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Closing the Gap between Accident Investigation and Training

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Mike is a professional 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 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 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 and is a now a member of the executive management team at CAE Flightscape, after CAE acquired Flightscape in August 2007.

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Lou is the Chief Safety Officer (CSO) for CAE's ab-initio, helicopter, business and commercial aviation training business. He joined CAE after a distinguished 26-year career at US Airways where he served as a line pilot, instructor pilot, pilot training manager, and courseware developer. He has accumulated more than 25,000 hours of flight time, and is type rated in nine commercial and business aviation jet aircraft. He served as director of flight operations for Flight International, the world's largest Learjet operator. Lou is a graduate of Embry-Riddle Aeronautical University, and has continued to serve the University as a Trustee and member of the President's advisory board. Lou is a recognized industry author, safety advocate, inventor and speaker on the application of technology to pilot training.

Abstract:

We use full flight simulators to train pilots to fly airplanes and to carry out emergency procedures fastidiously. But do we, can we, should we also train pilots to *prevent* accidents?

Intimacy with accident investigations and/or or serious FOQA events results in intimacy with many of the often subtle factors and human factors issues that can ultimately culminate in a catastrophic outcome. While written accident reports supply a wealth of information, there shortcoming is that they are time consuming to read. More importantly, people often read the same sentence yet have a very different understanding of the sentence. There is arguably a gap between accident investigation and simulator training in that the problems we typically see in training are often not the same problems that cause accidents or that we see in daily FOQA program results. This paper will explore a few accidents to demonstrate how improved intimacy about what happened based on objective flight data may benefit flight safety. As expert observers of cockpit behavior, instructor pilots, have a unique skill of reliably predicting the outcome of even small omissions or lapses in procedures. This instructor skill comes naturally as

a function of observing crews practicing skills over and over again. This same instructor skill, as acquired through persistent analysis of crew behavior, is now extended to all crew members through flight data animation visualization and analysis tools. These technologies can communicate subtle causal factors effectively and consequently enable instructors to improve scenario based training.

In addition to using flight data to develop enhanced scenario based training, applying FOQA concepts to the full flight simulator will enable airlines to cross reference problems encountered in simulator sessions with problems encountered in daily flight operations. Using flight data from the simulator session to objectively measure and report on the training pilot's performance allows the instructor pilot to focus on the subjective human factors aspects of the flight operation.

Understanding how seemingly benign events can lead to catastrophic situations is paramount to changing attitudes and vigilance in the cockpit. Augmenting simulator training to replicate real world situations based on improved intimacy with the sequence of events beyond the investigation report and beyond the statistics of FOQA programs promises to bring accident prevention to a new level.

The following accidents are examples cases where the author of the paper was directly involved in the flight recorder analysis and consequently has first-hand knowledge of the details of the accident sequence beyond what is ascertainable from the written reports. The authors believe that this level of intimacy can be more readily gleaned through the use of flight animations and the use of flight data to develop full flight simulator training scenarios.

Saab 340 Accident Example

On January 10, 2000, a Saab 340, HB-AKK operated as Crossair 498 crashed shortly after take-off from Zurich's runway 28 during night IMC. The aircraft was destroyed and all ten persons on board were fatally injured. The Swiss Aircraft Accident Investigation Board requested the assistance of the Transportation Safety Board of Canada (TSB) with the read-out and analysis of the FDR and CVR. Approximately 50 parameters were recorded on the aircraft's solid state FDR and 30 minutes of good quality audio was recorded on the aircraft's CVR.

Figure 1: Saab 340 accident site.

