



FLIGHT SIMULATION IN CIVIL AVIATION ADVANTAGES AND DISADVANTAGES

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KEYWORDS: Aviation training, Airline, Flight simulation, Zero flight time training, Innovation, Safety, Pilots, Cabin crew.

SŁOWA KLUCZOWE: Szkolenie lotnicze, Linie lotnicze, Symulator lotu, Innowacyjność, Bezpieczeństwo, Piloci, Persone.

ABSTRACT: The aim of this article is summarise the role and importance of flight simulation in civil aviation, notably its beneficial effect on the environment and its increasing impact upon training strategies. It has been prepared to provide background information to assist decision makers in government, industry, airlines and academia. Much of the training previously undertaken in aircraft is now conducted in flight simulators. Flight simulation is critical to the operation of civil and military aircraft organizations. International standards for flight simulation training devices have been established to ensure consistency for operators, regulators and manufacturers. Flight simulation continues to make a major contribution to improving aviation safety. Compared with airborne training, flight simulation reduces markedly the impact on the environment. A wide range of synthetic training devices has been developed for specific flight training tasks. For certain training tasks, effective training can be achieved with low fidelity synthetic devices. Advanced in computer technology enable flight simulation to provide very effective flight crew training. Flight simulation is used from basic training through to zero flight-time training for civil airlines and to mission rehearsal for the armed forces.

Celem tego artykułu jest określenie roli i znaczenia symulacji lotu w lotnictwie cywilnym i wojskowym, w szczególności jego korzystnego wpływu na środowisko i jego rosnącego wpływu na strategie szkoleniowe. Artykuł został przygotowany w celu dostarczenia podstawowych informacji wojskowej kadrze zarządzającej, w przemyśle lotniczym, liniach lotniczych i środowiskach akademickich. Duża część szkoleń wykonywanych wcześniej w samolotach jest obecnie przeprowadzana w symulatorach lotu. Symulacja lotu ma kluczowe znaczenie dla funkcjonowania cywilnych i wojskowych organizacji lotniczych. Aby zapewnić spójność dla operatorów-linii lotniczych, regulatorów i producentów statków powietrznych opracowano międzynarodowe standardy szkoleniowych urządzeń symulacji lotu. Symulacja lotu przyczynia się do poprawy bezpieczeństwa lotniczego. W porównaniu ze szkoleniem powietrznym symulacja lotu znacznie zmniejsza koszty szkolenia oraz wpływ na środowisko. Opracowano szeroką gamę urządzeń szkoleniowych do określonych zadań szkoleniowych. W przypadku niektórych zadań szkoleniowych można uzyskać skuteczne szkolenie z użyciem urządzeń o niższej wierności-odzworowaniu faktycznego lotu. Zaawansowana technologia komputerowa umożliwia symulację lotu, zapewniając bardzo efektywny trening załogi lotniczej. Symulacja lotu jest stosowana począwszy od szkolenia podstawowego do bardzo zaawansowanego szkolenia lotniczego bez wykorzystania lotów na rzeczywistym statku powietrznym, w szczególności pilotów przeznaczonych do pracy w cywilnych liniach lotniczych, a także do różnych prób misji wojskowych sił zbrojnych.

Synthetic training is highly effective in other sectors of aviation, particularly in maintenance engineering training and cabin crew training. Flight simulation reduces significantly the cost of flight crew training. Training in flight simulator can be more effective than airborne training. Simulation plays a fundamental role in research, development and evaluation of aircraft and aerospace systems. Increasingly, simulation supports procurement, where the complete product life cycle is modelled and analysed in a synthetic environment. The flight simulation industry exploits advances in commercial off-the-shelf technologies to increase capability and reduce development costs. Simulation will become pervasive in many industries and simulators will become essential tools in system design studies. Flight simulation is becoming recognised as major discipline of aerospace.

Flight simulation has evolved to become essential component of civil aviation operations capability. International standards ensure world-wide regulation of flight-simulation facilities. Flight simulation has radically changed flight training and is now an established discipline in aerospace.

