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"FLIGHT DATA: THEN, NOW and COMING SOON"

by

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Mike 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 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 of 2013.

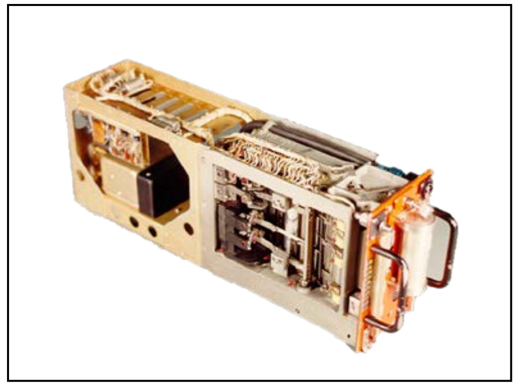
Abstract:

This paper will focus on past, present and future trends in flight data analysis and flight animation that are particularly relevant for the next generation of accident investigators.

Introduction:

Everything 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 email 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' that 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 have and are become 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 (pictured). Fortunately, I only had to deal with one of these in my career. 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 the 1998 Swiss Air 111 accident were both tape based recorders, recovered from the ocean. The tape was extracted from the recorder and immersed in water, and then cleaned in an assembly line like process (pictured) in order to playback on an open reel tape deck. Tape based recorders ruled throughout the late 60,s, 70's, 80's and 90's. Owing to the cumbersome nature of getting the data of 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 more than thousands of parameters. This trend will no doubt continue with the data rich architecture of aircraft today and increasingly data architectures of tomorrow. Data is increasingly used for accident prevention programs (FOQA) and both the US 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 is 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 in the palm of your hand (pictured) 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 used of telemetry to communicate events diagnosed onboard 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 right part ready and waiting at the gate to

minimize aircraft downtime. From time to time, people wonder why all data is not telemetered to the ground so there is no need for an FDR on board the aircraft. However, telemetry will not be *replacing* on-board recorders in the foreseeable future for many reasons which is beyond the scope of this paper.

Datamap Issues:

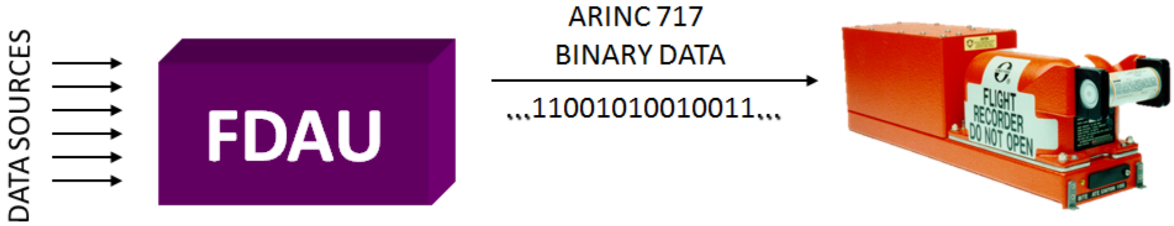
As an investigation group, it is worthwhile for us to appreciate the issues surrounding datamap evolution as it relates to flight data. What is a datamap? Flight data regardless of what recorder type, is a stream of binary 1's and 0's. It is not feet, not degrees, not knots. A software process converts 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 the example shown, the parameter in question is stored in a 12 bit word. 12 bits of 0's equals 0 and 12 bits of 1's equals 4095. Any combination of 1's and 0's in between will yield values from 0 to 4095. To convert to say airspeed for example, you might simply divide the decimal value by 4. These formulas can be simple (divide by 4) or they can be very complex, depending on the characteristics of the avionics on board. All of this information to process the binary data into meaningful engineering units is what is known as a DATAMAP.

