The Art of Flight Simulation

by Jonathan Gabbai on February 24, 2001

Abstract

Simulation is an established technique used in the man-machine systems area for training, evaluation of performance and research. The principal task of flight simulation is the creation of a dynamic representation of an aircraft's behaviour while allowing one or more human operators to interact with the simulation.

Personal experience within the simulation industry gave a small insight into what is a largely closed and highly specialised industry where several technical disciplines are combined to form a highly accurate representation of flight.

Such disciplines include computer graphics, hardware and software engineering, man-machine systems and mathematical systems modelling. One can thus conclude that the true art of simulation is the successful integration of very specific areas to form an accurate representation of an aircraft, and it is hoped that the broad technical spectrum that simulation encapsulates is reflected in this text.

1. The Simulation Industry

In order to introduce the reader to the concepts of simulation, it is apt to start with a description of the aviation industry and the inseparable connection it now holds with the simulation industry.

1.1 The history of simulation

On the 17th of December 1903, Orville Wright took-off from Kitty Hawk North Carolina in the Wright Flyer biplane making the first sustained, controlled and powered flight in history. Although this first flight lasted a mere twelve seconds, it heralded the beginning of a new age in travel transforming the way people looked at and travelled around the planet.

Twenty-five years later, a man called Ed Link began to take flying lessons. The lessons proved to be very expensive and Link believed that the attitude of his instructor hampered his ability to assimilate the flight instruction. Within a year, Ed Link had designed the first rudimentary closed-looped flight simulator and taught his brother to fly in it.

Although he tried to interest a number of companies in the device, none were interested and, somewhat dispirited, he took it around America and sold rides to the public for 25 cents.

Over time, with the developing US air transport industry, notably the military operated postal service, getting involved in increasing numbers of accidents due to bad weather, the US Army began to take an interest in Ed Link's trainer.

The military enthusiasm proved to be the catalyst for the now famous Blue Box Link Trainer and subsequently the adoption of the trainer by the military and later commercial operators, led to the creation of the multi-billion dollar simulator industry.

1.2 The simulator industry today

Simulation is an established technique used in the man-machine systems area for training, evaluation of performance and research. It is also gaining considerable importance in the entertainment industry. Focusing on the civil aviation side, the industry, unsurprisingly, mirrors the aviation industry in several key respects.

Like the aviation industry, there is huge contrast of technologies, with simulation companies dealing with latest hi-tech innovations to the servicing of old yet functional systems. Increasingly though, there is a trend to increase the functionality of old systems by upgrading them with newer technologies through the use of innovative hardware and software interfacing. The simulation industry also mirrors the aviation industry on a financial and corporate scale. As expected, orders for top range commercial flight simulators world-wide are proportional to the recent surge in airline sales; at least 45 full flight civil aviation simulators have been sold in 1998.

Although this may not sound like a huge number, the fact that one top specification, full motion simulator costs around 20 million pounds, the significance of this figure can be more appreciated.

The fact that purchasing of new simulators reflects the increase of fleet sizes and aircraft types being manufactured is no surprise. There is however a less obvious but more long-term aspect to the simulator industry that once again reflects and in some aspects impacts the aviation industry.

Firstly, one must consider ageing aircraft fleets still in service, many flying far beyond their intended life span. Simulators for these older generation aircraft are in service, but in most cases are as old as the real aircraft themselves. Since the purpose of simulation is to mirror the aircraft in every respect, when upgrades and new flight directives are issued by governing bodies for aircraft, if it affects the flight system or cockpit in any way it must be mirrored in simulation. If the modification or the update is not met, then the simulator will not receive a training certificate until all the requirements are met.

A second more dynamic way the simulator industry impacts the aviation world is through simulation of pre-production aircraft. This case was highlighted by the Boeing 777 project, where pilots were already training to fly the aircraft before it was actually built. Through this method of testing, pilot ergonomics can be met at an early stage, as well as testing new control panel systems and control methods.

Furthermore, once a test version of a new aircraft is available through a flight test, new aircraft performance data is fed into the simulator, allowing the pilots to "fly" the new aircraft. If there are any control problems, the changes are applied to the second-generation aircraft, emphasising the fact simulation has implications beyond that of being merely a training device.

Outside the civil aviation training industry, many more types of simulations exist. The military aviation industry, although not regulated in any form, is beginning to follow the very stringent certification standards adhered to by the civil aviation industry.

1.3 Simulator types

The definition of a simulator or simulation can vary in meaning between different fields and applications, but can generally be defined as follows.

> Simulation is a means of replicating an environment and specific conditionsused for the testing of wares or the training of people under controlled and monitored conditions

As can be seen, there is no definition of the capability and requirement of a simulator, except that it must replicate the environment and can be altered and monitored.

This is reflected by the various methods and techniques used to train pilots and test hard and software. Such systems even include early analogue pilot training simulators that can have parameters altered by varying valve settings using a screwdriver.

Below is a more general list of the basic types of simulators used in the civil aviation training industry, from software on an IBM PC compatible to the top end full flight simulators.

It is worth noting that certification bodies have standards that dictate the degree of realism and functionality for types of simulators, even those in the same category.