Today, a significant amount of civil flight crew training is undertaken in flight simulators utilising computers to create the illusion of flight. Many of the airborne exercises that dominated flight training as recently as the mid 1970s, have been replaced with training in flight simulators. Concerns that flight simulators were unrealistic and that aircraft provide better training have been dispelled and a wide range of part-task training devices has been developed to provide synthetic training on specific systems and procedures. This remarkable transition in flight training is accepted by flight crews, operators, unions, manufacturers and the regulatory authorities.

The complexity of civil aircraft has increased as a result of advanced avionics, expanding flight-crew training requirements and increasing the reliance on flight simulation. Many civil airlines operate large flight-training centres to undertake their flight-crew training and regular competence checking to maintain flight crew licences.

Recognising the impact flight simulation has made in civil training, international regulations have been established to ensure that civil flight crew training simulators operated by different organisations meet an approved standard. These standards not only ensure consistent regulation of flight simulators and flight training organisations throughout the world, they also enable manufacturers to build flight simulators that are compliant in different countries, encouraging competition while ensuring quality.

Most armed forces also utilise training centres with flight simulators for basic training, type conversion and tactical training for both fixed-wing and rotary-wing aircraft. In addition, flight simulators are used by aircraft and equipment manufacturers, systems developers, research organisations and academia for proof-of-concept studies and the design, development and evaluation of aircraft systems.

Flight simulation has not only radically changed flight training methods, reducing the training risk and improving training quality; it has also resulted in significant improvements in flight safety, alleviating airborne congestion and the impact of aviation on the environment, while reducing the cost of training. These trends are likely to continue for the foreseeable.

Training in flight simulator can be more effective than training in an aircraft. High levels of training transfer can be achieved with low-fidelity devices. For some simulators, all the flight-crew training can be conducted in the simulator. The Link Trainer was the forerunner of effective synthetic training devices. Developed in the USA in the late 1920s by simulation pioneer Edwin Link and used during the Second World War, it provided over half a million allied pilots with essential training in

instrument flying. Nowadays, such a device would be termed a part-taks trainer or Flight Training Device (FSTD) as it was optimised for a specific set of training tasks, eliminating time that would otherwise be spent in an aircraft (or nowadays, in a full flight simulator).

In flight simulation, the effectiveness of a training task is the „training transfer” resulting from training in sythetic device compare with that in an aircraft, often measured as the ratio of the numer of hours of airborne training that can be replaced with training in a symulator. Studies have shown that, for certain tasks, high levels of training transfer can be achieved with low-fidelity training devices.

FSTDs are used a instrument trainers and flight navigation procedures trainers (Figure 1).



Figure 1. Flight Training Device (FSTD). Source-The impact of flight simulation in aerospace-Royal Aeronautical Society Flight Simulator Group, March 2009.

Simple desktop training devices and laptop computers are also used to train flight crew and maintenance technicians, for example, to operate complex avionics or to practise engine start procedures without incurring actual engine wear and the associated cost. This use of flight simulation technology, with a computer-based approach to training, allows students to proceed at their own pace, while at the same time providing feedback on their performance.

Modern full flight simulators replicate aircraft handling characteristics with a high level of fidelity and offer a way to accelerate pilot experience which can be more effective than airborne training. For example, severe weather conditio (cross-winds, microburst, wind shear and turbulence) can be selected by the instructor, exercises can be repeated and a sortie recorded for subsequent deriefing analysis. Flight crews can also experience system failures and operational conditions that would be too hazardous to practise in an aircraft. A pilot encountering an engine failure will have practised the emergency in a flight symulator within the previous six months even though, with improvements in aircraft reliability, most pilots will rarely

experience a real engine failure. Line Oriented Flight Training in a simulator, a pilot can depart from Heathrow with ice and thick fog for a night-time landing at Frankfurt with one engine shut down and runway lighting failure, while coping with „en route” emergencies introduced by the instructor.