The Swiss AAIB IIC originally requested a 'readout' of the recorders. Consequently the TSB prepared printouts and graphs of the flight data along with a transcript of the audio which the IIC intended to take back to Zurich to conduct the analysis. People intimate with the process of recovering flight data realize that the original data is a sea of binary '1's and '0's that need to be converted into meaningful engineering units. Many investigators believe that flight data is 'factual' but the process to convert the data is fraught with the opportunity for error. Engineering conversion formula's, documentation, wiring, acquisition unit programming, software used to convert the data, timing issues, resolution issues, replay options, etc., will all affect the quality of the outcome. In fact, if the same source binary flight data is replayed with two different replay systems, it is highly *unlikely* that the same results will be produced. The data revealed that shortly after take-off the aircraft, in night IMC, entered an increasing right turn apparently consistent with control inputs. As a flight data analyst, when you see this type of data, you immediately start to question if the data is being processed properly or is working properly (in this case if sign conventions are correct) because on the surface, the sequence does not appear to make sense. The TSB started to work on a flight animation immediately, in an effort to understand if the data was properly processed because animations are an excellent means to validate the correct behavior of numerous interdependent parameters. The level of 'validation' of any given parameter should be proportional to what you intend to conclude. If you are putting a lot of weight on a given parameter, it is natural that you would check its validity more so than if it were a less important parameter. The IIC noticed TSB was working on an animation and asked if it would be OK if they brought the investigation team to Ottawa to analyze the data interactively using the animation as opposed to trying to analyze printouts and plots. Indeed, in this particular investigation, the early animation with the audio and transcript synchronized was very useful to conduct the analysis of the data and greatly expedited a common understanding of what likely happened. The Swiss team came to TSB and spent a few very fruitful days developing and studying the animation. Animations have two very distinct purposes; one is to assist in the analysis process and one is to communicate the findings. Often the display choices are different for each of these purposes. Some authorities still view animations as having little or no analytical value and use them only for communication purposes but in the case of this accident, the animation had tremendous analytical value and it would have been much more difficult to understand the sequence of events and gain confidence in the data quality without it.

Figure 2: Flight animation developed by TSB to support the investigation team.

It is not the intent of this paper to go into the details of this accident however the key points related to the subject of this paper are as follows. The pilot flying (Commander) became disoriented, essentially believing he was in a left turn when in fact he was in a right turn. During the standard instrument departure (SID ZUE 1Y), ATC issued a change in their clearance, essentially cutting the SID short, and instructed them to make a turn direct to VOR ZUE. The First Officer confirmed by radio stating 'turning *left* to Zurich East'. The SID calls for a left turn as shown in Figure 3. The First Officer reprogrammed the LRN (Long Range Navigation System) from the present position to ZUE. At this point in the flight, the aircraft was more or less 180 degrees in the opposite direction of ZUE. When re-programming the LRN, if the operator does not explicitly select left or right, the LRN will choose the turn direction offering the shortest distance. It just so happens that the aircraft was a few degrees closer to a right turn

