

Flight Simulators and Air Accident Investigation

Flight simulators are predominantly used for training and checking pilots, but how useful are they to an air accident investigator? There's not a simple yes or no answer to this question, however, the AAIB is a firm believer that when used pragmatically and within sensible bounds they are a powerful and versatile tool.

In this article, the aim is to briefly describe the major components of a modern flight simulator, pointing out some inherent limitations and advantages of the technology that is used, but also to cover a lesser discussed but nevertheless very important topic – how is the data that makes up the simulation derived and validated.

Having a firm grasp of both of these concepts is key to understanding when and how to use simulators in our investigations but, of greater importance, it allows a view to be taken on how much trust to place in the simulation and what it is telling you about the accident or incident. This is because, as investigators, it is crucial that only reliable evidence is used, not only when looking into what happened and why, but also in considering how the event could be prevented from happening again.

The term flight simulators covers a wide range of devices from the most basic, termed a flight navigation procedures trainer, which could be nothing more than a radio stack and a handful of instruments used to teach elementary navigational skills, up to a type specific simulator equipped with motion, visual and sound systems. This latter category of simulator, the full flight simulator, is the main focus of this article and is typical of what is found at most airline training centres around the world.



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Figure 1

A modern full flight simulator

Such a simulator is made up of several main components; an enclosure housing a dimensionally accurate and faithful replication of the cockpit, as well as space for the instructor, observers and the instructor's operating console, which all sits atop a motion system. This motion system, typically six legged, used to use hydraulically powered jacks, but with the ensuing maze of pipework and large, noisy pump rooms, hydraulics have generally lost favour to more space effective and almost entirely maintenance-free electric jacks. Similar hydraulics or electrical means are also used in the simulator to give feel to the aircraft controls, replicating how they would feel in flight. The other main components are a wrap-around visual screen, the means to project a full-colour image onto this screen, and a multi-speaker sound system, all of which are integral to the enclosure. Away from the simulator bay, there will be a room housing a series of computers for running the simulation model, as well as for the visual system, motion system and other support functions such as a software development facility.

The job of the motion system is to fool the human body into believing it is turning or accelerating just as if it were flying. Not only that, it also has to add to the basic motion of the simulated aircraft, the effects of turbulence or, perhaps, that resulting from an engine malfunction or of skidding on ice.

This may seem easy to achieve, until you consider that each jack typically has 60 inches of travel and, as all the jacks are attached to the same frame which supports the enclosure, they all need to work in unison. It then becomes hard to see how the surge of acceleration felt by a pilot on releasing the brakes at the start of a takeoff roll, which in reality takes place over several hundred metres of runway, can be recreated on the ground with less than 60 inches of jack travel. This is especially true when you take into account the need to gracefully stop the jacks before they hit their end-stops.

As such, although it is true that the initial surge is recreated in the simulator by a rapid acceleration over the short travel of the jacks, to give the impression of continual acceleration, the enclosure of the simulator is then tilted skywards. This tilt, whilst portraying a visual image that is not pitching up, fools the brain because the effect of gravity bends the hairs that we all have in our inner ears backwards. Normally these hairs give us an indication of whether we are tilting our heads but because they also move under a longitudinal acceleration and as the visual image we are being presented with is not tilting, our brain is confused. This sensation is then misinterpreted and it feels like we are rapidly accelerating down the runway.

This illusion that the simulator uses to such good effect is called a somatogravic illusion. Such illusions, likely have contributed to a number of fatal accidents, such as the Afriqiyah Airways crash to an Airbus A330 at Tripoli in May 2010. In these cases, often after executing a missed approach or go-around in inclement weather or at night, the aircraft's rapid acceleration with power causes the pilot, who is devoid of an outside view, to misinterpret the acceleration as a pitch up. In effect, this is the same illusion the simulator is using to function but in the reverse sense. Often and, incorrectly, this illusion is then opposed by the crew with a pitch down movement of the flying controls resulting in a dive, usually, from too low a height to allow for recovery of the aircraft's flightpath.

Although it is possible to convincingly demonstrate such scenarios in a simulator, as NASA showed at Ames Research Center with a heavily modified Boeing 747 full-flight simulator, we also use other receptors within our bodies to orientate ourselves. Any attempt to therefore replicate the feeling of somatogravic illusion, without also correctly stimulating these receptors is perhaps not representative. It is therefore very important for investigators to be aware of how the simulator technology is being employed, as this may impose restrictions on the use of the simulator for certain types of investigations.



Figure 2

Instructor Operating Station

A simulator's motion platform is always also trying to creep back to a central position, at a rate just under that which our bodies can perceive the movement of the jacks – another example of a simulator taking advantage of the limitations in our senses. This gives the motion system the greatest range of travel available for the next motion cue which is clearly beneficial if you're trying to deliver the feeling of heavy turbulence. However, the side-effect of this need to continually centralise and, of the limited travel range of the jacks, is that conventional motion platforms are just not set-up to deliver any sustained g forces.