1.3.1 IBM PC Based Simulators

As well as having a popular use for simulation games, the PC is beginning to be used more commonly as a cheap yet powerful means of instrument training. Tutorials with instructions and interactive sessions are used to good effect for introductory training.

Typically, familiarity with aircraft mechanics, performance, instrumentation and maintenance are carried out with pilots, mechanics, flight crews and air-traffic controllers. For an example of such set-ups, see figure 1.3.1.1.

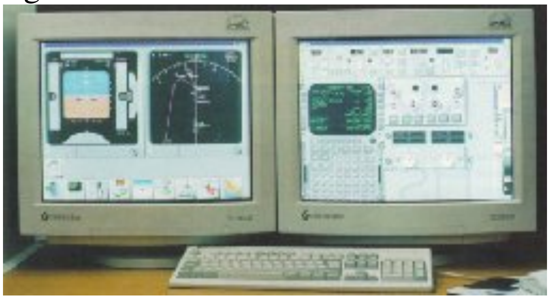

Figure 1.3.1.1 – PC Based Trainer

1.3.2 Instrument Only Simulators

Although basic in appearance, instrument only simulators are highly effective in the use of small aircraft pilot training, where familiarity can be gained in low visibility flight and navigation. Typical scenarios such as Dutch Roll recognition and correction are used for training, aiding pilots to recognise problems with only instrument cues. See figure 1.3.2.1 for an example.

Figure 1.3.2.1 – Generic instrument trainer

1.3.3 Fixed Simulators

Simulators that have graphical capabilities, but no motion are called fixed simulators. They are similar to instrument only simulators, but will typically have more functionality and control capabilities. Fixed simulators are widely used due totheir size and cost advantage over the full flight simulators. An example of this type of simulator is shown on figure 1.3.3.1.

Figure 1.3.3.1 – Fixed platform trainer

1.3.4 Full Flight Simulators

Simulators that are have motion platforms that move to provide physical sensations of flight are usually aircraft specific and are highly functional, from the real pilot seats to the numerous circuit breakers. The full flight simulator (FFS) will be the focus of this report, with more information breaking down the subsystems that make up an FFS detailed in the following section. An example of the exterior of an FFS is provided in figure 1.3.4.1.

Figure 1.3.4.1 – A typical full flight simulator. Note the large cables and tubes on the left. They provide air-conditioning to the cockpit and link wires to the computers driving the simulator (outside picture)

2. Mechanics of a Simulator

In order to gain an understanding of the complexities involved in constructing, maintaining and upgrading a simulator, this section is intended to give the reader a basic understanding of the workings of a generic simulator and the key issues involved.

2.1 A definition of the generic simulator

As mentioned in section 1.3, there are many different types of simulators, varying in complexity and function. However, even the simplest simulator, such as a desktop software package, is remarkably similar to a multi million dollar full fight simulator; it receives a pilot stimulus, processes it and then outputs the required information accordingly. This being the case, one can see that a full flight simulator is merely a more immersive and spatially accurate representation of a conceptually simple input and output process.

With that in mind, a description of a generic full flight simulator can be presented (see section 2.2), although it is an equally valid description of a fixed simulation without the motion platform, or even an instrument only simulation, which lacks the motion and visual cues described below.

2.2 How a simulator works

The principal task of flight simulation is to model the dynamic behaviour of the flight vehicle – no matter whether an existing type or of a generic model. To achieve this goal, a simulator consists of different components. The first part is a model of the system simulated. With regard to flight simulation, this is the mathematical description of an aircraft and its environment modelled as precisely as is necessary. The second element is the device through which the model is implemented. Today, this mainly is via a digital computer, running an operating system suitable for real-time operations used for deriving states from the aircraft model and its environment.

With regards to the pilot interface for a full flight, high specification simulator to be of benefit, it is required to immerse and thus convince the user that it is in fact the real thing. This in not only to facilitate an effective training experience through a realistic environment, but more importantly to subconsciously trick the brain into reflexive actions given appropriate subtle stimulation.

In order for this trick to be effective, all the sensory inputs must be correctly timed and accurate, otherwise even the smallest of errors could break the illusion, causing confusion and thus preventing the required reflex pilot action. Consequently, sensory input cues must be catered for, specifically audio, motion and visual stimulus.

Furthermore, to complete the illusion, the pilot must be capable of affecting the simulation through his input, such as the control column and throttle. In addition to the normal controls, all other possible control interfaces such as circuit breakers and air data computers that exist in a real aircraft must also be fully functional in the simulator.

The one final requirement for a simulator is the ability of an instructor to control the environment that the aircraft is in. This is facilitated through a man-machine interface, usually placed inside the simulator, behind the pilots. Recalling the description on the definition of a generic simulator described in section

2.1, the basic components of a simulator can be broken down into seven distinct processes, illustrated below in figure 2.2.1 and expanded on in sections 2.2.1 to 2.2.5