For experienced flight crews, type conversion can be conducted in a flight simulator. For the most part, this involves familiarisation with aircraft systems and procedures specific to the aircraft. For a simulator qualified to the highest level (and with the approval of the regulatory authorities) flight crews can undertake all type conversion training in a flight simulator. The term „zero flight-time” (ZFT) has been coined for these flight simulators. The training afforded by a ZFT simulator is accepted as being so good, that the first time a pilot may fly that aircraft type is with passengers, albeit with a training captain on the flight deck.

Flight simulation has made a major contribution to improved aviation safety. It also offers considerable financial saving to airlines and reduces the environmental impact of civil aviation.

Airline flight crews must undergo two days training and checking in a flight simulator every six months. Typically, the ratio of simulators to aircraft is 1:30 for narrow-body aircraft increasing to 1:15 for wide-body aircraft, with capital costs amortised over 15 years. For an airline with 1.000 pilots, recurrent training and checking using aircraft would cost some 60 mln USD annually. Flight simulator operating costs are less than one tenth of this figure and the economic benefit is critical to airline success. Moreover, many flight simulators are operated intensively for over 20 hours each day, producing significantly less carbon emissions and environmental noise than equivalent airborne training.

The technology developed for flight simulations has been applied in other sectors of aviation, where simulation provides safer and more effective training but at significantly reduced cost in comparison with „live” training:

Aircraft technicians can practise installation, removal and fault-finding of equipment in a synthetic environment without using actual aircraft parts (Figure); Cabin simulators provide valuable training for civil airline cabin crew, particularly emergency procedures (Figure 2). Example of Cabin Crew Simulator. Source: 07.10.2018



Aircraft technicians can practise installation, removal and fault-finding of equipment in a synthetic environment without using actual aircraft parts (Figure). Cabin simulators provide valuable training for civil airline cabin crew, particularly emergency procedures.

Flight simulation is at the leading edge of several technologies, particularly in computer graphics, distributed computing and mechanical actuation. Since the early 1990s, advances in flight simulation have paralleled the computing revolution and the growth in PC-based technologies, with dramatic increases in computing speeds and memory together with falling costs.

In a flight simulator, a pilot's visual, motion, aural and tactile sensors must be stimulated in such a way to provide the same cues as in flight. The illusion of flight must be sustained at all times, smoothly and consistently, and the instructor's interaction must be unobtrusive. False cues will break the illusion, possibly reducing the training benefit.

The mathematical modelling of the dynamics of an aircraft, its engines and electrical and mechanical systems, emulating the avionics systems, moving the heavy motion platform on which the simulator cabin is mounted and generating high-fidelity out-of-the-window images are all very demanding tasks in terms of computer processing. In a modern simulator, these computations must be completed in less than 20 milliseconds; nowadays, this high computational performance can be achieved with a distributed network of microprocessors.

Aircraft motion is simulated by moving the simulator platform vertically, fore and aft, and side-to-side, and rotating it about these three axes. This is a particularly challenging requirement for mechanical actuators which must be adequately responsive to stimulate realistic acceleration cues, while ensuring safe, reliable and noise-free operation.

Although the displacement of a simulator platform is typically limited to a few metres, by combining knowledge of the physiology of the human motion sensors with a mathematical model of the actuators, the flight crew in a simulator can experience motion cues remarkably similar to those in an aircraft.

Visual cues are provided by computer-generated images viewed through the cockpit windscreen or in a helmet-mounted display. The observed scene must faithfully replicate all appropriate geographical features and airfields and be displayed with the correct depth of image and with the scene viewed without distortion by all flight crew, and possibly an instructor. This image rendering process is achieved by graphic engines, developed specifically for flight simulation or, more recently, adapted from PC graphics technologies.

The most common type of visual system uses three or more projectors to display the image via a curved mirror (Figure 3).