Binary Value	Decimal Value	Engineering Units
000000000000	0	0 knots
000000000001	1	.25 knots
000000000010	2	.5 knots
000000000011	3	.75 knots
000000000100	4	1 knots
111111111111	4095	1023.75 knots

CONVERSION FORMULA

The DATAMAP is a function of the acquisition system on the aircraft typically the FLIGHT DATA ACQUISITION UNIT or FDAU, whose job is to collect data from the various sources and package it into this single stream of data that goes to the FDR and/or QAR in a standard format known as ARINC 717 (ARINC 767 is a new generation of the standard used on the Boeing 787). The FDAU parameter programming therefore is what defines the DATAMAP. People often mistakenly wonder how many 'parameters' the FDR is. The answer is that it is



however many were programmed by the FDAU. The FDR does not dictate how many parameters are recorded – the FDAU does.

You can think of datamaps as the 'secret decoder ring' needed to program your replay station to get the correct information out in meaningful engineering units. If you do not have the right datamap, you will not get the right data. Although technically there should be one datamap for any given FDAU, unfortunately this is not the case. There are literally dozens of datamaps done by different people, at different times with different expertise levels, possibly with different documentation, and with different ground stations. Airlines are a lucky as they have a fixed fleet and can define these datamaps well in advance for their replay system but safety boards have to scramble in the wake of an accident not knowing what will show up tomorrow.

The first job of an investigator; then, now and for the near future is to obtain/build/import and validate the data map. This is easier said than done and there are many competing pressures. In the earliest days when I was in the Board, we used to publish the data datamap as an appendix to the engineering report. Of note, 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 was handled only by a small number of governments around the world; about 5 in the 1980's. Most airlines only handled the data for annual maintenance readout purposes.

It is worthwhile spending some time one datamaps due to their importance and in the context of then, now and coming soon and the next generation of accident investigators. Back in 1988, when the first Airbus A320 crashed, a significant controversy arose in part due to problems with the datamap. A few prominent parameters were not properly configured in the replay system (latitude and longitude if memory serves me correctly) and this resulted in the credibility of the readout being put in question by groups with stature and credibility. The aircraft hit trees during an unscheduled flyby at an airshow and the flight data was 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 readout the data and make it 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 length to discredit the readout and the media pursued conspiracy theories that hampered the official investigation to the point where 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 replaced the accident flight recorders with flight recorders with data showing false information.

People with credibility examining the flight data provided by the authorities did not understand the datamap process and thought that flight data was supposed to be factual. Well it is not factual, period but rather the result of a process with the opportunity for error.

Many airlines today using flight data for FOQA now and more and more governments have flight data analysis tools. This has increased the commercial market place for replay tools which 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 in fact 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 80's and 90's participated heavily). When we started to see hints of 'proprietary' concerns at Eurocae meetings in the early 1990's, we developed guidance material that essentially states that all of the documentation to readout 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 manufactures 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 where we took many steps forwards and then one step backwards with the notion that how the data is structured against the ARINC 717 standard should be a secret.

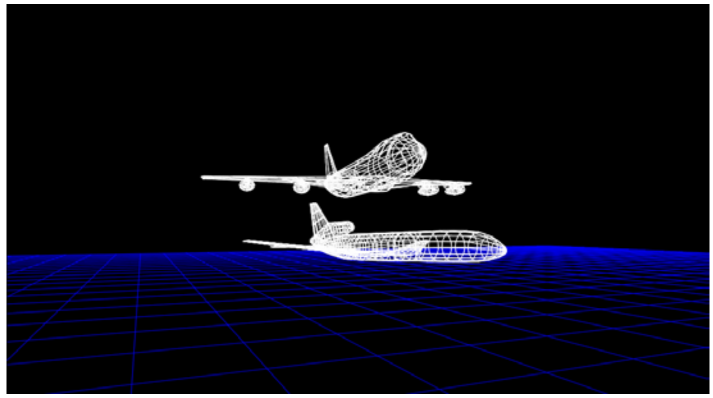
ARINC (a standards organization) has developed FRED – Flight Recorder Electronic Documentation Standard also known as A647A. A647A started out in the TSB Canada as the FRCS or Flight Recorder Configuration Standard as a result of Boeing sending me a 'book' for the documentation of one of its aircraft datamaps in the late 1980's. 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. So 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 they should be proprietary; so you can't get them so easily.

