(Copies of the guide may be freely shared for the purposes of advancing safety. To obtain a copy, contact the lead author at joel.morley@bst-tsb.gc.ca.)

Conclusion
Investigating O&M factors increases the scope and complexity of an investigation. However, an investment in this area will lead to greater safety payoff though safety action that addresses the systemic issues that shape human performance.

TSB’s approach to improving our ability to investigate for these issues is one of continual development. The tools briefly described here and documented in the second edition of The Guide to Investigating for Organizational and Management Factors were developed in order to capture and systematize the learning that has taken place in the 11 years since the first edition of the guide was produced. The tools will help guide data collection and analysis and make the thinking related to these issues explicit and accessible to the investigation team.

Aviation Safety Management Systems are one of the items on TSB’s Watchlist. Implemented properly, SMS allow aviation companies to identify hazards, manage risks, and develop and follow effective safety processes. Canada’s large commercial carriers have been required to have an SMS since 2005. However, the board has included this item on the TSB’s Watchlist since "Transport Canada does not always provide effective oversight of aviation companies transitioning to safety management systems, while some companies are not even required to have one." The tools developed for this guide will help the TSB monitor this important Watchlist issue.

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Tools overview
While a complete overview of the tools presented in the guide is beyond the scope of this article, the following provides a brief overview of their purpose and approach.

Tool 1: Scoping Tool
Purpose: To determine the level of effort in investigating O&M factors, document the decision, and assist in planning the investigation.
Approach: Presents a series of questions to identify situations in which the scope of the investigation should include organizational issues and documents decisions about scope. Issues to be pursued are identified, and a plan for the next steps in the investigation is documented.

Tool 2: “Who Knew What?” Analysis
Purpose: To document the flow of information with respect to a specific hazard in the organization.
Approach: Hazards (unsafe conditions) identified in the investigation are followed to identify who had information prior to the occurrence, what was done with this information, whether appropriate mitigations were put in place, and if the action taken was reasonable and consistent with established procedures.

Tool 3: O&M Factor Assessment Tool
Purpose: To explicitly demonstrate the link between hazards that were unmitigated or unaddressed and the unsafe conditions/underlying factors identified.
Approach: Links made in ISIM analysis are explicitly examined to ensure that there is a clear relationship. Having arrived at the unsafe conditions and underlying factors using “why?” the examination involves working back up the causal chain asking “how?”

Tool 4: Safety Culture Assessment Tool
Purpose: To develop a clear picture of the organization’s safety culture (the organization’s capability to foster safe work and effective safety management practices).

Tool 5: Quality Assurance Tool
Purpose: To ensure that a compelling argument for change has been developed and presented in the analysis.
Approach: A series of questions are presented to review the analysis for clarity of links, reasonableness, sufficiency, and generalizability.

Figure 2. How O&M tools build upon ISIM.

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Preparing the Next Generation Of Investigative and Regulatory Authorities

...will pose different challenges for different countries. Some must focus on building capabilities in flight data analysis; others may need to improve institutional capabilities; and still others may need to establish authorities that have technical capability and real authority.

By Robert Matthews, Ph.D., FAA, Ret.

(Adapted with permission from the author’s technical paper entitled Preparing the Next Generation of Investigative and Regulatory Authorities presented at the ISASI 2013 seminar held in Vancouver, B.C., Canada, on Aug. 19–22, 2013, that carried the theme “Preparing the Next Generation of Investigators.” The full presentation, including cited references to support the points made, can be found on the ISASI website at www.isasi.org under the tag “ISASI 2013 Technical Papers.”—Editor)

The theme of this year’s ISASI seminar, “Preparing the Next Generation of Investigators,” implicitly asks what types of skills and resources accident investigative and regulatory agencies must recruit or develop for a rapidly changing aviation system. The most honest reply is “it depends.” It depends on a country’s current safety baseline, whether the country is rich or poor, whether it has a functioning state, and more. For example, investigative and regulatory authorities in rich countries with sustained low accident rates likely will focus on building more extensive programs in flight data analysis and the integration of other “big data” tools. However, they must do so with some caution to ensure that they maintain existing skills and avoid the trap of assuming that traditional investigative skills will become less valuable.

At the other end of the spectrum, many countries with high long-term accident rates need to prepare for today; tomorrow may need to wait. Some countries may face the institutional challenge of establishing, for the first time, regulatory and investigative authorities that have technical capability and real authority within the broader political-economic system.

Needs also will vary according to the size and complexity of national aviation systems. Countries with large populations and big national systems will have different needs than will countries with smaller systems—while some countries with smaller systems have different needs if they have large international hub airports.

Some countries also are or soon will be new entrants into the aircraft manufacturing market. They will require substantial expansion of the relevant regulatory and investigative capacities or must build entirely new capacities from the ground up to ensure that they can meet their ICAO obligations as countries of manufacture. National needs also will be somewhat different for counties that have large general aviation (GA) sectors and whether they must prepare for the entry of unmanned aerial systems in big numbers into civil aviation, but such needs are still far off in the future for some other countries.

Countries with low accident rates

Depending on who is counting, about 35 countries can claim to have very safe systems. Twenty years ago the list would have been limited to a smaller group of Organization for Economic Cooperation and Development (OECD) countries: Canada, the U.S., western Europe, Australia, New Zealand, and Japan. But the list now includes Chile, China, Singapore, South Korea, and several countries in central Europe and the Gulf. More countries soon will expand this list even further. All these countries face the same basic challenge of ensuring that their air transport systems continue to get safer and safer, as aviation has done persistently for 100 years.

Accident rates for these 35 countries have reached a level that was thought to be unachievable not long ago. These countries account for nearly 77% of worldwide
airline revenue flights, but accounted for just 15% of all hull losses in the past five years. As of this writing (June 2013), in the four years that have passed since Air France 447 (53 countries have had a combined hull-loss rate on the order of 0.06 per million flights and about 0.035 per million in passenger operations, or 1 in every 28 million flights. They have had zero hull losses and zero fatalities in about 50 million passenger flights since the First Air accident in Canada in August 2011.

Performance like this may become routine in the future, but it is dramatic stuff today. A single event will temporarily end this happy story, but numbers like these illustrate why accident rates are inadequate as a primary measure of safety trends. Accident rates measure how frequently things go badly wrong, so they still have value, but they say little about changes in risk or safety margins. Flight data analysis and big data are filling that void, at least in air transport.

Flight data analysis

Moneyball, a popular book and movie, illustrates the value of big data and how the data change what we believe is important. In that movie, team manager Billie Beane uses the analysis of endless data to determine which players can help his team win baseball games. When Beane tells his coaches that he plans to sign a player whom they had rejected, he asks his sheepish analyst to tell them why: “He gets on base.” When his coaches recommend a different player based on their self-described “gut feeling” that he is a good hitter, Beane asks, “If he’s such a good hitter, why doesn’t he hit better?”

The message in Moneyball is simple: If we have good data and good analytical tools, we should use them to make sense of things. The message has direct application in aviation. Good data provide evidence and replace intuition or perhaps even some folklore about what is going on and what is important. With so few major accidents today in aviation, we must use flight data analysis if we hope to know what is going on with safety and risk in airline operations.

With this evidence, we need not rely on a rare accident or two to determine whether known risks are increasing or decreasing, whether old problems need new attention, etc.

Most ISASI members are familiar with the early successes of flight data analysis in the U.S., such as issues related to the risk of CFIT accidents, midairs, stable approaches, and more. I will spare you those details, but those early successes remain good examples of how data analysis adapted the knowledge gained from years of accident investigation and traditional analysis to introduce new insights into known risks that contribute to the most lethal types of accidents.