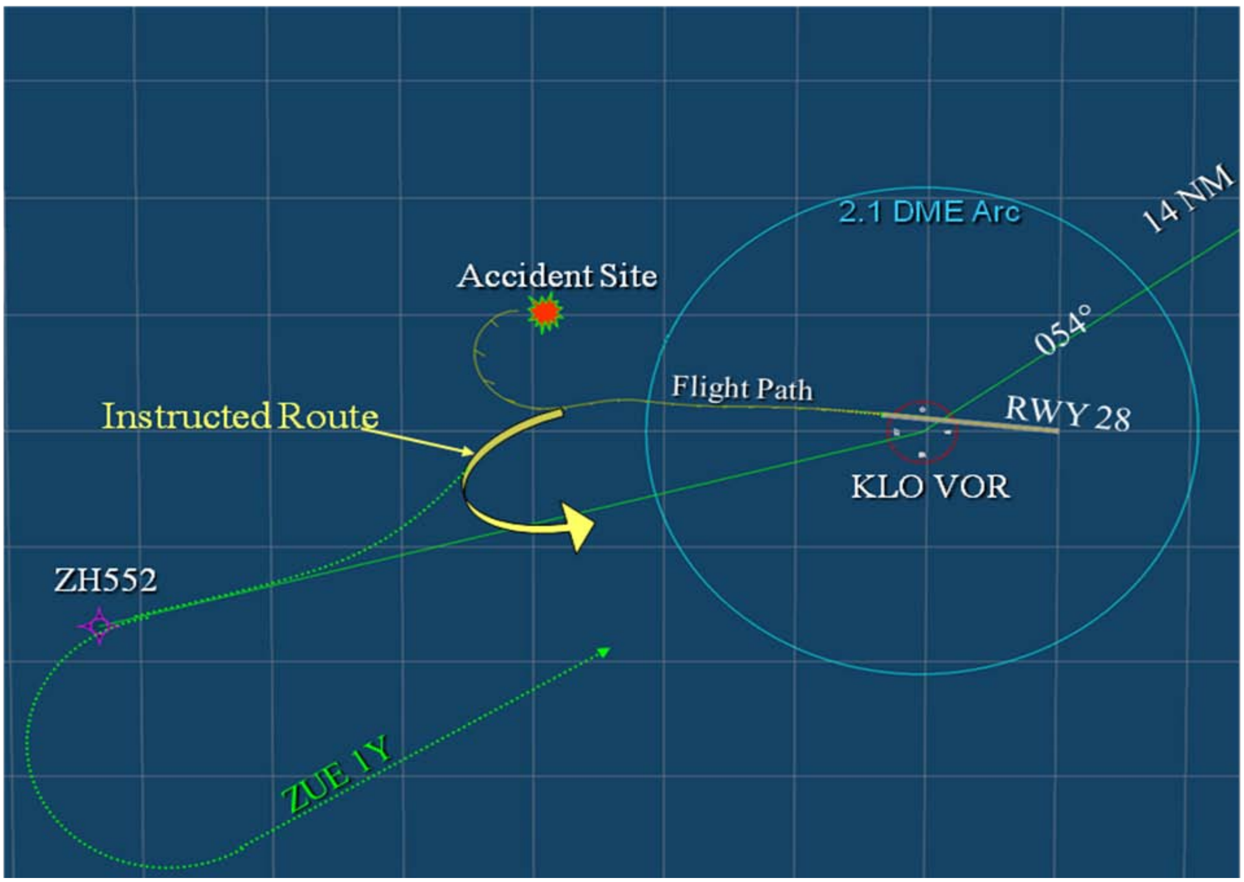

Figure 3: Planned route, instructed route and flight path to crash site.

at this point and it was apparent that the First Officer inadvertently programmed a right turn by not explicitly selecting left. With both crew members believing they were to turn left and both crew members believing the flight director was programmed for a left turn, when watching the animation with the CVR transcript integrated, it becomes relatively easy to understand how the Commander could become disoriented and roll the aircraft into a right turn into the ground. To further validate this early theory in the investigation, the TSB derived the theoretical behavior of the command bars (since this was not a recorded parameter) and displayed them in the animation which further supported the supposition that the Commander became disoriented.

The Swiss AAIB report makes several excellent safety recommendations to prevent a recurrence. While the Swiss report is very thorough and filled with excellent safety information, it is still questionable as to whether this accident or similar accidents where the crew are essentially 'tricked' into a situation by a series of seemingly harmless events will effectively be prevented in the future. To the author's knowledge, there is no simulator training whereby crews are exposed to the sequence of events identified in this accident. Even worse, there are many flight crews who have no knowledge of this accident or the specifics of what caused it. The safety community has benefited from the lessons learned from this accident but are flight crews flying similar equipment benefiting from the lessons learned. The current approach is for the safety community to learn the lessons and implement changes by way of recommendations but it would arguably be much better if the crews could learn the lessons directly by exposing them to the sequence in the simulator environment.

Airbus A310 Accident Example

Figure 4: Undercarriage from A310 accident

On January 30, 2000, an Airbus A310 registered as 5Y-BEN crashed shortly after take-off from runway 21 in Abidjan in night IMC. The aircraft's flight data recorder and cockpit voice recorder were brought to TSB Canada for readout and analysis. The aircraft's FDR recorded alternating streams of steady '1's and '0's indicating the Flight Data Acquisition Unit (FDAU) had malfunctioned and was sending erroneous data to the FDR. The CVR was of good quality and, although cryptic to determine the sequence of events, eventually enabled the investigation team to piece together what happened. Although there was no flight data available for this investigation, it is perhaps a good example of a case where the crew was essentially 'tricked' and flew the aircraft into the ground without ever understanding the problem.

The aircraft's stall warning system activated on lift-off which surprised the flight crew. As they attempted to diagnose the problem, the flying pilot instinctively pushed forward on the control column to eliminate the stall condition. However the aircraft was not in a true stalled condition and in less than one minute, the aircraft was essentially flown into the sea. It was concluded that one of the angle of attack vanes must have been damaged causing the aircraft stall system to trigger as soon as the weight on wheels logic went to 'air'. No amount of forward control input could avert the stall (stick shaker) condition. Simulator tests confirmed that the only way to reach the crash site was to fly the aircraft in an 'un-stalled' condition.

The French BEA wrote a detailed report on this accident but the question again comes up; have we done enough or what more can be done to ensure there is not a repeat of this accident. As with the previous example, the author's know of no scripted simulator training where crews are given a false stall warning on lift-off in night IMC to see how they react to this real life known situation. Given the same circumstances, it is probable that many crews would react the same way as the crew in question did so it is arguably a matter of time before this accident repeats itself.