With the advent of solid state recorder, Eurocae decided that since the FDAU defines the datamap, why not have the FDAU write the datamap to the FDR during each cold start? Indeed the new B787 is the first aircraft in the world where the FDAU writes the datamap to the FDR on power up. This means we are moving towards *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 B787, although there are still issues with FRED that are such that if falls 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 you will have the datamap. But for all the B787's out there, there are tons of other aircraft where it will continue to plague until we can get some clear FAA, EASA, etc. regulations.

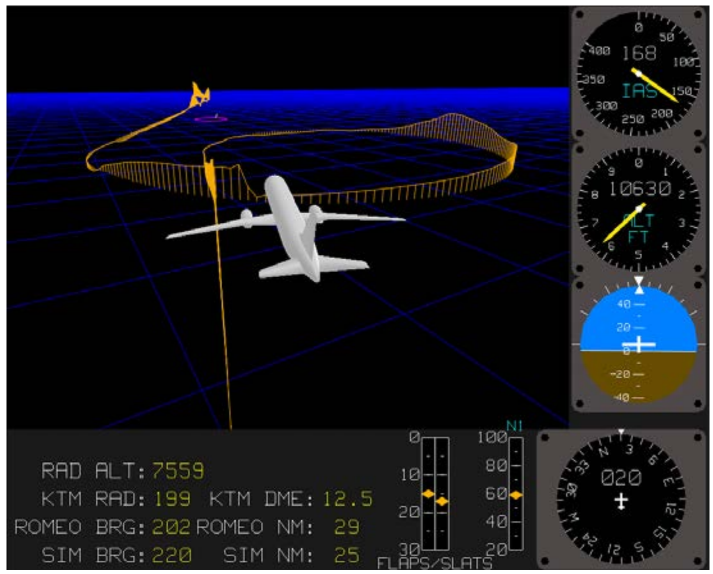
In summary, datamaps are key to the FDR analysis process. In my opinion, the *documentation* should not be secret or proprietary. It is understandable that if someone has to interpret the documentation and spend weeks building a datamap, it has value. However if the documentation is in FRED and is plug 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 pre-configured 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 inacceptable for the investigation authority to take days or weeks to produce the flight data. Heaven forbid in the meantime there is a repeat accident that could have been prevented. 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 as 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 fight data, the datamap should never be the problem area. Make flight data proprietary not the datamaps!

When we get to the point where 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 in the after math of an accident with the potential for errors similar to the A320 accident of almost 30 years ago.

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 1980's. The wireframe animation pictured 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 seen here was done on an HP minicomputer that we paid $80,000 for in 1985. To develop an animation was a very manual process which meant that you really had to know what you are doing.