More recently, flight data analysis has begun to focus on runway excursions (REs). This reflects the major improvement in the rate of major accidents. Even if we were capable 10 to 12 years ago of the kind of data monitoring that we can do now, REs simply would not have been on our list then because, to put it a bit crudely, they did not kill enough people. We had bigger targets to worry about 12 years ago. However, while the frequency of other major accident scenarios decreased sharply, the rate for REs remained unchanged. Consequently, despite the relative infrequency of fatalities, the sustained frequency of REs means they account for an increasing share of remaining fatalities and hull losses.

In response, flight data analysis has used the knowledge gained from accident investigation and traditional analysis to identify and monitor dozens of parameters to measure trends in problems that contribute to REs. Table 1 lists a sample of those problems, each of which requires integrating recorded data for multiple parameters from thousands of flights per day. By monitoring the identified problems, we can measure whether the risk of REs is increasing, decreasing, or remaining stable. We also can learn with some precision exactly which contributing problems are increasing or decreasing and identify where to put...
Variations of flight data analysis are starting to penetrate other sectors of aviation. The most promising examples come from large flight training centers, some aircraft manufactures, and especially from the International Helicopter Safety Team’s toolkit for helicopter flight data monitoring (HFDM). HFDM is being applied by some emergency medical services (EMS) operators but mostly by large offshore energy operators. As energy exploration moves into deeper water further off shore, activity in this sector will continue to increase. If HFDM can influence safety in that sector, and have some influence in EMS, it will be a great success.

In sum, flight data analysis, integration with other data, and the sharing of summary data provide new insights and new evidence about important issues that we simply would not have any other way. Such programs have made a substantial contribution to aviation safety in a short time and are a must for any country that hopes to understand changes in risk to a safe system. How- ever, these programs have limitations, particularly for regulators.

A need for some caution
As ISASI members understand, digital data from aircraft or ATC cannot tell us what crews or controllers were thinking, what they meant to do, whether they were working with a good knowledge base, etc. Conversely, voluntary reporting programs may tell us what people thought was going on, but they do not tell us what an aircraft was doing or what inputs or instructions actually took place. When these different programs are integrated, we have a much more capable tool, but we are a long way from an ideal integration of the data.

The primary problem is a structural limitation that the aviation community has imposed on itself. Data leave a company only in summary format with so much attention to corporate and personal anonymity that we significantly reduce the potential usefulness of the data. The attention to anonymity made sense early on. Given the cultures at most airlines and in most regulatory agencies in the 1990s, the notion that employers or regulators might use the data for less than noble purposes was not crazy. As an old joke notes, “I may be paranoid, but they still might be out to get me.”

As a result, we rarely can integrate different databases to examine specific events in detail. In all but a few cases, we can integrate and analyze only summary data. That has been valuable, but summary data do not let us gain a full understanding in specific events about the interaction of crew intentions, actual inputs, etc. Even within a given air- line, analyses often are prohibited from integrating a pilot’s voluntary report with FDR data from the subject flight, and the airline may not even be permitted to interview the pilot.

Tim Logan of Southwest Airlines noted this problem in his presentation on SMS (Safety Management Systems) at last year’s ISASI seminar in Baltimore, Maryland. He noted that programs like FOQA/FDM, LOSA, manufacturers’ data monitoring, ASAP, and voluntary disclosure were developed separately and have yet to be fully integrated, even within many organizations, let alone across organizations, and that the quest for confidentiality continues to limit the full promise of these programs. He said: “In a perfect world, we could use the same techniques we have developed for accident investigations, such as flight data information, crew interviews, and a review of the associated data in the investigation to identify hazards. [However,] the overhang from discipline and enforcement prevents these programs from [taking] full advantage of the information gained. The result is reduced learning from [each] event and a reduction in the effectiveness of the overall safety program.”

The best progress on this front has come from the Aviation Safety Information Analysis System (ASIAS) in the U.S. and the European Operators FDM Forum (EOFDM), established jointly by operators and regulators. In the U.S., ASIAS uses a third party, Mitre Corporation, to combine vast amounts of proprietary and public data to conduct systemwide monitoring. Also, through CAST, individual projects permit analysts from participating organizations to use selected proprietary data and otherwise confidential analyses by Mitre. This has been wonderfully useful as far as it goes, but such studies are few in number and work under specific charters from a committee of contributing organizations. Charters, findings, and recommendations require agreement among participating parties, and subsequent implementation of recommenda-

Challenge to authorities
Investigative authorities, which have not been very active in programs like CAST/ECAS or ASIAS/EOFDM, must figure out a way to get in this game and get the benefits of flight data monitoring and other data. Yet if not done properly, involvement could compromise investigative authorities. Assume an investigative authority fully participates in an analysis and a report, complete with mutually agreed to findings and recommendations. Then assume a major accident later raises doubts about the wisdom or strength of those findings and recommendations. An investigative authority could at least appear to have a stake in defending the report, which could invite doubts about the integrity of a subsequent accident investigation.

Investigative authorities have a public mandate to remain objective and independent, which gives investigative agencies a level of public trust and moral authority that they must protect. They cannot risk even the appearance of being compromised by self-interest. They must remain above the fray, and they must appear to remain above the fray.

Yet investigative authorities assume real risk if they remain detached from flight data analysis. As integrated flight data analysis builds a bigger library of knowledge, investigative authorities could issue conclusions and recommendations that are flatly contradicted by good evidence to which they have no access. This would damage investigators’ credibility in the aviation community, and two or three such events might destroy all broad public trust or moral authority. This risk is more than a remote possibility, and the damage could be substantial.

However, investigative authorities have several middle-ground options. They could pursue agreements for summary briefings or the option to submit specific questions, subject to agreed to conditions, to which they could expect meaningful answers. Investigative authorities could also pursue agreements to participate in studies, but with explic-
it disclaimers that they neither endorse nor challenge findings and recommendations. This would give investigators new access to solid data on selected issues with little risk to investigative independence. It also would enable others to benefit from the insights and perspective that an investigative authority can bring to the table.

Getting into the game in the right way is not an easy challenge for investigative authorities, but they must figure this out. Otherwise they will simply forfeit the evidence that new data and good analytical tools offer. That is not in their interest, the public’s interest, or the industry’s interest.

Regulators who have embraced flight data analysis face a different challenge. They must continue developing their capabilities in flight data analysis and its integration with other data and tools; but while doing so, they must avoid deprecating other skills and resources that remain necessary. In short, regulators must avoid a degree of irrational exuberance in which they forget the fundamentals while they rush to exciting new opportunities (apologies to Alan Greenspan).

**Basic purpose of analysis**

Start with the basic purpose of analysis in any government agency: to inform decisions on public policy. To do that, we must first make sense of the data and then communicate our sense-making to others. That rather basic role and the related skills sometimes get overlooked with contemporary data tools. Too often “analysis” merely presents very complex data in equally complex charts, each of which requires extensive explanation to a room full of people. When that happens, it suggests we have not yet really figured out what the data mean or, perhaps because we have been so immersed in the data, we come to believe that the data speak independently and really do not require much explanation. The catch, of course, is that data never speak independently. Someone must speak for the data and interpret the meaning for others who have not been immersed in the data. Speaking for the data is an analyst’s primary job.

Speaking for the data requires several skills that have been allowed to deteriorate somewhat. First, analysts must be numerically literate. They need not be great mathematicians, but they must know 2 times 6 is 12, not something between 10 and 14. They also must be able to write coherently in a local language. Writing a report or memo or preparing a presentation that explains our findings is critical to our task. That is where we structure our thoughts, see whether our logic can survive some scrutiny, define issues for decision-makers, tell them what we have learned and, if appropriate, tell them what course of action we think is best. Without clearly written documents or clear presentations, analysts are asking decision-makers to do their own analysis and to do the analyst’s job. When we hear someone declare after a rigorous analysis that “okay, now we just need to get someone to write this up” or “someone to make some slides,” we are listening to someone who does not understand the central task.