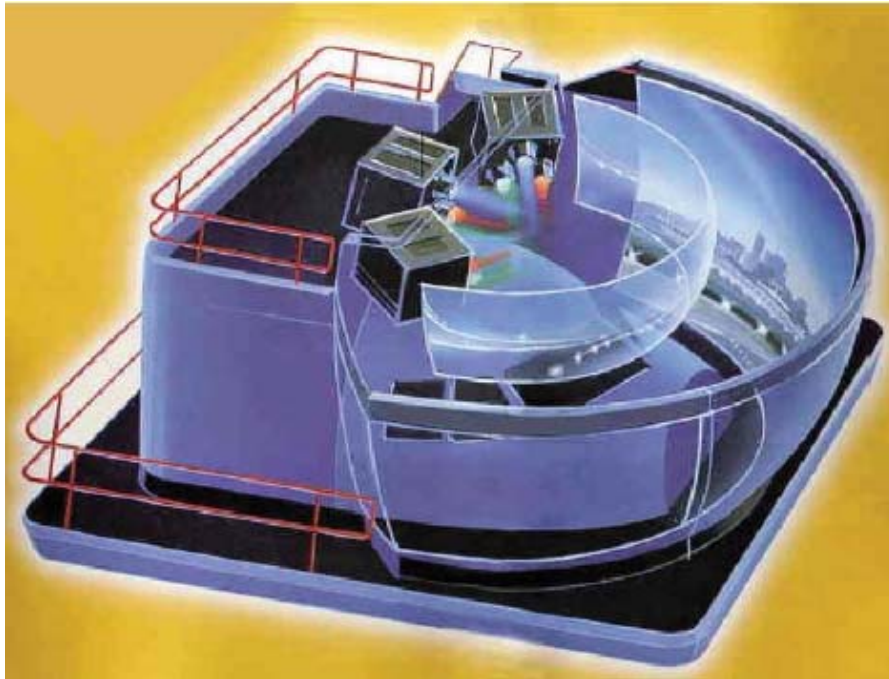


Figure 3. Curved mirror projection system. Source-The impact of flight simulation in aerospace-Royal Aeronautical Society Flight Simulator Group, March 2009.

The modern aircraft is a system platform. Flight simulation offers major advantages in designing and developing aircraft systems to analyse designs and to verify system performance prior to airborne trials.

During the development of aircraft systems, a simulator can provide valuable insight into system behaviour and performance, recording data to verify the design. In addition, a simulator can be used to analyse human factors' issues which are often required in pilot-in-the-loop studies. An engineering flight simulator provides this essential design support and enables designers to monitor system behaviour and the interaction between the pilot and the systems. Large amounts of data can be recorded and analysed to confirm that system fulfils its design specifications and meets its requirements.

A range of engineering flight simulators is used from desktop systems, through to fixed-based simulators. The use of engineering flight simulators achieved significant reductions in cost and design time on the Boeing 777 and Airbus A380 programmes. Aircraft manufacturers also use „iron-bid” rigs, fitted with actual aircraft equipment and systems, to verify the performance of actuators and sub-systems and to support systems integration.

The role of flight testing has changed significantly as a consequence of the capability of engineering flight simulators. It was used previously to verify the airborne performance of aircraft equipment; however, with advances in simulation and modelling, it may be used to verify results obtained from simulation.

Some systems evaluations extend to operational environments, where several aircraft interact with a near-traffic management system or a mission-control system. In these environments, proof-of-concept trials conducted in a flight simulator provide valuable insights into system capabilities and limitations.

During the development of an aircraft or aircraft systems, several different simulations may be undertaken, including aerodynamic modelling, structural analysis, operational analyses and flight control system design. Advances in computer

technology now allow the designer to combine simulation tools and provide visualisation tools to assess system performance.

These concepts, termed „Synthetic Environments” (SEs), may be applied to the whole life cycle of a system or platform from initial concept through design and production to flight test and in-service use. Such end-to-end simulations afford more degrees of freedom for „what-if” studies. Detailed trade-off studies, undertaken prior to the procurement phase of a large project can result in major overall saving and considerable emphasis is now being given to the development of SE tools and methods where manufacturers and procurement agencies work closely together to optimise the capability and cost of large-scale programmes. Simulators can now be interconnected and combined to provide insight from the initial operational requirements, through all phases of development to maintenance and operational deployment. The considerable potential benefits of SEs have become possible only as a result of the advances in flight simulation over the past decade.