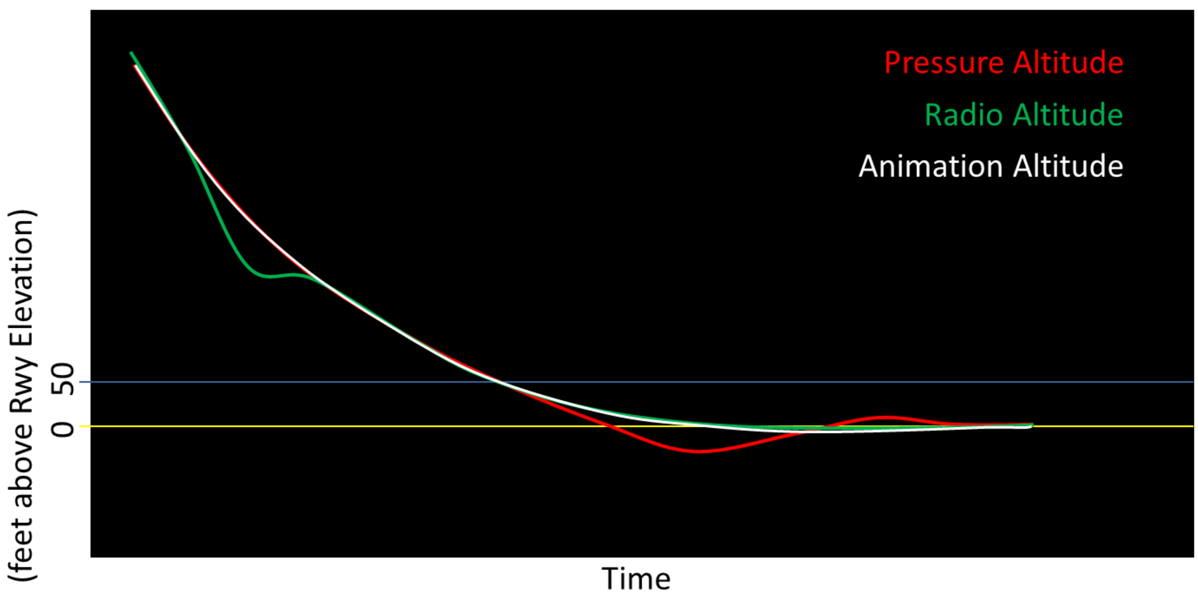


The bottom picture is from an A310 that hit a mountain in Kathmandu. The animation we did at the time (around 1990) had a very simple terrain profile by subtracting pressure altitude from radio altitude – which is the orange line you see under the flight path. The instrumentation was very simple compared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

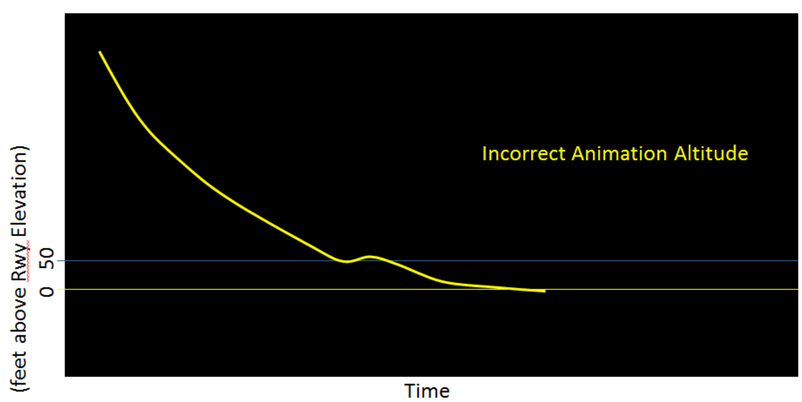
Animation today is photorealistic and getting moreso all the time; approaching Hollywood realism quality and with very inexpensive readily accessible software compared to not long ago. Google earth and Xplane for example, provide access to very well developed terrain and weather modeling. Despite all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

The following is just one example of many that 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 ever careful because ‘seeing is believing’. In this example, 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 data is shown in green. 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, not an actual drop in flying height because we see no drop in the pressure altitude. . What most animation system do is, in the interests of getting a 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 yellow line in the figure.



As with all methods they work for many cases but not 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, data map and math. The good news, the trend is to record high resolution position data and much higher sample rates with aircraft like the new B787 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.

As investigators it is also worthwhile exploring the current 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 is not shown to the pilot in the cockpit.   When investigating an event, a replica of the cockpit may therefore not always 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. 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 than 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, 3d 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 and 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.

Pictured below is an example of what I mean. I did this very quickly (less than an hour) just 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 put two rings around the aircraft. Trend arrows can be used to show altitude and turn rates. Wind speed and direction is 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 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 like 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 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 moreso than ever given the proliferation of automated systems, to understand the underlying principles of the process.