Equally important, particularly in GA but also in air transport, most issues that regulators must address require something more like a “small-data” approach. Automated and integrated queries can simplify or easily expand the scope of our search for pertinent data, but that is rarely enough, except for the simplest of questions.

**Importance of reading**

Most issues in the air transport sector and especially in GA require that analysts actually read accident and incident reports, other studies, etc. **Reading** gives the analyst an opportunity to understand individual events, and reading a well-documented accident report is still the best way to confirm the nature of a flight or to understand the interaction of pilot input, ATC, human factors, airworthiness, weather, etc., in a given event.

For example, analysts who rely only on automated searches to identify certain types of events often will simply miss much of the evidence they seek. In the U.S., EMS accidents are a good example. An automated search will miss some accidents that occur while an EMS operator is enroute to pick up a patient or after the operator has delivered the patient.

The same is true for an analysis of air tour operators. Consider an analysis of stall-related accidents. We do not have the benefit of a discrete field that would give us the option of hitting the “stall” button, and accident databases include multiple reports that describe stalls but never use the magic word.

Consequently, many cases will be missed by straightforward searches. In addition, an analysis only of coded fields will miss most of the story that remains and may not only fail to inform us in full, but is quite likely to misinform us. Similarly, evidence for some issues even in air transport, such as pilot fatigue, can be identified only by **reading** well-documented reports.

Reading reports also enables an analyst to understand the strengths and weaknesses of different databases and to avoid misinterpreting some data fields. For example, assume an analysis of IFR vs. VFR accidents in the U.S. An analyst might start by sorting the NTSB database on the field entitled “Flight Plan Filed” under the assumption that “IFR” identifies only accidents that occur while flying IFR and that “VFR” identifies only those accidents that actually occur while flying VFR. Wrong. The field identifies just what it says: accidents in which IFR was filed. Many accidents identified as IFR involve events in which the pilot cancelled IFR in flight, never opened the flight plan, perhaps reverted to VFR in response to an emergency, etc.

Accidents that occur in instrument meteorological conditions (IMC) offer another example. An analyst might sort the NTSB database for “prevailing weather,” assuming that “IMC” identifies all the accidents that occur in IMC. Wrong again. The data field identifies just what it says: prevailing weather. VMC may have prevailed in the general area, but the accident may have occurred in an area of heavy fog, or in a cloud bank, or in a rapidly developing thunderstorm, etc.

Many other examples could illustrate the same point: analysts must be willing to read reports. The frequent, italicized emphasis here on “**read**” is conscious. Any time an analyst declares “I can’t read 50 reports,” ask “why not?”

**Data do not exist**

The same is true when analysts declare that “the data do not exist.” We might ask how hard they looked and whether they have considered building a new dataset to address the issue. This might require reading reports to identify factors not discreetly identified in coded fields, or it could require that we manipulate easily available data that are not ideally organized for the issue at hand (arithmetic literacy rather than an exhaustive knowledge of mathematics). Building a new dataset also might require search-
ing press articles, academic articles, etc. The required time and cost may not be justified, but at least that would be an informed choice. Either way, we need to ask questions when we hear that the data simply do not exist.

In sum, most air carrier activity now takes place in countries that have very safe systems. Those countries must continue building their capability in flight data analysis and its integration with other data and tools in order to monitor risk and have an informed sense of what risks might be improving, remaining stable, or increasing. However, they must recognize some practical limitations of these approaches, and they must maintain other fundamental skills.

**Other countries**

At the opposite end of the spectrum, 13 countries have fantastically high accident rates, including the Congo (DRC) and Sudan, which alone account for 14% of world hull losses over the past five years (2008–2012) with just 0.1% of airline departures. To put this in scale, the resulting rate would produce eight hull losses every day among the 35 “safe” countries. Up to 11 more countries qualify as outliers, though not at this fantastic scale. Many of the 13 countries here simply lack anything approaching functioning states, which excludes them from a realistic conversation about preparing the public sector for tomorrow’s aviation skills. (See Table 2.)

Between the two ends of the spectrum, the rest of the world has a wide range of accident rates. A handful of countries in this large middle likely will join the safe club in the reasonably near future, while others still have some distance to go.

Table 2 identifies six countries that have high accident rates but that have or likely soon will have many of the basic resources required for substantial improvement in safety, such as adequate national wealth or an adequately educated local workforce (Indonesia, Iran, Kenya, Pakistan, Russia, and Venezuela). The biggest challenge facing some of these six countries will be institution building. However, the absolute number of major accidents remains high enough in these six countries that they still have significant room for improvement even without flight data analysis or any other elements of the data. Tools like flight data analysis certainly would not hurt, but they probably can wait because some easy pickings remain.

Table 2 shows three other countries with significant aviation systems, Brazil, Colombia and Mexico, that have made substantial progress in recent years. Their five-year rates are beginning to approach those of the 35 safe countries, though the immediate challenge is to sustain the improvements. These countries already are active in regional bodies such as ICAO’s COSPAC, and some are trying to strengthen their investigative and analytical capabilities. Several other countries also are approaching this level, though their systems are smaller. All these countries soon will approach a level of safety, or perhaps already have reached such a level, at which they will need to develop greater capabilities in flight data analysis and related systems in order to sustain their improvements.

**Other influencing factors**

For the past several decades, the international market in air transport aircraft has been organized around duopolies that dominate different sectors. Airbus and Boeing have dominated the air transport jet market for several decades, Bombardier–Canadair and Embraer have dominated the regional jet (RJ) market at least since the 1990s, and ATR and Bombardier have dominated the market for large turboprops. Those firms likely will continue to dominate their respective niches for some time, but things are changing, as China, Japan, and Russia enter those markets. Boeing projects demand for 35,000 airliners over the next 20 years, with continued growth of airline travel in Asia, growth in

### Table 2

<table>
<thead>
<tr>
<th>Countries</th>
<th>Total Departures</th>
<th>Hull Losses</th>
<th>% Dep.</th>
<th>% Hull Losses</th>
<th>Hull Loss/ Million Dep.</th>
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<tbody>
<tr>
<td>World Totals</td>
<td>154,300,000</td>
<td>154</td>
<td>100</td>
<td>100</td>
<td>1.0</td>
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<tr>
<td>35 States with Low Rates</td>
<td>118,424,000</td>
<td>24</td>
<td>76.7</td>
<td>15.6</td>
<td>0.2</td>
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<tr>
<td>Congo &amp; Sudan</td>
<td>178,900</td>
<td>21</td>
<td>0.1</td>
<td>13.6</td>
<td>117.4</td>
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<tr>
<td>11 Other States with High Rates</td>
<td>1,063,400</td>
<td>23</td>
<td>0.7</td>
<td>14.9</td>
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<tr>
<td>Subtotal</td>
<td>1,242,300</td>
<td>44</td>
<td>0.8</td>
<td>28.6</td>
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<td>Indonesia</td>
<td>2,264,400</td>
<td>9</td>
<td>1.5</td>
<td>5.8</td>
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<td>Iran</td>
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<td>1.9</td>
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<td>Venezuela</td>
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<td>4.2</td>
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<td>Brazil</td>
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<td>Colombia</td>
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<td>1.3</td>
<td>1.6</td>
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<td>Mexico</td>
<td>2,591,900</td>
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<td>1.7</td>
<td>0.6</td>
<td>0.4</td>
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<tr>
<td>Subtotal</td>
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<td>5.3</td>
<td>4.5</td>
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<tr>
<td>Rest of the World</td>
<td>19,930,900</td>
<td>43</td>
<td>12.9</td>
<td>27.9</td>
<td>2.16</td>
</tr>
</tbody>
</table>
over 20 years, with 13,000 of those jets. To put some scale on the geography of growth, Boeing estimates a global demand for 25,000 new single-aisle jets.