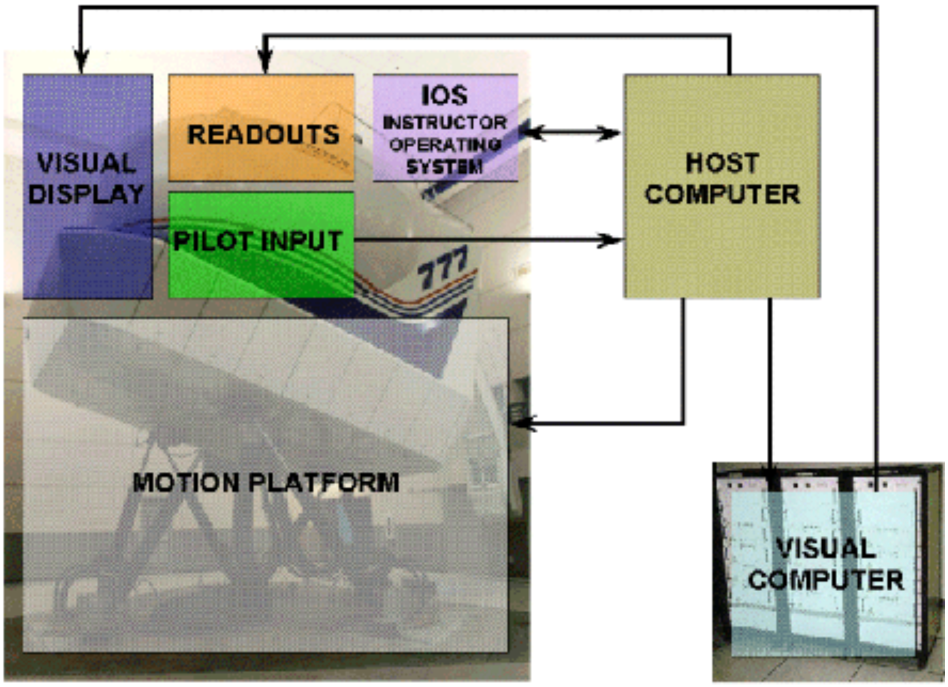

Figure 2.2.1 – Generic simulator context diagram

2.2.1 The host computer

The host computer is where all the required inputs and outputs are processed. Although host computer makes vary from the commonly used 1970′s Encore Gould to the latest UNIX, VMS and even PC systems, the general architecture remains the same.

Host computers are single or multiple processor systems. They normally communicate through Direct Memory Access (DMA) and control satellite computers that are dedicated to provide motion, vision, sound, instructor's facilities and control loading. In addition, the host drives all the general-purpose peripherals and, through electronic interfaces, drives the dedicated peripherals of the flight deck – mainly original aircraft components.

The core element of all simulation is held within the software code based inside the host. The code ranges from electrics and engine systems to navigation and malfunction processing. The most significant area of code though, is used to calculate the aircraft's flight dynamics and will usually include provisions for icing effects and malfunctions.

Furthermore, numerous types of environmental phenomena representing simple wind fields, turbulence and wind shear up to complex rotors, microburst, and clear air turbulence are commonly catered for. The implementation of the mathematical model is mainly written in FORTRAN 77, C, C++, or ADA. An example of the modular software layout is provided in figure 2.2.1.1 below.

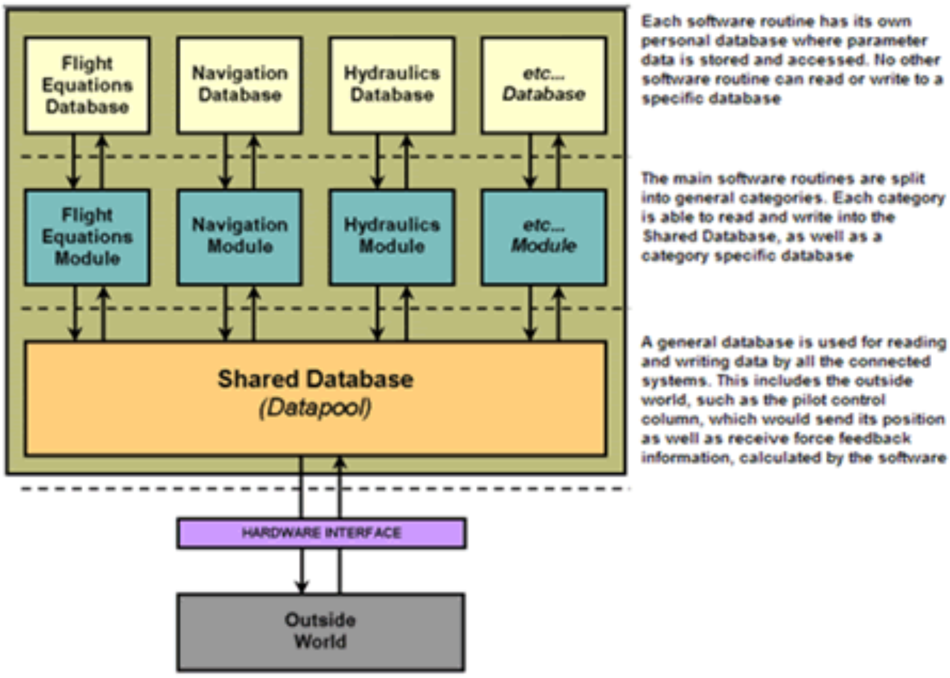

Figure 2.2.1.1 – Generic host context diagram

Modelling an aircraft means reproducing the basic physical behaviour of the aircraft and its systems as functions of time and logical interrelationships. Aerodynamic properties vary with atmospheric conditions thus, changes in the atmosphere need to be integrated. Subject to the purpose of flight simulation, different aspects in the behaviour of an aircraft can be reproduced with reasonable accuracy. Taking flight dynamics as an example, this extends from simply calculating a point-mass system to solving the complete aerodynamic and flight mechanical equations in real-time.