B727-200 Accident Example

On July 7, 1999, a B727-243F registration VT-LCI crashed in Kathmandu into the Champadev hills at 7550 feet approximately five minutes after take-off in IMC. The accident was investigated by the Ministry of Tourism and Civil Aviation of the Government of Nepal. No report from the Government of Nepal could be found searching the internet however the following was found on the NTSB website:

'*The investigation determined that the probable cause of the accident was the failure of the flight crew to adhere to a Standard Instrument Departure (SID) and the failure of the controllers to warn the flight of terrain. Contributing factors were determined to be an incomplete departure briefing, unexpected airspeed decay during the initial climb, inadequate intra cockpit crew coordination and communication and the slow response to the premonition given by the air traffic controller.*'

The flight recorders were replayed at the TSB Canada. In this accident, the crew was a little late in carrying out a right turn as required by the SID and was consequently flying towards mountainous terrain. When they realized they were late, they immediately began a right turn to regain where they were supposed to be. During the right turn, they received a GPWS warning – Pull up. Instead of executing the escape maneuver in response to the GPWS which requires a wings level maximum climb, they increased their turn radius to the right. In this case, given they knew they had made a mistake and had just corrected the mistake; it is understandable that when confronted with a GPWS their instinct was to tighten the turn rather than execute an escape maneuver. How many crews would do the same thing in the same circumstances? Is this accident also a matter of time before it repeats itself? Simulator training replicating this sequence for pilots frequently flying in airports with mountainous terrain might go along towards re-enforcing the need to carry out an escape maneuver in all cases.

Closing the Gap

All three of these cases exhibit similar human factors problems in that the crew did not correctly diagnose the problem and/or did not respond in a way which would have avoided the accident. In all cases the crew was competent, well trained and representative of the industry. It can be argued however that their response was understandable which means another crew confronted with the same scenario may well respond the same way. There have been numerous similar accidents where crews did not respond the way they were trained. It is the author's opinion that this is in part because the training environment does not replicate real world scenarios such as the three examples presented. One reason that the training environment does not replicate real world scenarios like this is because the people developing the training simply do not know the intimate details of the accident sequence, having not been involved in the investigations. The same logic can apply to serious FOQA events. It really does not matter if the aircraft hits the ground or not in the end. FOQA events of high potential for safety action need to be investigated and well understood and ideally used to develop simulator training scenarios if we really want to prevent them from becoming an accident.

Flight animations have the ability to disseminate complex information in a highly intuitive and entertaining manner in a fraction of the time it takes to read a report. Like any good movie, you tend to pick out details that you did not see before, each time you watch the movie. Written reports also do not lend themselves to assessing timing issues while animations provide an immediate sense of timing which can be important to the overall understanding of the accident. Finally, flight animations are an excellent means to communicate *what* happened to a wide cross section of people. Without consensus as to *what* happened there is little point on trying to understand *why* it happened. Further, the *what* happened is exclusive in that there are only one set of facts. The *why* on the other hand is not exclusive. For every *what* there are many opinions as to *wh*y and there is not necessarily a right answer. Despite the best efforts of the investigation community, unless you investigated the accident, many people simply do not know the intimate details of the accident as it is impractical to glean this level of intimacy from a written report. Flight animations have a unique ability to quickly communicate *what* happened which greatly facilitates determining *why* it happened and more importantly, how to prevent it from happening to you.

Simulator training today largely focuses on how to fly the aircraft and how to respond to an emergency. It has not progressed to 'evidence based' training in which we use objective flight data to develop explicit scenarios from known accidents, incidents and FOQA events. If you ask a simulator instructor pilot for a list of problems training pilots experience in the simulator, you will discover that there is little or no correlation to the list of problems that are known to cause accidents. This suggests that there is a gap between the flight safety community and the training community and that there is benefit from a much closer relationship than exists today in many airlines. It is timely for the industry to look at ways to improve the ability for the training community to exploit lessons learned by using actual flight data as the objective common base between the two communities. Coincidently, IATA within its ITQI (IATA Training and Qualifications Initiative) is actively exploring flight data from FOQA programs from volunteering airlines in an effort to change the regulations regarding simulator training to allow for evidence based training. The following is an extract from the ITQI 2008 report from IATA's website:

> *Progress in the design and reliability of modern aircraft has prompted an industry review of pilot training and checking requirements. In addition to the wealth of accident and incident reports, flight data collection and analysis offers the possibility to tailor training programmes to meet real risks. The aim is to identify and train the real skills required to operate, whilst addressing any threats presented by the evidence collected. The IATA best practice document will facilitate regulatory change and enable more efficient, safety driven and cost effective training.*