The immediate challenge to Airbus and Boeing will come from the established RJ manufacturers, Canadair and Embraer. Each manufacturer will soon enter the market with jets ranging from 100 to 130 seats, blurring any meaningful distinction between RJ and single-aisle jets. Later challenges will come from Russia’s revamped Tupolev and especially from China’s C919. The development of China’s new jets has fallen behind schedule, but China will get there.

The RJ market for aircraft in the 70- to 100-seat range also will change soon. Russia recently delivered its first Sukhoi Superjet 100 to a Western operator (Interjet of Mexico). Mitsubishi of Japan expects its MRJ to enter service by early 2016. China hopes to do the same with its ARJ. China’s Xian also has begun exporting its STOL-capable MA60 turboprop. The MA60 is not certificated in much of the West, but it will continue to capture some orders. It already is active in Indonesia, Laos, the Philippines, Russia, and Bolivia, as well as China’s domestic industry.

All this change places new demands on regulators and accident investigative authorities in China, Japan, and Russia. At a minimum, they must establish new capabilities in airworthiness certification and continued product oversight to ensure that they meet their ICAO obligations as the country of manufacture. They also must build investigative authorities with more global reach because they will face accidents abroad in aircraft operated by foreign carriers. Better capabilities for the analysis of manufacturers’ data also will be important after those aircraft enter service. All three countries have made real progress, but the changes remain a challenge.

Growth in domestic fleets and domestic air travel also will pose a challenge for regulators in markets like China, perhaps India, and parts of Africa and the Americas. To put some scale on the geography of growth, Boeing estimates a global demand for 25,000 new single-aisle jets over 20 years, with 13,000 of those jets to be sold in Asia. This increases the probability that the countries now entering the aircraft manufacturing market can expect to find some customers.

Many rapidly growing countries will have to build competent regulatory and investigative authorities almost from the ground up, though some, such as China, already are well along in this task. In many countries, challenges may go well beyond establishing the necessary technical capabilities. Challenges will include fiscal limitations and institutional barriers to ensuring that regulatory and investigative authorities have real authority as well as technical capacity. Some aviation authorities also will face a shortage of appropriate skills among the local labor force and will have to compete with rapidly growing local economies for qualified workers.

Needs in general aviation

GA systems with broadly based, private ownership of small aircraft likely will remain concentrated in the same regions where they exist today. That mostly means selected members of the 35 safe countries, plus perhaps Brazil, Mexico, and South Africa. However, the growth in business aircraft will change the geography of GA somewhat. As with the airliner market, Asia appears to be the Promised Land. Beechcraft has noted that the business fleet, including turboprops, grew by two-thirds in Asia over the past decade (through 2012), reaching 1,566 in 2012, including about 900 jets. The business fleet in Asia grew by an annual average of 4.5% from 2003 through 2007, then by an average of 5.7% from 2008 through 2012.

Asia’s business aircraft fleet is still relatively small for a region with such large populations and high overall growth rates. Yet, even if overall growth rates in Asia slow a bit from their recent levels, the business aircraft fleet in Asia should maintain annual growth rates on the order of 5 to 7% for some time.

Growth in business aircraft should continue in other countries as well. Brazil, Mexico, and Russia are obvious candidates. Parts of Africa also may see high growth rates in this fleet, albeit from a small base. In many of these countries the growth in business aviation will be in addition to rapidly growing airline systems, which only increases the urgency to build stronger regulatory and investigative authorities.

In addition, investigative authorities in all countries with any meaningful GA activity will be affected by the rapid increase in onboard memory on GA aircraft. This will affect the mix of skills those authorities require, and it will mean more and more of the GA investigations will take place in the lab.

Conclusions

Preparing the next generation of regulatory and investigative authorities will pose different challenges for different countries. Countries with sustained low accident rates must focus on building their capabilities in flight data analysis and related data in order to identify and monitor risk. Investigative authorities in those countries must find a way into that game, but they must protect their independence while doing so. Regulators in those countries must continue building their resources in this field but without losing sight of some basic skills.

Other countries that are approaching the status of safe will need to continue moving in the same direction, but also may need to improve institutional capabilities. Other countries that have high accidents may need to establish, for the first time, regulatory and investigative authorities that have technical capability and real authority. In some countries the number of accidents remains high enough that preparing for tomorrow may need to wait while easier pickings are addressed.

Other factors also will influence countries’ needs. Some face rapid domestic growth, and, once again, institution building may be a big challenge. Countries entering the international airliner market face additional demands for building new regulatory capabilities in airworthiness and significantly expanded investigative capabilities with a global reach. Finally, the size and complexity of future general aviation systems also will affect national needs. No one size will fit all.
The Airbus A320 wing strike at Hamburg Airport in 2008, like many other occurrences, was flashed around the world within hours of its occurrence via YouTube.

Aircraft Accidents and Social Media

By Johann Reuss, Senior Safety Investigator and Deputy Director of the German Federal Bureau of Aircraft Accidents Investigation (BFU)

(Adapted with permission from the author’s paper entitled Airbus A320 Wing Strike at Hamburg Airport Going Around the World Within Hours Via YouTube presented at the ISASI 2013 seminar held in Vancouver, B.C., Canada, on Aug. 19–22, 2013, that carried the theme “Preparing the Next Generation of Investigators.” The full presentation, including cited references to support the points made, can be found on the ISASI website at www.isasi.org under the tag “ISASI 2013 Technical Papers.”—Editor)

On March 2, 2008, an Airbus A320 on a scheduled passenger flight from Munich to Hamburg experienced high and variable wind velocity on short final. During the attempt at landing on Runway 23 with a strong crosswind component from the right, the left main landing gear touched down followed by a left wing down attitude that resulted in the left wingtip touching the ground. A go-around was initiated; and after radar vectoring, a second approach to Runway 33 was made to a successful landing. No aircraft occupants were injured, but the aircraft left wing tip was damaged by the runway contact.

A plane spotter video taken on the ground and distributed via the Internet within the next hour after the occurrence resulted in media hype. Several television programs picked up the video for their evening newscasts, and newspapers carried reports about the event (see Figure 1)

Initially the press praised the pilots for their “heroic” reaction. Then the press started to ask why the pilots didn’t use a different runway in the first place, one that was better suited for landing in strong winds. When the news media realized that the 24-year-old female copilot flew the aircraft, they asked, “Why was an inexperienced copilot on controls in such bad conditions and not the captain himself? Still later a weekly magazine revoked a “pilot’s fault” declaration. Airbus’s fly-by-wire system was then blamed for causing the serious incident. These prejudgments were strengthened by several statements given by self-appointed professionals.

In conformity with the federal German law relating to the investigation into accidents and incidents associated with the operation of civil aircraft (Flugunfall-Untersuchungsgesetz–FLUUG), the German Federal Bureau of Aircraft Accident Investigation (BFU) classified the occurrence as a “serious incident” and opened a formal investigation.

The BFU finalized a comprehensive investigation by publishing the final report in May 2010, which included 12 safety recommendations. The investigation found that this serious landing incident (see Figure 2) took place in the presence of a significant crosswind,
and the immediate causes were as follows:
• The sudden left wing down attitude was not expected by the crew during the landing and resulted in contact between the wingtip and the ground.
• During the final approach to land, the tower reported the wind as gusting up to 47 knots, and the aircraft continued the approach. In view of the maximum demonstrated crosswind for landing, a go-around would have been reasonable.