At the lower end of the fidelity range, the simulation provides an aircraft of a generic type; it flies like any aircraft without mimicking the behaviour of a specific type. At the upper end, as in all full flight simulators which we will concentrate on, the pilot feels like he is flying the original aircraft of this type. The degree of modelling an aircraft may impose restrictions on the capability of flying, for instance by using a Cartesian co-ordinate system of only small extent. Additional provisions make possible long distance flights and observing the curvature of the earth. Finally, advanced methods of state descriptions, for example by using the quaternion method, even permit aircraft acrobatics and is commonly applied in full flight simulators.

2.2.2 The instructor's interface

On a training simulator, all the scenarios are typically selected and controlled by a qualified training instructing. The instructor usually sits within the simulator behind the training pilots, where he can see and modify the training conditions as shown on figure 2.2.2.1

The scenarios, environmental and malfunction selections are all operated through a custom user interface, typically via a touch screen control page. The Instructor Operating Station or IOS sends the required instructor requests to the host, which then carries them out in the simulator output.

Figure 2.2.2.1 – A typical IOS layout within a simulator. Note the touch screen implementation

At the touch of a button, virtual or real, the instructor can view or edit essential aircraft parameters such as the fuel content, the navigation or even the actual position of the aircraft. To further aid training, option such as total simulation freeze, fuel freeze and repositioning are possible.

A typical example of an IOS page is provided on figure 2.2.2.2 It shows a touch-controlled page that displays a zoomed out map of all the simulated airports around Northern Europe. Keys at the bottom of the screen can control various map parameters as well as short cut keys that are linked to important pages such as Lessons and Malfunctions.

Figure 2.2.2.2 – A typical IOS page showing a map of airport locations

The IOS is a crucial man machine interface that controls the simulator, the simulated environment and the pilot training. As a result, it will be further expanded on throughout this document.

2.2.3 The pilot's interface

This section covers both the pilot input and the readouts, both shown in the simulator context diagram on figure 2.2.1. The readouts can be considered as all the outputs informing the pilot of the aircraft's state, although the visual and motion system which also do that will be considered in separate sections.

In a research simulator, basic instrumentation is necessary to perform the primary flying task, while additional equipment depends on the experiments. For testing purposes, the use of original aircraft equipment can be made to induce interface and power supply problems under controlled conditions. In a training simulator however, the entire cockpit is replicated, hence the need for all the instruments and controls to be present.

The main form of pilot input are the ones that affect the aircraft's control surfaces as well as the engines, namely the control stick and the throttle. Secondary controls include the computer systems and the numerous circuit breakers (CB's) that are used to bypass electronic functions. This is illustrated in figure 2.2.3.1 below, displaying the extent of functionality a simulator can exhibit.

Figure 2.2.3.1 – A typical simulator cockpit

Actual “off the shelf” aircraft hardware and instrumentation are used for almost everything forward of the circuit breaker panels. Real throttles, real switches, and flight directors or EFIS displays, real FMC CDUs (flight management computer – control display units) and even real pilot seats are used. This has become such an integral part of simulation that aircraft computer systems such as navigation are designed with simulator applications in mind.

This is best illustrated when considering an IOS function called “Flight slew”, where the instructor can move the aircraft great distances in a matter of seconds. When this happens, all the aircraft systems are still functioning, with the aircraft position changing at speeds exceeding real life safety margins by great factors.

Functioning systems that look at the aircraft position will realise that something outside the operating range is happening and decide switch off, as opposed to outputting misleading data. To avoid this happening, such systems are designed to include a special switch or jumper that, when set, indicates that the system is being used in a simulator so that they can ignore such data and thus not switch off.

Certain system displays are of course “simulated”. To indicate the altitude, real aircraft use pneumatically driven altimeters, where pitot static pressure causes a small bellows inside the instrument to indicate altitude. In a simulator, however, it is impossible to replicate this directly, so the altimeters must be driven using servomotors as calculated by the host computer.

However, the indicated value isn’t merely the computed value, but a simulated representation of the instrument itself, include possible inaccuracies and delayed responses. Advanced flight simulators can also simulate the aerodynamic forces perceived when using the controls of the aircraft through control force feedback. Equipment used varies from spring-loaded control sticks to computer-controlled servos.

2.2.4 The audio and visual systems

The sound simulation system reproduces all sounds audible in the cockpit. Advanced sound systems are not only capable of reproducing those sounds originating from aircraft systems, but of even those emanating from the environment, for example aerodynamic and weather sounds.

Sound systems range from average quality, low fidelity systems which use filtered random noise, with the filter banks controlled by the host computer systems, to top end high fidelity outputs.

The synthetically generated sounds are derived from a high-quality recording of the chosen sound sources. They are synchronised in sympathy with aircraft controls and conditions, as for instance engine rpm, to create correlating variables representing frequency and amplitude. Loudspeakers installed around, above, and below the flight deck allow approximately realistic sounds in a simulated high fidelity polyphonic environment.