Simulator Brief-Debrief

TSB Canada was one of the first (if not the first) in the world to use mini-computer technology to animate flight data in a true 3-d environment for the purpose of understanding and communicating an accident sequence. This same technology has been applied for some time to the simulator community where flight animation is used to replay 'flight data' from the simulator to debrief the flight crew after the session. CAE is actively pursuing applying FOQA concepts to the full flight simulator whereby the analysis software provides automatic reports of problem areas in the flight such as out of sequence procedures, incorrect procedures, missed or late procedures, etc. This allows the instructor pilot to focus attention on the more subtle human factors aspects of the simulator sessions. The simulator brief-debrief system currently under development at CAE to achieve the 'Close the Gap' philosophy has the following key attributes:

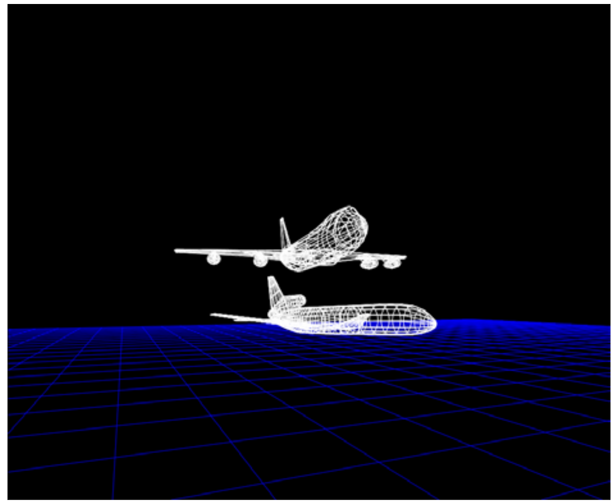

Figure 5: First animation on a mini computer done by TSB, 1985 (courtesy TSB)

- Simulator replay uses the same core animation analysis software that was developed for accident investigation and FOQA event animation which allows for the replay of accident and/or FOQA animations directly on the debrief system to enable instructors to develop evidence-based scenarios. Simulator sessions can also be replayed by the FOQA animation system fostering increased collaboration between training and safety departments within the airlines.

Figure 6: Simulator session animation replay using same core technology as accident investigation replay (Courtesy Oxford Aviation).

- Interface from the FDR/QAR replay system to drive CAE full flight simulators with recorded flight data to replay accidents or serious FOQA events in the full flight simulator.

- Simulator record session control by the instructor to mark events of interest for quick navigation as well as potential for real time notification of problems during the simulator session.

- Automatic report of problem areas during the replay.

- Ability for the crew to have an electronic copy of their session plus real aircraft replay for self study.

- Collection of data (with appropriate security and airline approvals) across simulators to study regional differences.

- Ability to begin to compare simulator session ‘flight data’ to aircraft flight data to compare and ensure that simulator training continues to evolve to reflect real world scenarios (evidence-based training).

- Video and audio synchronized with the replay of the simulator flight data.

Summary

Many people in the accident investigation business see the same core human factors issues over and over again. A combination of individually benign events led to a situation ‘outside the box’ of current simulator training. It is of course impossible to train for every scenario possible but it is technically possible to train using objective aircraft flight data from past accidents and serious FOQA events. Evidenced-based training scenarios need to be developed using objective flight data to ensure pilots appreciate the need for vigilance, communication and a strong safety ethic. Many pilots read the accident headline and conclude that this would not happen to them; that the pilots in question were not doing a good job. If these same pilots participated on the investigation, they would undoubtedly conclude that this could happen to them as well since they begin to appreciate the subtleties of the sequence. Any pilot who works for a year at a safety investigation authority comes out of that experience with a real appreciation for what really causes accidents and is a safer pilot for it. We cannot afford to send all the worlds pilots for a one year sabbatical at an investigation agency. What we can do is give these same pilots and instructor pilots’ easy access to flight data from accidents and serious FOQA events ideally in the form of interactive flight animations so that they can appreciate the intimate details of what went wrong. We can include simulator brief and debrief using actual flight data as an integral part of the training process; not an option. We can train instructors to leverage the technology to the benefit of the safety of flight. This will facilitate the creation of evidence-based training and allow the industry to better correlate problems identified through investigation and FOQA programs to problems encountered during flight simulator sessions. The main problems in the simulator are typically not related to reasons why airplanes crash. This is because we still train to regulatory requirements and to carry out emergency procedures. This is not to say we should no longer do this; the more the real aircraft data and the simulator data match in terms of problem areas, the more we will know that we are closing the gap between accident investigations and training.

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