The report said, “The following systematic causes led to this serious incident:
• The terminology “maximum demonstrated crosswind” for landing was not defined in the operating manual (OM/A) and in the flight crew operating manual, Vol. 3 (FCOM), and the description given was misleading.
• The recommended crosswind landing technique was not clearly described in the aircraft standard documentation.
• The limited effect of lateral control was unknown.”

The investigation showed that wingtip contact with the runway was not due to a single human error, a malfunction of the aircraft, or inadequate organization; rather, it was due to a combination of several factors. The approach was stable up to about eight seconds before touchdown. Given the effect of the wind, the sidestick inputs were logical. The comprehensive factors and the following analysis are mentioned in the final report. A major influence was given to the weather and the decision-making processes.

Operational aspects
Because of the weather associated with Hurricane Emma, on March 1, 2008, the Airbus A320 left Munich Airport on a scheduled flight to Hamburg at 1231 hours, about two hours behind schedule, with a crew of 5 and 132 passengers.

Given the ATIS (Automatic Terminal Information Service) weather report of wind of 280°/23 knots with gusts of up to 37 knots, the crew decided during the cruise phase of the flight on an approach to Runway 23. The runway then was also in use by other traffic. During the approach to land, the aerodrome controller gave several updates on the wind. Immediately prior to touchdown, the wind was reported as 300°/33 knots, gusting up to 47 knots. At the time of the decrab-procedure, there was no significant gust.

The initial descent was flown by autopilot and the copilot assumed manual control from 940 feet above ground. After the aircraft’s left main landing gear touched down, the aircraft lifted off again and immediately adopted a left wing down attitude, and the left wingtip touched the ground. The crew initiated a go-around procedure. The aircraft continued to climb under radar guidance to the downwind leg of Runway 33, where it landed at 1352 hours. The flight crew had wind information issued by ATIS and the tower. The resulting wind components for Runway 23 and Runway 33 are shown in Figure 3.

After the decision to approach Runway 23, the latest wind information given by the tower was 300/33 gust 47. The earlier updates on wind included gust with 47 knots. According to the operations manual (OM/B) and the flight crew operations manual (FCOM) “33 knots gusting up to 38 knots” was defined for the maximum demonstrated crosswind for landing.

The crew did not interpret the wording given in the operations manual instruction: “The steady crosswind and gust component for takeoff and landing must not exceed the values specified in [the operations manual]. Where no gust limit is specified, gust exceeding crosswind limitations must be considered whenever judged operationally significant.” As a flight operational limit, the gusts were not viewed as a limiting factor.

The BFU found that the aircraft certification method for setting the crosswind landing limits or guidelines, respectively, permitted a method of demonstrating compliance that did not take into full account the real effect of crosswinds.

The values for maximum demonstrated crosswind were presented differently for different types within the Airbus family (average wind speed plus gusts, average wind speed including gusts).
For a better understanding of why the flight crew did not view the maximum demonstrated crosswind for landing as a limiting factor, the BFU initiated an anonymous survey to 81 ATPL airline pilots employed by five different airlines. The objective of the survey was to establish how pilots understand the term maximum demonstrated crosswind for landing given in handbooks and how this is interpreted in practice.

The survey was conducted by the BFU personnel using a questionnaire, and pilots were asked to provide spontaneous answers. There were three questions with possible answers provided. The answers given are represented by the following distribution diagrams.

**Question 1**

What is the practical meaning for you in normal flight operations of the term “maximum demonstrated crosswind” as stated in the OM/B?

- a) This value is a limit.
- b) This value is a guide.
- c) Right now, I am not sure.

**Question 2**

The “maximum demonstrated crosswind” is the

- a) Maximum crosswind speed at which the authority of control surfaces can be maintained during a crosswind landing?
- b) Maximum crosswind speed that could be demonstrated during type certification test flying, due to the weather conditions?
- c) Maximum crosswind speed that, following test flying, has been set as a representative limiting value for line pilots?
- d) Right now, I am not sure.

**Question 3**

The handbook sets the “maximum demonstrated crosswind” at 33 knots, gusting 38 knots. The crosswind component (gust) for the approach is 40 knots. Which of the following responses is correct?

- a) The aircraft may land if the gusts are assessed as not operationally relevant.
- b) The aircraft may not land because this would exceed the aircraft’s operational limitations.
- c) Gusts are not to be considered when calculating crosswinds, only the steady wind counts.
- d) Right now, I am not sure.
Due to the different interpretations of gust data and maximum demonstrated crosswind for landing, the BFU issued among other safety recommendations the following:

“EASA should place a contract with a suitable research institute (DLR, university, or similar) to determine what measuring systems are suitable to detect the presence of near-surface gusts on airports, and how the resulting gust data and wind direction information should be processed and communicated to pilots. The results should lead to a process through which the information so obtained can be standardized and incorporated into the regulations governing air operations.”

In response to the above-mentioned safety recommendation, EASA assigned the NLR Transport Safety Institute to conduct a study regarding gust detection practices to support flight crew decision-making. The study was published in December 2011.

The BFU directed a further safety recommendation regarding maximum demonstrated crosswind demonstrated for landing to the aircraft manufacturer that has been accepted as well.

The manufacturer should adopt a uniform presentation of maximum crosswind demonstrated for landing for the entire range of the same series of aircraft. The maximum demonstrated crosswind for landing should be described either as a dual value (average wind speed and gust) or as a single value (average wind speed including gusts). Manufacturers should make recommendations to air operators as to the suitable maximum crosswind component for landings.

**Aircraft (lateral control)**

When the left main landing gear first touched the runway, the lateral control system condition thus met all the requirements for the transition from flight mode to ground mode so the system switched from lateral flight mode to lateral ground mode even though the aircraft was once again in the air.

The aircraft was designed so that the effect of lateral controls (along the longitudinal axis) would reduce by about one half of full deflection as soon as one main landing gear touched down. The reduced effect of the controls was not documented in the system description and was unknown to pilots or the training department.

By now the flight control laws logic has been modified with a modification of transition from flight to ground lateral law. This improvement was certified in 2012 in the ELAC standard L96 and is available through Service Bulletin Ref. 27-1225.

**Landing technique**

The descriptions of different crosswind landing techniques (crab-angle, sideslip, or a combination) contained in flight operations documentation FCOM, FCTM, FCOM bulletins, and Flight Operation Briefing Note (FOBN) were not uniform and in part contradictory. The crosswind landing description given in FCOM was less suitable for use in very strong crosswinds because it could result in the aircraft drifting from the runway centerline.

There were different descriptions given in the aircraft manufacturer’s flight documentation with respect to the use of rudder in crosswind conditions. One FOBN issued by the aircraft manufacturer described a technique for landing in strong crosswinds that would have been suitable for the Hamburg landing in question, but it was not part of the official operations manuals. The description of the crosswind landing technique given in the company operations manuals did not correspond fully with the one given by the aircraft manufacturer in the FCOM.

There were differences between the landing techniques described the operations manual volumes covering “Aircraft Type” and “Fight Training”; under strong crosswind conditions, the wings low with crabbed approach technique described in the flight training volume would have been more suitable and was the method taught and practiced in the simulator.

In response to a safety recommendation regarding landing techniques, the aircraft manufacturer has updated the descriptions of the different landing techniques and has reviewed the published FOBN regarding crosswind landings.

**Lessons learned**

The discussed serious incident is a concrete example that demonstrates why it is important to investigate serious incidents and not just accidents. Nevertheless, limited resources and number of investigators do not allow all safety investigation agencies to investigate serious incidents. It has not been reconsidered that the investigation of a serious incident can be very complex as well.