Although the audio cues generate a realistic and convincing effect, the most important and impressive aid used to enhance the flight sensation illusion is the visual system.

The vision generation technique universally used is computer-generated imagery or CGI, and consists of a data base, an image generation system and display hardware. The database represents the terrain and the objects simulated in the air or on the ground. The image generation system accesses this data and converts it to obtain a correct perspective view, updated in real-time.

High-end visual systems use close to perfect concave mirrors and lenses to produce a realistic display. Using these mirrors, an infinite horizon can be mimicked convincingly, along with altering view positions through the lens. Should the pilot look right, the horizon and visual details will appear to change in depth and scope convincingly.

The simplest outside vision is night vision. Due to restrictions on the human eye, this can use few details, relatively low update rates and few colours. Daylight scenes are the most complex, needing more colours, filled areas, higher refresh rates and thus, more computing power. The information used to convey the outside world, day or night, is stored in a terrain database. For simpler flight simulators, the database consists of generic scenes. A flat surface carries an irregular texture (e.g., patches of different shades of green) necessary to give a motion cue. A generic airport consists of one or more runways of selectable dimension and orientation. A limited number of generic mountains may enhance the scene.

More sophisticated systems simulate a number of actual airports, for example 30 or more airfields world-wide. For manoeuvring in the terminal area, approximately 50 Nm x 50 Nm of simulated terrain surrounds each airport. More recent simulator visual systems use regularly updated terrain information from satellite data. Although costly, such information can become invaluable for military training carried out before a real combat mission.

The database can also contain information used for simulating environmental effects. According to the terrain profile, the probability of turbulence and wind shear at low altitude can be simulated. The higher probability of thermal uplift over terrain is also simulated accurately.

To display these outside scenes, one needs to convince the brain that movement is occurring. For this to be accomplished, the said object or scene must be updated at 30 Hz at least. An update rate of 50 Hz, used on televisions, is ideal. This however, causes a high demand on the custom visual hardware, with display performance varying significantly with age and cost.

Latest top range simulators incorporate some of the best visual systems on the market with computers that are capable of producing millions of calculations a second. This allows detailed real time rendering of complex visual representations with shadows, sun glare effects and motion blur. Furthermore, advanced systems provide depth cues and simulation of limited visibility in fog by shifting colours for distant objects to blue or white. They also pay attention to lighting conditions and even raindrops on the windscreen are simulated by modifying the image.

An example of such a system is the one used to train pilots for the new Boeing 777 aircraft. A picture showing the degree of visual detail in daylight is presented below in figure 2.2.4.1

Figure 2.2.4.1 – An example of a top end visual system depicting a daylight scene

One example of a system not solely using computer graphics for image generation is the wide-angle collimating closed circuit TV vision system with enhanced visibility effects. It employs a television camera "flying" over a model board based on the simulators location, although this method of implementation is becoming rarer. Cheaper visual systems, the inherent space restriction and the need for frequent updating of the terrain models all mean that this method is becoming quickly outdated.

2.2.5 The motion system

The motion system of advanced flight simulators provides real-time approximations to the rotational acceleration and the specific force vector at the pilot's position in the mimicked aircraft.

Due to mechanical constraints, it is never possible to generate the entire motion of an aircraft in a simulation. Thus, in order to provide the necessary sensations to the pilot a method known as acceleration onset cueing is used. A motion platform is essentially a "kicker" which reproduces the initial onset of acceleration and then backs off its movement in a controlled way. High specification civil aviation trainers typically use 6 degrees of freedom (DoF) allowing subtle vibration simulation through to hard manoeuvre training. A typical 6 DoF simulator is shown below in figure 2.2.5.1

Acceleration onset is followed by a washout phase below human sensory threshold and the platform is then reset, ready for the next acceleration onset demanded by the host computer. These are demanded as a result of pilot controlled action, environmental factors such as windshear and turbulence and also in reaction to aircraft and engine system operation and malfunctions.

Figure 2.2.5.1 – A 737-300 Simulator with 6 DoF

The above mentioned cueing methods are effective for producing short acceleration effects but not for simulating cues of sustained surges. This is solved through a simple trick – what simulation is really all about. Platform pitch angles are used to give cues of "kick-in-the-back" for acceleration and "hanging in the straps" for deceleration. The host computer pitches the visual image to the same pitch angle as the platform and the pilot receives strong cues of longitudinal acceleration or deceleration rather than pitch.

This system of motion cueing works well because it matches the way the body's motion sensors respond in the real world. The body's sensors are all acceleration-sensitive devices and can thus be triggered by the kick produced the motion platform. However, for motion cues to be effective, they must be perfectly correct otherwise poor motion becomes far worse than no motion at all.

Latency, or the time taken for calculations to be sent to the motion platform, has a significant effect on simulator performance. High platform latency complicates visual cueing because the body senses acceleration before visual displacement is registered by the brain. Put simply, since acceleration is required before motion can occur, it follows that, in a simulator, the visual system must not react before the motion cues are felt.

The effects of such miscues can lead to "simulator sickness", common in the 1970s. However, latency times have been reduced to 100 milliseconds or less, significantly lower than transport delays of 300 msec for older models produced in the 1970s.