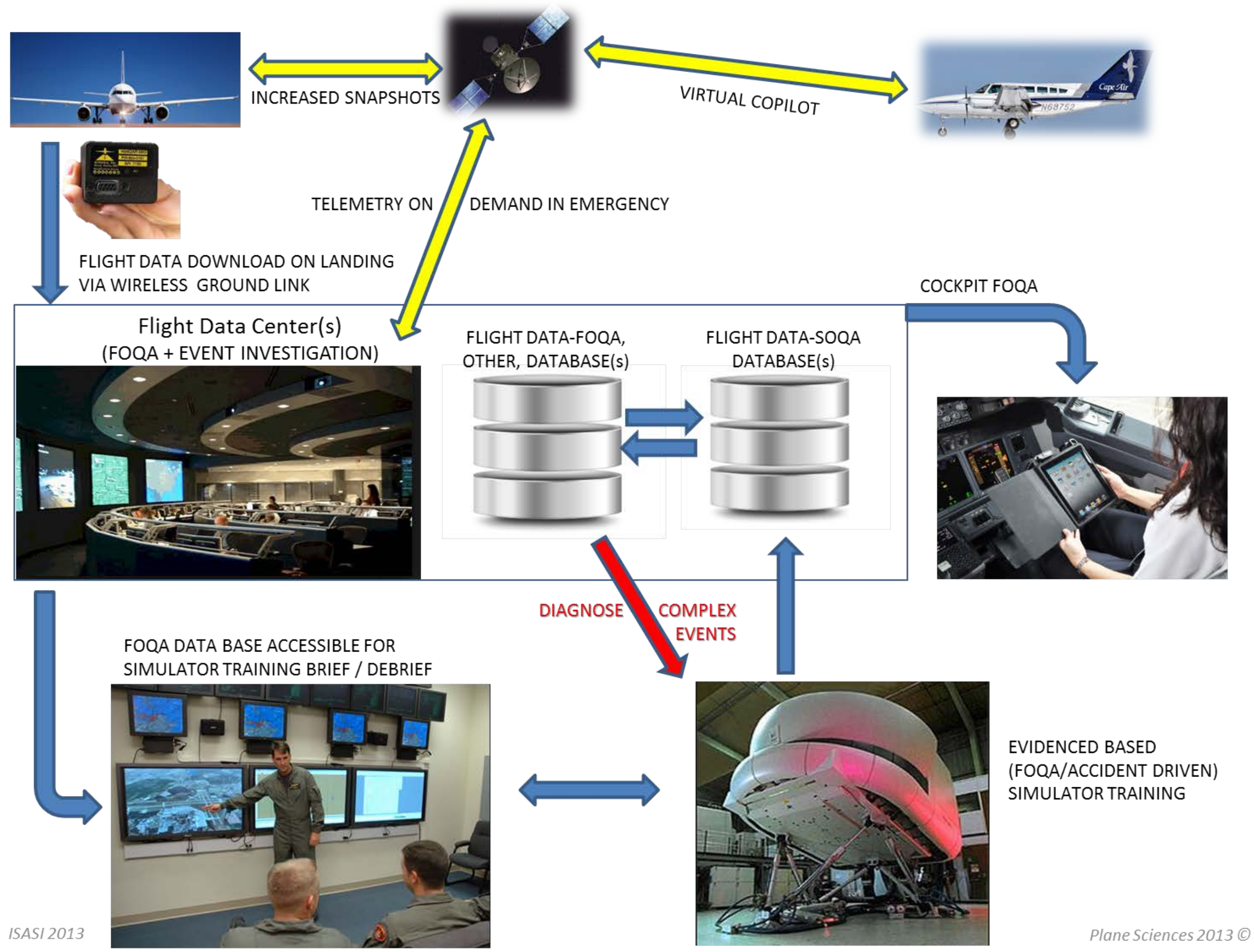
Coming Soon:

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 B787 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 B787 there is 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 their primary mission is to advance safety. In Canada at least, the word 'Safety' was chosen in the naming of 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 US ASIAS data sharing programs.

The diagram below is my vision of the future when it comes to the flow and use of flight data. Much of this is materializing in various small ways already.



Following the data flow from the top left and going counterclockwise:

Flight data is downloaded from the aircraft wirelessly on the ground after the flight. It goes to a 'Flight Data Center(s)' and Flight Data Centers areideally linked. The events are put into a 'FOQA' database as is the case now at each airline (not linked). Simulator training facilities should (as well as other stakeholders for specific purposes) have access to the flight data centers to faciliate evidence based training in both the simualtor itself or in the brief/debrief enviornment. 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 where 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 affect change.

In the air, diagnostic driven reports will come to the data centers (as the do now and have for many years) via sitcom. What may come soon is that in extreme cases, the flight data could be transmitted in real time to the ground both forwards and backwards 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 a on board 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 we have more data than we know what to do with in the aftermath of an accident.