The aim of every investigation is to reveal and eliminate safety deficiencies in daily aircraft operation. For this reason, it is necessary to determine systemic causes and to issue final reports and safety recommendations. A safety recommendations database is a helpful tool to improve safety for the future. A forward-looking example is the EU-Regulation 996/2010 where this requirement is laid down.

Nowadays photographs and videos taken by amateurs, passengers, or security cameras at airports are common practice. Videos showing the sequence of events can be helpful for investigators. However, if not taken properly, photographs and videos can easily misrepresent a scene and lead to false conclusions or findings about an accident.

Safety investigation agencies and safety investigators have to consider that photographs and videos taken by amateurs are interesting for the news media. The Internet, including sites like YouTube, enables a global distribution of video and photographs within minutes. A news media hype, followed by misinterpretations and false conclusions, is very likely. To restrict blaming or prejudging pilots, airlines, manufacturers, or other involved organizations, it can be good policy for safety investigation agencies to supply the news media with factual information and official photographs as early as possible.

**Preparing the next generation of investigators**

Recent accidents and serious incidents such as the Airbus A380 engine disintegration, the Boeing B777 multiple engine failure, and the Airbus A320 crosswind landing at Hamburg Airport are examples of complex occurrences and investigations. In addition to the complexity, the news media impact was eminent.

It is assumed that safety investigation agencies and safety investigators have to deal with occurrences like those mentioned above. The complexity of the aviation system and the activities of journalists and the news media will increase more and more.

In respect to the ISASI 2013 seminar theme “Preparing the Next Generation of Investigators,” it might be helpful to initiate two improvements (among other approaches): to establish a global knowledge database “from safety investigators for safety investigators.” The repository of safety knowledge related to aviation safety in general can be a portal, a common entry point that enables investigators to access data made available on the (Continued on page 30)
Investigating Runway Overruns—A Manufacturer’s Perspective

By Frederico Moreira Machado, Air Safety Investigator, and Carlos Eduardo Bordignon Martinez, Air Safety Investigator, Embraer Air Safety Department

According to the IATA Safety Report 2012, runway excursions continue to be one of the leading causes of accidents worldwide. Aiming to help prepare the next generation of air safety investigators, we present key topics related to runway overruns that were gathered by Embraer from years of assisting in investigations of this type throughout the globe.

Comprehending landing distance figures provided by manufacturers depends on concepts set forth regarding design and operating requirements. Each country has its own set of aviation regulations. Here we focus on those of the U.S. and the European Union (EU).

Design requirements
The applicable regulations in this section are United States 14 Code of Federal Regulations (CFR) Parts 23 and 25 and European Certification Specification (CS) 23 and 25. Unless otherwise noted, this section will refer to both U.S. and Europe design requirements, since the structure of both is very similar. The most important sections related to landing distances are Section 23.75 for Part 23 and Section 25.125 for Part 25. These requirements demand that the manufacturer determines the horizontal distance necessary to land and come to a complete stop from a point 50 feet above the runway threshold at VREF for standard temperatures at each weight and altitude within the operational limits established for landing. The distances obtained by the manufacturer based on these requirements are known as unfactored landing distances.

Importantly, the main braking devices for determining landing distances are the wheel brakes. If the airplane employs any deceleration device that is dependant on the operation of the engines, then landing distance figures for engine inoperative must be determined as well. The dry unfactored landing distance provided by the manufacturer is determined in two parts. The first part corresponds to the airborne distance, which is the distance between the point in trajectory in which the aircraft is 50 feet above the runway surface and the touchdown point. The second part is the ground distance, which is the distance from touchdown to the complete stop. The ground distance may be divided into a transition phase, in which the decelerating devices are beginning to be applied, and a full braking phase, in which the decelerating devices are fully operational. Figure 1 illustrates both parts of the landing distance.
The ground distance is determined from the deceleration resulting from the dry runway braking coefficient as obtained from flight tests. FAA Advisory Circular (AC) 25-7C details the acceptable means of compliance with landing distance requirements for transport-category airplanes (§ 25.125).

For EASA-certified aircraft, CS 25.1591 mandates that manufacturers determine the landing distance for runways contaminated with standing water, slush, snow, or ice. If the performance information for runways covered with these contaminants is not supplied, the airplane flight manual (AFM) must contain a statement prohibiting operations on the surfaces for which this information is not supplied. EASA Acceptable Means of Compliance (AMC) 25.1591 provides a methodology for determining performance data for runways covered with the aforementioned contaminants.

Operating requirements
Let’s now discuss operating requirements that affect landing distance, in particular the concept of factored landing distances. Factored distances are determined from multiplication of the unfactored landing distances by factors that depend on the type of operation, (scheduled air carrier, business, etc.), runway conditions (dry, wet, or contaminated), and aircraft conditions (in case of system failures that affect landing performance). Further, we will focus on requirements related to flight dispatch, i.e., requirements that forbid takeoff if specific conditions anticipated during landing at the destination or alternate airport are not met.

United States
The basic operating regulation in the United States is 14 CFR Part 91—General Operating and Flight Rules. All citizens who wish to operate their own aircraft have to comply with the requirements in Part 91 (§ 91.1). Additionally, fractional ownership operations demand compliance with Subpart K, which brings specific requirements for this type of operation. Large aircraft are those with a maximum certificated takeoff weight of more than 12,500 pounds (§ 1.1). Except for large airplanes operating under Subpart K, there is no requirement for the application of landing distance factors in Part 91. Before takeoff, as a preflight action (§ 91.103), operators are required only to be aware of the runway lengths at airports of intended use as well as the required landing distances published on the aircraft’s approved flight manual, if any.

As an example, the operation of an Embraer Phenom 100 (which has a MTOW of 10,472 pounds) under Part 91 does not require the application of the landing distance factor over the unfactored distance.

Requirements for commuter and on-demand operations are described in 14 CFR Part 135. Subpart I gives landing distance limitations at destination and alternate airports for the following categories:

- Large Transport Airplanes/Reciprocating Engines (§ 135.375 and § 135.377)
- Large Transport Airplanes/Turbine Engines (§ 135.385 and § 135.387)
- Large Nontransport Airplanes (§ 135.393 and § 135.395)
- Small Transport Airplanes (§ 135.397)
- Commuter Airplanes (§ 135.398)
- Small Nontransport Airplanes (§ 135.399)

Requirements for domestic, flag, and supplemental operations are described in 14 CFR Part 121. Operators of turbine-powered airplanes under this part are required, before takeoff, among other actions, to ensure that the aircraft’s weight on arrival, allowing for normal consumption of fuel and oil in flight, would allow a full stop landing at the intended destination within 60% of the effective length of the runway (§ 121.195). The resulting landing distance based on this requirement is illustrated in Figure 2. This requirement is also applicable for alternate airports (§ 121.197). For turboprop-powered airplanes that can’t comply with this requirement, it is permitted to take off if the airplane can accomplish a full stop landing within 70% of the effective length of the runway of an alternate airport.

Requirements for commuter and on-demand operations are described in 14 CFR Part 135. Subpart I gives landing distance limitations at destination and alternate airports for the following categories:
The first three categories in the list have specific requirements for the application of a factor over the unfactored landing distance. The last three are required to comply with some of the landing distance requirements from the previous categories.

Regulation also requires operators to apply a factor of 1.15 over the factored landing distance, as applicable for each different kind of operation, if weather reports or forecasts indicate that the runways at the destination or alternate airports may be wet or slippery at the estimated time of arrival (§ 91.1037, § 121.195, and § 135.385). That means an additional safety margin of 15% over the factor described in the previous paragraphs.