It must be noted that many simulators are fully functional in every sense, but lack a motion platform. This is more the case for military simulators, where air combat manoeuvring is not a high-gain task, at least until accurate visual tracking becomes necessary for gun engagements. Furthermore, motion platforms are typically used in tandem with high-end visual systems to provide an overall effect. This means that simulators with low quality visuals or poor ground detail seldom required the use of motion platforms, as their training aim is purely on the instrument side of things

In general, though, motion systems are highly effective training devices, as a pilot is used to experiencing these motion cues and will thus respond naturally to effects such as turbulence without knowing why. This is because the brain is capable of subconsciously assessing and acting on the motion feedback before even registering a displacement in the visual scene – an important aim for all realistic simulations.

3. The Need for Simulation

It is clear that the design, running and updating of training simulators is expensive and non-profiting for the airlines. This begs the question as to the use and purpose of simulation. In order to home in on the importance of this, one can draw upon a typical project, as well as exploring other applications of simulation.

3.1 Areas of flight simulator applications

For training, operating simulators can significantly reduce the cost compared with the use of real equipment. For research, it is the only way to test new equipment and procedures without endangering safety while remaining within research budget. Evaluation of performance of the system involving both human and machine under all kinds of dangerous external effects is also possible in a simulator.

In a flight simulator, a variety of failures in human and machine behaviour can be reproduced without compromising aviation safety. Thus, it is possible to investigate the impact of new features, new equipment, or new procedures on the avionics system. With regard to training, the flight crew can gain the necessary operational skills required without affecting other aircraft.

Training objectives may comprise practice of flying skills, check rides, cockpit resource management, line-oriented flight training, aircraft conversion and recurrent training. Research areas of interest consist of pilot-aircraft integration, man-machine interface optimisation, flight control systems development, Air Traffic Control (ATC) integration with avionics, workload analysis and the development testing of simulation models.

3.2 Pilot training

Training facilities mainly use certified six-degree-of-freedom moving base Full Flight Simulators with full outside vision. These accurately replicate the cockpit and characteristics of a specific aircraft type or even one single aircraft. The devices are capable of an advanced simulation of flight condition, flight dynamics, and navigation. They include other aircraft and meteorological variables like wind, gusts, and thunderstorms in the simulation.

They also simulate the full range of aircraft subsystems like engines, the electric, hydraulic and pneumatic systems as well as and warning systems. Stabiliser trim, artificial force on control elements and audio cues such as aerodynamic noise, landing gear bumps and noises while on the ground are also catered for. Finally, initiation of system faults is feasible, with around 300 available in the most capable of trainers.

Simulators used in training are tightly monitored by regulatory bodies such as the CAA and FAA, with different levels of certification aimed at different types of simulators, from the basic instrument only trainer to the top range, full motion simulator.

Should there be the necessity to add a new training scenario, the regulatory body will inspect the update and, should it pass the new scenario it is declared ready for training.

3.3 Research and simulation

Considering research applications where hardware is tested, the simulator equipment used is of a wider scope and more flexible than the pilot training variety. As an example, Raytheon's flight simulators are both competent at mimicking a variety of aircraft, such as the Boeing B747-400, the Fokker 100, and the Cessna Citation.

Depending on the purpose of simulation, different degrees of fidelity are necessary while a perfect representation of reality is not possible. A very simple, hence cheap simulation of aircraft speed and position may be sufficient to test navigation procedures. However, full flight simulation suggests itself if operation of new equipment is to be tested under the influence of turbulence. An example is UKS' MBB-HFB 320 HansaJet simulation device. Providing a model of the entire flight dynamics, only a generic database for navigation exists, and it features an experimental cockpit instead of the HansaJet's original cockpit. When using flight simulators for research, access to internal data of a hardware and software nature of the simulator is necessary. Thus, the behaviour of the simulated aircraft and systems can be adapted to the experiment under consideration.

Aircraft research in a simulator provides an ideal environment to test the man-machine interface, as well as recreating an accurate representation of the electrical components present in an aircraft and provides a hands-on method of testing hardware and interfaces.

On the other hand, training simulators tend to be high-performance full-flight simulators providing all the sensations that may influence the behaviour and performance of a pilot. Consequently, FFS's should be the ideal equipment for experiments in the man-machine systems field, where the study of human interaction with the electronics system is monitored to provide an optimum and ergonomic environment.

However, officially certified training simulators lose this certification when changes to the simulator system occur. Considering the fact that a FFS costs about £200 pounds an hour to run, there is a need for high-performance simulators that still provide access to internal data and structures. The ZFB in Berlin operates such a combination where a certified Airbus A340 FFS is available for training sessions. Furthermore, a Scientific Research Facility (SRF) supports research experiments. Both share the 6 DoF moving base mock-up of the A340 flight deck.

The SRF runs on an identical, but separate computer system. When preparing experimental flight simulator sessions, the SRF loads a copy of the original software of the training simulator. All modules of the simulation software are accessible and documentation of the interfaces is available. Thus, customised modules designed according to the needs of the experiment can replace parts of the simulator software. Changing from training to research mode and vice versa takes about 20 minutes. A simultaneous operation of the SRF when the FFS is in training mode is also possible. Software simulations replace functions of the avionics hardware on the flight deck that are functionally not accessible in parallel operating mode. If the cockpit is not available during preparation of an experimental flight, the software can be "flown" from a workstation, operating the flight controls and malfunctions by using a touch screen.