Take, for example, the recovery of an aircraft from a high altitude stall such as the event that the AAIB investigated to a Cessna Citation Jet in December 2013. During a series of recovery manoeuvres, this aircraft experienced sustained g forces well above those expected in normal service. One of the effects of such g forces is to make any motor action, such as moving your arms, physically much harder to achieve and in any upset

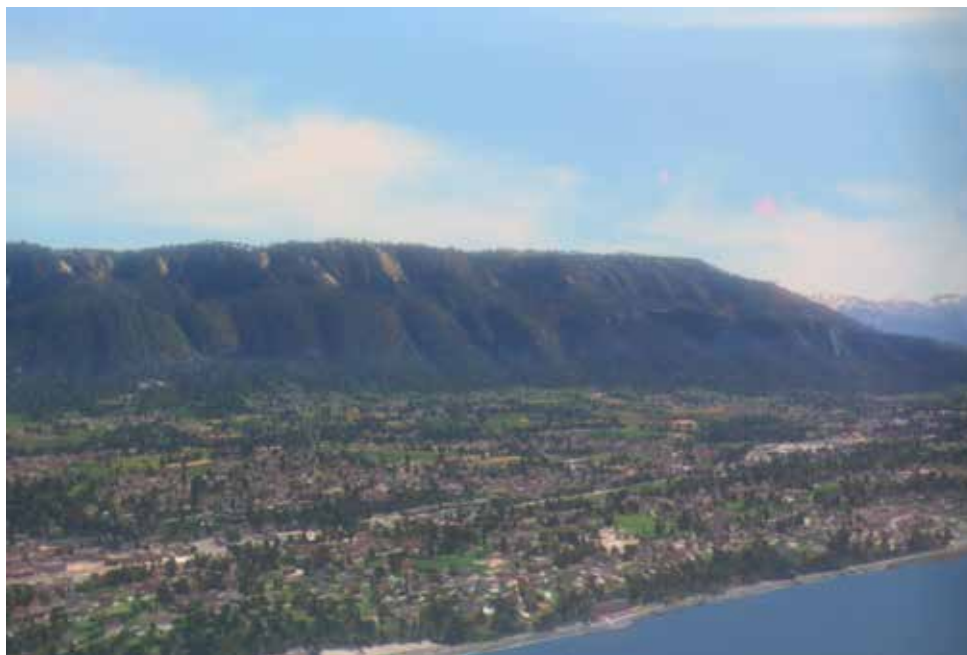
recovery training performed in simulators, these physical limitations cannot be faithfully reproduced. In fact, most simulators which have been programmed to allow for the training of upset recovery, purposefully disable the motion system not only to avoid injury, but also to avoid any training in a situation which doesn't reflect the reality of the event. Again, with this in mind it is easy to see how the limits of simulation technology have a direct bearing on how and when simulators are used for accident investigation work.

The latest visual systems on a simulator are highly capable and are able to create very persuasive models of the real world. This could be an airport environment, at night, with all the correct runway, taxiway and cultural lighting or an off-shore helideck, complete with articulating cranes, forming part of an extensive oil installation.

In the case of helicopter simulators this image can be very expansive, covering a field of view of up to 240 degrees horizontally and 80 degrees vertically - to provide all of the necessary visual cues for taking off and landing vertically. A field of 180 degrees by 40 degrees is more typical for fixed wing simulators. The vastly increased computing power of modern image generators, the processing units and heart of a visual system, allows these scenes to be rendered with photo-realistic textures, shadows correct for the time of day and season, and real-world physics-based models for effects. These effects could include the halos seen around airfield lighting in foggy conditions, the white-out experienced by helicopter pilots landing in snow or that of sand blowing across a runway in a desert environment. It is also worth highlighting that all of these scenes would be rendered with great accuracy to the height of the underlying terrain; this data often being accurate to a few metres.

It is this ability of the visual system to fully immerse and absorb a crew into their environment that is of immense benefit to an accident investigator. As an example, consider a runway incursion by an airliner at a major airport that occurred in foggy conditions at night and how, as an investigator, you could use a simulator to try and understand why this happened. In this instance, the precise taxi route taken, the sequence of lights and marker boards that were seen during the taxi, as well as the modelling of what would have been visible given the exterior visibility and cockpit window frames is a task well suited to use of a simulator.

The visual system is also responsible for portraying a whole manner of linked effects, such as thunderstorm cells. In these cases, the weather displayed outside of the cockpit needs to correspond both with the internal depiction of such storm cells on weather radar displays and also how turbulent a ride the motion system is required to deliver. Other systems are similarly linked, such as the Traffic Collision and Avoidance System and Enhanced Ground Proximity Warning System. It is this level of sophistication that allows complex scenarios to be re-enacted with ease in a simulator, again showing the value of using simulators, both for initial event investigation and the analysis of "what-if" scenarios.