Figure 3 illustrates the application of this factor over the factored landing distance. Therefore, the resulting wet landing distance is not the product of analytical methodology to calculate the distance based on a theoretical coefficient of friction. Neither is it the result of flight tests on a wet runway. It is simply the result of multiplication, as mandated by operational requirements.

On the other hand, for contaminated runways (presence of standing water, snow, ice, slush, or other contaminants), U.S. regulation does not mandate operators to evaluate the required landing distance for such conditions when they are expected to be found at the destination before takeoff. Landing distance figures for contaminated runways are provided in operational manuals as guidance material.

Finally, it is important to point out that the operational requirements discussed here are those related to flight dispatch. If the anticipated conditions are not verified when the aircraft reaches its destination due to contamination or any system malfunction that adversely affects landing performance, the operator does not have to comply with factored landing distance requirements considered for dispatch. Rather, the flight crew is expected to reassess the landing distance for that particular unanticipated situation in order to decide to proceed with landing. However, presently there are no operational requirements that mandate pilots to perform this inflight reassessment of the required landing distance.

Europe
As of 2013, each country in the EU has its own set of basic operating requirements, as regulated by the country’s respective national aviation authority. However, commercial passenger and cargo transportation operations are regulated in EU countries by EU-OPS, a regulation whose purpose is the harmonization of technical requirements and administrative procedures applicable to commercial transportation by airplane.

Regarding landing performance, there are two relevant sections to be mentioned: OPS 1.515 (Landing Performance—Dry Runways) and OPS 1.520 (Landing Performance—Wet and Contaminated Runways). Section 1.515 states that an operator must ensure that the landing mass of the airplane for the estimated time of landing at the destination or any alternate aerodrome allows a fullstop landing from 50 feet above the threshold within 60% of the landing distance available (turbojet-powered) or within 70% of the landing distance available (turbo-prop-powered).

Section 1.520 states that when weather reports or forecasts indicate that the runway of intended landing at the estimated time of arrival may be wet, operators shall ensure that the landing distance available is at least 115% of the required landing distance, as mandated by Section 1.515. That represents an additional 1.15 safety factor over the factored dry landing distance. In addition, operators are further required to apply the same 1.15 factor over the required landing distance when runway contamination is anticipated. Since EASA mandates that manufacturers provide contaminated landing distance figures, operators must apply this 1.15 factor over the required landing distance for contaminated runway.

Braking systems
The braking system plays a critical role in aircraft deceleration during the landing run on the ground. For this reason, investigators should be familiar with some aspects related to its operation. The basic operation of brakes involves converting the kinetic energy of motion into heat energy through the creation of friction.

The higher the braking force, the shorter the stopping distance. However, the braking force can’t be increased indefinitely. Figure 4 presents the typical behavior of the braking force as a function of the slip ratio. The maximum braking efficiency is obtained with a slip ratio of approximately 10%. The anti-skid (discussed on page 27) ensures that the brake pressure is adjusted so that the slip ratio remains near the optimal range.

Hydraulic systems on large aircraft typically range from 3,000 to 5,000 psi. It has been determined that it’s not possible to apply the maximum braking pressure on the brakes because this would lock the wheels and take the slip ratio to 100%, out of its optimal performance range.
Anti-skid systems

As previously explained, anti-skid systems maintain the wheels in the optimum slip ratio during landing, attaining the maximum possible braking performance at that particular runway. Each wheel fitted with brakes has its rotation monitored. Whenever the rotation tends to slow down toward wheel skidding, the system alleviates braking action on that particular wheel so that it resumes rotation.

New certification designs tend to opt for fully modulating systems (based on the sensed wheel speed in a closed control loop for which the reference is pilot braking command), which provide the best braking performance. Investigators should verify what system type was installed in the aircraft under investigation and if the observed system performance matches that system type. AC 25-7C brings typical plots for brake pressure and wheel speed for each of the types of anti-skid.

Precaution should be taken when comparing such plots with FDR data because FDR sample rates for these parameters are usually less than those used for certification test purposes. Therefore, the high-frequency oscillation might not be noticeable on the FDR plots.

An alternative to that may be found in tests of flight data, which are performed with instrumented prototypes to produce high sampling rate data for aircraft certification purposes. Aircraft manufacturers usually retain these data for several years, which might then be used to analyze a particular aspect of the braking system operation of that particular type design.

Electronic brake control units from several suppliers record a fault log for shop maintenance purposes. This fault log might reveal important aspects of the system operation. Downloading such nonvolatile memories (NVM) should always be considered when investigating runway excursions. In addition, since anti-skid systems are not developed by the aircraft manufacturer, in most cases, the airframe will not have access to the details of the algorithm of the anti-skid system. Therefore, it might be important to involve the braking system supplier in the investigation as well.

Auto-brake systems

Auto-brake systems provide automatic braking at preprogrammed deceleration rates for landings and rejected take-offs. The system modulates hydraulic pressure to the brakes in order to achieve a constant deceleration rate corresponding to the selected level.

Even the greatest auto-brake setting, however, might not correspond to the highest possible deceleration under certain conditions. Imagine, for example, a situation in which the auto-brake target deceleration is met solely with the use of brakes. In this case, if reverse thrust is actuated, the auto-brake system would alleviate brake pressure to maintain the target deceleration rate.

Therefore, it is important to investigate whether the auto-brake system was engaged during the runway excursion. Modern aircraft with these systems have FDR parameters that register auto-brake operation. However, if such parameters are not available, investigators should resort to other elements of information such as the NVM from the auto-brake controller, interviews with the flight crew, etc.

Runway aspects

As discussed earlier, the landing figures provided by manufacturers depend on concepts set forth regarding design and operating requirements, which in turn assume that the runway in question complies with design and maintenance requirements. Just as with aircraft design, airworthiness and operational requirements, each country has its own set of requirements for runways.

U.S. 14 CFR Part 139 establishes the requirements for airport certifications. The requirement §139.305 introduces the need for maintaining and repairing the paved areas, including the runway. FAA AC 150/5300-13A, entitled “Airport Design,” and the cascading advisory circulars cited within, include guidance on runway location, orientation, and physical characteristics such as length, surface conditions, and slope.

EASA aims to have a common aerodrome regulation sometime in 2014. Document NPA 2011-20 (B.III)–Draft Certification Specification reveals that this common requirement will be essentially ICAO Annex 14. Chapter 3 of ICAO Annex 14 contains information on physical characteristics of runways (including shoulders, turn pads, strips), taxiways, and surrounding areas. These requirements include, but are not limited to, the orientation of the runway, slopes on runways, and runway surface.

When analyzing runway overruns, it is of foremost importance to consider the runway aspects that could affect the available friction coefficient between the pavement and the aircraft tires. The effect of surface material on the tire-to-ground coefficient of friction arises mainly from differences in surface texture. There are two components that make up the runway pavement texture (see Figure 5):

- Macrotexture: Primarily created by the size of the aggregate used or by the treatment of the surface. It is the created texture between individual stones. It can be seen by the human eye.
- Microtexture: Texture of the individual stones. It’s barely visible to the human eye.

The runway texture is also intimately linked to drainage capacity. At high aircraft speeds, the water in the tire/ground interface is highly affected by the pavement macrotexture. Rough surfaces (open macrotexture) provide more drainage than smooth ones (closed macrotexture) at high aircraft speeds. As a consequence, poor macrotextures increase the probability of hydroplaning.

Let’s look at the runway overrun involving an ERJ-135, registered ZS-SJW, on Dec. 7, 2009, at George Airport in South Africa. The South African Civil Aviation Authority (SACAA) final report indicates that the runway surface macrotexture fell below half of the value prescribed by ICAO after it had been treated with a bituminous fog spray, which filled the voids between the pavement aggregates (see Figure 6, page 28).
For a deep and comprehensive description of the runway aspects affecting braking performance, including measurement methods and reference values, refer to ICAO Circular 329: Assessment, Measurement, and Reporting of Runway Surface Conditions 2012. The Transportation Safety Board of Canada (TSB) final report (A10H0004, ERJ-145 N847HK, 2011) on the runway overrun involving an ERJ-145 contains an analysis of the runway characteristics affecting the aircraft braking capacity.