3.4 Simulating the environment

Along with the topological database for vision simulation, other effects of the environment are important. Simulation of weather phenomena is substantial for training simulators. This includes constant winds affecting navigation as well as winds changing in speed and direction at low altitudes with an impact on take off and landing. Wind shear is of special significance. Enhanced systems also reproduce additional effects like variation of air density and temperature with altitude, turbulence and microbursts.

More recently though, simulation of the environment has begun to encompass other aircraft within a scenario, being controlled by Air Traffic Control. This has been taken to the point where several simulators can be linked up to an ATC simulation, with all participants benefiting from the learning experience a dynamic environment presents. The capability of linking up simulators has become even more significant in the military field. Here, air and ground simulators such as the A-10 "tank buster" aircraft can be operating with several allied tank simulators linked up to fight a simulated enemy. Throughout a scenario, a simulated command and control can make tactical decisions that can be reviewed and picked apart once the simulated exercise is over.

Another increasingly important aspect of the simulated environment for training is called Cockpit Resource Management, or CRM. This involves the training of a flight crew as a team that works and communicates together. CRM typically aims to remove the fear of questioning a higher-ranking flight officer. Flight crew training has also been an increasingly important training factor. In this case, a full motion mock-up of the aircraft fuselage is used to train air stewards how to deal with emergencies such as splash down and a smoke filled cabin.

The aim for aircraft human resource instructors is to combine the cockpit CRM training with the cabin crew training, so that the traditional divide between the flight crew and cabin crew is shortened through combined training.

4. Conclusions

4.1 The benefits of simulation

As can be seen in the discussion on the use of simulators presented in section 3, the tendency for companies to use simulator training is increasing. As well as increasing the amount of training provided, companies are also increasing the scope covered in simulation.

Such examples include the military which is integrating several types of simulators to provide diverse training scenarios as well as airline companies that integrate cockpit flight training with crew training, enhancing team skills – a key theme in the nineties.

One can thus conclude that simulators are a necessity in today's training environment. Reflecting on the civil aviation aspect of things, operating costs, traffic congestion and subsequent flight operating restrictions have made complete actual training too costly and therefore inefficient. Furthermore, simulators offer a much wider scope of training possibilities.

Through the host computer, IOS and visual systems, any desired position, environmental condition or emergency can be presented. The increased use of flight simulation has therefore reduced the need for extensive actual flight training, with the additional advantage of producing better trained and more competent flight crews.

4.2 Overall conclusions

Unlike most fields where one can specialise in a small sector and have little appreciation about the wider picture, working in simulation is different. It is actually about the understanding and appreciation of how all the various aspects of simulation are pieced together to produce a realistic and dynamic environment.

From the obvious visual system and the motion platform interaction to the more subtle aspects such as an HSD card in the Host computer that sends pilot input data to the flight dynamics software, simulation requires an awareness of the processes involved.

Working in the industry for six months provided an appreciation as to what is involved in simulation – the seamless integration of very different skills into one box that is accurate enough to trick the brain into reflex actions.

And with old simulators being upgraded instead of being scraped, with constant directives that demand new hardware to be implemented in aircraft and the year 2000 computer problems round the corner, the simulation industry is now proving to be more resourceful, vibrant and varied than ever.

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Flight Simulation Facilities, 1993 – Dussoye, S.S. and Borys, B

An Advanced Facility for Cockpit Studies, 1990 – Lypaczewski, P.A.

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Seymour Black September 28, 2007 at 1:29 am

I would like to use information and quote your document on Simulators for my upcoming term paper on simulators.

Thank you
Seymour Black

Ritesh Kumar October 1, 2007 at 7:57 pm

The coverage on the topic is indeed extensive and a detailed one…i would be happy if allowed to include some contents in my project report on flight stimulators
Thanking you,

Ritesh kumar
(INDIA)

Brad Funk [November 6, 2007 at 2:51 am]

I am completing my masters degree in aeronautical science and would like to reference your work in my graduate capstone project.
Please let me know if you would be willing to let me do that.

Thank you,

Brad.

[Christian Nagl] [July 19, 2008 at 8:58 am]

This is a wonderful overview about Flight Simulator technolgy. Thank you for the valuable information.
I'm just writing my master thesis in computer science about didactic aspects of Flight Simulation provided by the entertainnment industry. I would be very happy and proud to include information of your work therefore. May I reference/cite some parts of your article ?

Thank you,

Chris
(TU Vienna, Austria)

Pawel Burdzy [August 19, 2008 at 7:48 pm]

I am writing my thesis about Computer Simulators. Besides this I've done computer program which simulate Cessna 172 SkyHawk. Could I copy some parts of text, mainly about how simulator is builded to my work?

J. M. Wright [September 6, 2008 at 2:48 pm]

I'm writing a technology assessment report and would like to reference your article.

Thank you,

Michael

Andrew Dow [November 6, 2008 at 4:17 am]

I would like your permission on using some of your information about your thesis on the art of flight simulators in my Masters Project that I am currently working on.

Please let me know.

Thanks,

Andrew

Sruthi Yarlagadda [November 9, 2008 at 2:59 am]

I am doing an independent study on Flight simulation and would like to refer to your paper as part of it.