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Figure 3

The scene, as rendered by a high-end image generator, on approach to Runway 18L at Chambéry, France

An investigator also needs to be mindful of how the data that forms the simulator is derived and over what flight conditions the data is valid. To answer the first part of this; when a new aircraft type is first certificated, it follows hundreds of hours of flight testing and it is this flight test data that, predominantly, the simulator is based upon. To expand upon this, all qualified simulators have a document called the Qualification Test Guide,

that contains tests on every facet of an aircraft's handling and performance – be it engine-out climb rate against distance and time, or the aircraft's response to a sharp input on the rudder. It is these tests that show how the simulator is performing in relation to the flight test data and the tolerances on each parameter of a test are incredibly tight. Therefore, by virtue of the need to qualify a simulator to its Qualification Test Guide, both when it is put into service and continually throughout its life, the simulator models are created to model the supporting flight test data. In fact, most aircraft manufacturers offer a verified simulator data package to simulator manufacturers once their flight testing is complete. In some cases, a preliminary data package is also provided prior to the completion of flight testing to allow for simulator availability to support an aircraft's entry into service.



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Figure 4

A set of Qualification Test Guides supporting the simulators at a typical training centre

However, this is also a simplistic answer, as take a relatively modern aircraft such as a Boeing 777, which was initially offered with engines from all three major manufacturers and, latterly with variants of these engines having different thrust ratings. The original flight test campaign would have data for some manoeuvres flown with one particular engine type and other areas covered by flight test data with a different engine type or thrust rating. If it were necessary to complete a whole flight test for each individual engine variant it would be a rather lengthy and costly exercise. Not only will these engines operate and perform differently at the engine level (albeit their thrust output may in some cases be similar) they are also likely to be different aerodynamically and thus this would have an effect on the aircraft's performance and handling. Product improvement throughout the lifetime of an aircraft type also means, that when the original flight test campaign is over, the heavily-instrumented original test aircraft may no longer be available or even cost effective to use for minor airframe or system updates.

This leads to the manufacturer supplementing or replacing elements of a simulator's data package, to reflect a particular engine variant or build standard of the aircraft, with what is called 'engineering data'. This data is derived from the manufacturer's theoretical model of the expected behaviour of the aircraft system or engine.

Further, in some cases, where the performance or handling of the aircraft is not particularly sensitive to the engine variant, the aircraft manufacturer and regulators prefer that flight test data is used and may insist that such data is used but from a different engine variant. Likewise, where the aircraft's performance is highly sensitive

to the engine variant, this requirement will outweigh any preference for flight test data and engineering data will be used instead. This complicated choice of data, with which to underpin the Qualification Test Guide, has therefore led aircraft manufacturers to producing matrices of the available data for aircraft types and these are called Validation Data Roadmaps.

The answer to the question of over which flight conditions is the data valid is, in contrast, simpler to answer. In short, the limits of data validity generally correspond to the operating envelope of the aircraft and, in some cases, to just beyond. This is because this envelope has been well-defined by flight testing. Yes, there will be some data points from the flight test to cover, for example the stall regime, but beyond a certain combination of angle of attack or sideslip little or no data is released to simulator manufacturers. Thus, use of a typical simulator to re-create a prolonged high angle of attack stall scenario, such as that experienced by Air France 447, the A330 lost in the Atlantic Ocean in June 2009, is unrepresentative.

Another area in which knowledge of how a simulator has been constructed is useful, is when discussing malfunctions. These are a set of proscribed scenarios designed to train for various system component failures, such as a pump in a hydraulic system or an engine catching fire or suffering severe damage. In certain cases, such as a flight control failure, these failure modes will be well understood and modelled because these conditions would have been flight tested or studied in-depth in the wind tunnel. In others, such as the hydraulic pump failure, the logic of the system in which the failure has occurred will be well documented and thus the software model is likely to be highly representative. However, for some malfunctions, such data may not be readily available and therefore an empirical view would have to be taken on the effect of the malfunction. In these cases, it is prudent to rely less on what the simulator is illustrating especially if it were key to the incident or accident scenario being investigated. A simple example of such a modelling dilemma which is often seen concerns engine relight envelopes. Some operators and simulator manufacturers will model an engine that can only be relit within the engine manufacturer's prescribed relight envelope. Others introduce a 'soft edge' to the relight envelope, allowing for a possible restart outside of the prescribed envelope, but which may be more representative of real life engine to engine variation. Another point to consider is that a typical aircraft's avionics bay is crammed full of electronic boxes but, quite often on the simulator, the replication of these boxes will instead be by lines of software code. Indeed, this software may even be retargeted, as it is known in the industry, to a different processing platform than for which it was originally designed and as such, errors or unexpected side-effects of using different processing hardware can creep in. Often, this type of inaccuracy can be hard to trace, but the simulator manufacturers work tirelessly to ensure the accuracy of their simulators.

It is clear that simulators can enable accident investigators to understand not only what may have happened, but how. Equally, by explaining some of the potential limitations of the technology that is used, the pitfalls of becoming over reliant if the investigator does not take the time to understand how the simulation is working, both from a hardware and a software stance, are evident. Overall, it is important to say that the pace of

technological change within the simulator industry has always been historically rapid and, some of the limitations that are present in today's simulators will be overcome in the near future. As such, the AAIB continues to see simulators as a key investigative tool.