**Interface aspects**

**Runway Friction (measurements and limitations)**

The friction coefficient is a dimensionless ratio of the friction force between two bodies moving, or tending to move, in relation to another and the normal load pressing these two bodies together. By its own definition, friction involves two bodies, and therefore it is not correct to think about it as an inherent characteristic of a body (runway pavement, for example).

In trying to predict aircraft braking performance on a runway, the aviation industry developed several friction-measuring devices that act as a “calibrated second body” to measure the friction coefficient developed between the device and the runway surface. ICAO Doc. 9137, Chapter 5, describes in detail the technical specifications of the most used friction-measuring devices.

For the scope of this article, it is important to highlight that up to this date there is no universally accepted correlation between measured friction coefficient and aircraft braking performance, especially for wet runways, although satisfactory correlation between the friction-measuring devices was obtained for dry runways and, to a lesser extent, snow and/or ice-covered runways.

With the use of aerodynamic and thrust data for the aircraft, manufacturers are able to estimate the aircraft braking coefficient based on recorded flight data. However, investigators should keep in mind that this is the net result of the interaction among the aircraft tire, pavement, weather (winds, temperature), pilot technique, and the design and operation of the aircraft braking system.

**Hydroplaning**

Hydroplaning is a phenomenon in which a film of standing liquid contaminant on the pavement causes the tire to lose contact, partially or totally, with the surface. Whenever a tire meets a region covered with a film of fluid, the tire “squeezes” water out of the contact region with the runway, exerting force over the fluid. As predicted by Isaac Newton’s third law, the displaced fluid will react with an equivalent force of the same magnitude with the opposite direction against the tire, contributing to reduce the tire footprint (the area in contact with the runway surface). This force is called hydrodynamic force.

The hydrodynamic force exerted on the tire increases with speed and will eventually lift the tire, causing it to completely lose contact with the surface, a condition known as total hydroplaning. Figure 7 illustrates conditions of partial (A) and total hydroplaning (B).

The condition of partial hydroplaning is usually referred to as viscous hydroplaning. It is characterized by reduction of the braking force due to the tire footprint reduction. While in this condition, the tire may tend to skid more easily during braking.

The condition of total hydroplaning is known as dynamic hydroplaning. Its main characteristic is the complete loss of contact between the tire and the pavement, which are separated by a layer of fluid. In this situation, an unbraked wheel may considerably slow down its angular speed and, in more critical cases, even cease to rotate. While in this condition, the breaking force is negligible, and the only deceleration force relating to the tire comes from the drag resulting from the displacement of fluid.

When a locked wheel slides over a layer of water, a third type of hydroplaning known as reverted rubber (or vapor) hydroplaning occurs. Tire heating in the footprint contact patch causes the film of water to become a cushion of steam. The heat reverts the rubber to its uncured state (thus reverted rubber).

The Brazilian Aircraft Accident Investigation and Prevention Center (CENIPA) final report (Phenom 100 PR-UUT, 2010) on the runway overrun involving a Phenom 100 gives an example of reverted rubber hydroplaning, which is easily identifiable by the tire tread (see Figure 8).

From what has been discovered, tire treads may reveal important circumstances regarding their interaction with the pavement. Therefore, investigators are advised to take pictures of the entire circumference of the tires. If the tires get covered with mud or other substances due to the excursion, it is advisable to take pictures before and after the tires are washed.

Reverted rubber and, to a lesser extent, dynamic hydroplaning are likely to leave a white mark on the runway due to the formation of steam that cleans the surface. Good investigation practice dictates, independently from suspicion of any type of runway contamination, to document tire marks on the runway with a handheld GPS. When doing so, investigators are encouraged to check the relative color of the marks left by the tires. Marks with a clearer shade compared to the runway could hint at the occurrence of dynamic or reverted rubber hydroplaning. Figure 9 shows these kinds of marks.

Embraer experience to this point suggests that the reverted rubber condition is related more to wheels locked by the action of the emergency parking
brake (EPB) actuation than to dynamic hydroplaning. Emergency brake systems usually are not equipped with an anti-skid function, and its usage overrides the main braking system (usually equipped with an anti-skid function) and can cause the wheels to lock. When seeing this type of evidence on the tires, investigators are encouraged to verify if the EPB was used during the landing run.

There are several factors that influence the occurrence of hydroplaning. Among them are thickness of the water film, airplane groundspeed, tire pressure, tire tread quality, tire footprint, runway friction, and runway construction. Together, these factors determine the degree of reduction of the braking force and loss of directional controllability.

During the 1960s, the U.S. National Aeronautics and Space Administration performed several studies on hydroplaning and has kept improving its studies since then. It’s been determined that a film of water as thin as one tenth of an inch is sufficient to cause dynamic hydroplaning. From these studies, NASA produced equations that determine the critical speeds above which hydroplaning may occur. These equations provide a good reference from which to comprehend hydroplaning. For a nonspinning wheel that touches down on a flooded runway, NASA determined the critical speed (VP) as

\[ V_P = 7.7 \sqrt{P} \]

where P is the tire pressure in psi. It is important to mention that once a wheel starts to hydroplane, it will not necessarily leave this condition when its speed falls below VP. This effect is known as hydroplaning hysteresis and, according to empirical data, may reach values of up to 13 knots.

**Conclusion**

This article was adapted from a paper delivered at ISASI 2013 that covered several subjects. The article’s intent was to provide Embraer’s perspective on runway excursion investigations in which it took part. The authors recognize that the topic’s complexity makes it impossible to compile all the knowledge that is desirable to be part of the repertory of the next generation of investigators in a single paper. However, we hope this material, which originated from Embraer’s commitment to continuously assist in investigations involving its products, may serve as a reference and contribute to future investigations with the purpose of making air transport safer.

**Acknowledgement**

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AIRCRAFT ACCIDENTS AND SOCIAL MEDIA

(Continued from page 23)

websites of safety investigation agencies, regulators, industry, and other aviation organizations. The concept of Media-wiki products—anyone can comment, propose modifications to an existing article, suggest a new topic, or submit a draft article—might be reasonable. A good example is the repository SKYbrary issued by Eurocontrol related to air traffic management (ATM) safety.

There is a need to improve education and training for future safety investigators. The common approach to hire experienced pilots, engineers, psychologists, and ATM controllers for safety investigator jobs is still appropriate. But in addition to these assumptions, it is necessary to set up a mandatory education in safety and accident investigation. The education should include theoretical and practical applications for the different functions like investigator, investigator-in-charge, and accredited representative. The ICAO Circular 298 AN/172 (Training Guidelines for Aircraft Accident Investigators) might be a helpful guideline.

PRESIDENT’S VIEW

(Continued from page 3)

iner, Bill will be missed and remembered for his special contribution to civil aviation in Botswana and the world as a devoted and active member of the International Society of Air Safety Investigators. Even at his mature age, Bill still flew, and it is everybody’s conviction that he has departed this life as a happy man since he still could do what he cherished most—flying.”

Now these two aviators heed the words of the unknown author who wrote “To fly west, my friend, is a flight we all must take for a final check.” Godspeed to them.
Aloft Aviation Consulting is an aviation-focused consulting group whose principals and expert associates have extensive experience as former FAA accident investigators, regulators in the U.S. and Europe, and with air traffic operations, airlines, and airports around the globe.

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