Please let me know if can do that.

Bob Gabriel [November 12, 2008 at 12:18 am]

Mr. Gabbai
I am doing research on a paper relating flight simulation and electronics. I would appreciate your permission to reference your paper. Please let em know.
Regards,
Bob Gabriel

Matthew Poynter [November 27, 2008 at 4:42 pm]

Dear Mr Gabbai,

I am a Britiah student currently studying Aircraft Maintenance Engineering in university. My final year project is on the conceptual design of a flight simulator including a simple prototype. This is only dealing with the mechanical aspects of the motion platform but, I would still like to know if I can include information, quotes and referances to your paper. I would also appriciate any further information, or sources of information on the mechanical side of flight simulation that you may be able to point me in the direction of.

Regards

Matt Poynter

Clinton Pando [March 13, 2009 at 1:37 pm]

Sir,

I am writing a paper on flight simulators and their application in aviation training and would like to reference your paper.

 Stephanie Miller [March 28, 2009 at 2:58 pm]

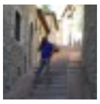
Mr. Gabbai,

I am also writing a research paper for a Masters class and would like the opportunity to cite/reference information from your paper if at all possible. Please advise…thank you!

Steph

[Ragavanandam...] [April 19, 2009 at 5:10 am]

tnks for ur detailed info..!!
these details helped me in finishing my final yr project work..!

 Remo Ricchetti [April 22, 2009 at 12:01 pm]

dear mr Gabbai

I would like to reference your work in a report on simulation technologies.

thank you
RR

Thahir A [May 5, 2009 at 2:57 pm]

Thank you for your sharing about flight simulation technology. I would like to know if I may refer this paper for my project of special topics in design. I'm very happy if you allow me to do that.

Regards

Tahir from Indonesia

Rodrigo De Marco [May 6, 2009 at 5:47 pm]

Mr. Gabbai,

I work in a aviation training center as a trainee at the maintenance services for our full flight simulators. I'm writing my final year research in the university about some experiences I'll do with one of our FFS. I wanna know if I could reference your article as theoretical support about the simulators technology.

Rodrigo
EPA Civil Aviation Training Center
Curitiba, Brazil

Paul Druse May 10, 2009 at 9:51 pm

Great stuff, would also like to cite for term paper

Anna Jiroutova May 30, 2009 at 5:10 pm

Dear Mr. Gabbai,
I would also like to ask for permision to quote you in my Extended Essay which I am writing as part of the IB (International Baccalaureate) program.

Thank you,
Anna

Ancelica September 23, 2009 at 4:03 am

Dear Jonathan Gabbai,

Your article is very informative and interesting. Iwould like to take a snippit of your information and use it in my desitation.

It would be like this:

Flight Simulators

The principal task of flight simulation is the creation of a dynamic representation of an aircraft's behaviour while allowing one or more human operators to interact with the simulation. The definition of a simulator or simulation can vary in meaning between different fields and applications, but generally defines as replicating an environment and specific conditions for training people under controlled and monitored conditions. (The Art of Simulation, Jonathan Gabbai)

If you would be kind enough to quote from you that would be wonderful.

I await your kind response,

Yours truly,

Ancelica

Jason Stark February 6, 2010 at 2:35 pm

Sir,

In the same vein as the other posts, I am completing a Masters in Defence Studies and would like your permission to quote from your thorough and extensive article.

Flying Officer Yogesh Betolia February 15, 2010 at 5:49 pm

Dear Sir
Thanks a lot for detailed, yet basic information about the concepts of flight simulation. This topis forms a part of my syllabus, and it will really help me a lot.

Regards
Fg Offr Yogesh Betolia

dan February 16, 2010 at 8:53 pm

I would like to ask permissin to use part of this article in a project i am doing for school.

Thank you,

Dan

Faisal Caeiro February 28, 2010 at 3:16 pm

Thank You for your information it will be very useful for me for my final year project. May I quote some of the parts in my project

Michael Mota February 28, 2010 at 6:26 pm

Hello,

May i have your permission to cite your great article in my computer science honors thesis?

Mike

Andrew Pence September 1, 2010 at 9:08 pm

Mr. Gabbai

I would like to use information and quote your document on Simulators for my upcoming Embry Riddle term paper on simulators.

Thanks
Andy Pence

Becky Phillips January 4, 2011 at 2:55 pm

Sir,

I am requesting permission to use and quote some of your article for an historical project.
Thank you,
Becky

Joel Correia [March 12, 2011 at 9:43 pm]

Hello
I would like to use some of the information in my thesis.

Thanks
Make me know by e-mail please.

Joel Correia
Portuguese Air Force

Amanda Deng [June 2, 2011 at 11:10 am]

Hi! This is an very interesting topic. I have a BS in Aerospace Engineering and have worked closely with the pilots on F-16 Helmet system as a flight test engineer at Edwards AFB. I am facsinated by the Scaled Composite SpaceShipTwo project and one problem they encountered, from what I learned, is to better practice attitude flight control for the pilot during powered air launch and re-entry. I am just wondering if there is simulator for that narrow field of scenerio, and what skill set should I be developing if I want to work (with pilots) in developing better flight training system and writing better flight procedures for them.

Much appreciated!

Amanda

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