INTRODUCTION

The simulator is one of the greatest advances in aviation safety. Simply, they are an identical replica of a cockpit where pilots can train for any emergency that is so real they are often bathed in perspiration.

During World War II, primitive single-place Link trainers were state-of-the-art, while airlines used austere Cockpit Procedure Trainers or CPTs. These were fixed mock-ups with pictures of flight instruments, knobs, and handles to enhance familiarization of flight crews with specific aircraft. The introduction of motion in flight-training simulation occurred in the late 1950s, when images from a black-and-white TV camera racing across a model landscape around an airport were projected onto a screen outside the windshield of a fixed cockpit replicating the controls and flight instruments of a real jet airliner.

By the time the Boeing 747 arrived in 1970, simulators had advanced to having six degrees of motion, but even then, flight crews passed their initial tests in simulators and then acquired final flight qualifications in real aircraft taken out of service for training. For perspective, in the first two years of jetliner operations from 1959, training accidents cost more lives and aircraft than those lost in operational service.

Modern simulators are exact replicas of the cockpits of literally every type of commercial aircraft. Their realism lets you feel the movement of an actual airplane and experience sounds and sensations like the nose wheel clunking into locked position below the cockpit floor after takeoff, or the bump felt on landing as the main gear meets the runway. This ultra-reality, coupled with the advent of the digital glass cockpit allows Zero Flight Time Training (ZFTT) which evolved in the late 1970s. Now, conversion training for pilots transitioning between different aircraft types can be accomplished in the simulator with final flight checks conducted during routine revenue flight operations.

Aircraft manufacturers also benefit from cockpit simulators by ‘flying’ them for hundreds of hours before a new aircraft design ever leaves the ground. This enables designers to rearrange instrumentation or improve informational displays, as well as provide detailed data and analysis of the aircraft’s proposed handling characteristics. Thus, millions of dollars are saved by avoiding costly design errors that might only become apparent after the real aircraft has flown.

Today’s impressive airline safety record is a direct result of advances in flight simulation. In the early 1960s, Boeing estimated a staggering rate of 60 crashes-per-

one million departures. Today, that statistic is only one-per-million departures. Additional safety benefits include routine training for such hazards as tire blow-outs, rejected takeoffs, engine failures and stalls at low altitude, all of which pose serious dangers to crews flying real aircraft. Most importantly, simulators don't disturb airport neighbors with noise or produce any polluting emissions, and they certainly don't burn any fuel!

ORIGINS OF SIMULATION

The importance of training has been recognised since the inception of manned flight. The mythical story of Icarus and Daedalus is usually related to a warning about flying too high because the heat of the sun would melt the glue used to hold together the feathers of the wings - this is probably not a correct interpretation of the warning. The more probable warning was about the danger of flying too high before adequate training and becoming more acquainted with the controls and performance of the flying machine.

The pilots of the first powered aeroplanes learnt by progressing through a graded sequence of exercises on real aircraft. After "passenger flights", the student would attempt rolling (taxi in modern terms) where a low powered machine would be driven along the ground enabling rudder control to be practised. The student would then progress to a higher-powered machine making short hops using elevator control after longer hops eventually achieve flight. A variation of this method known as the "penguin system" using a reduced wingspan landborne aircraft was developed during World War 1. This method was also used at the French Ecole de Combat with a cut down Bleriot monoplane, but was actually considered as early as 1910 with the method suggested in a letter to Flight.

Other early devices attempted to achieve the same effect, especially for testing new aircraft prototypes, by using aircraft supported by balloons, overhead gantries or railway bogies. Related to these ideas were the first proposals for truly ground-based trainers which were in effect aircraft tethered to the ground but capable of responding to aerodynamic forces (Figure 4).

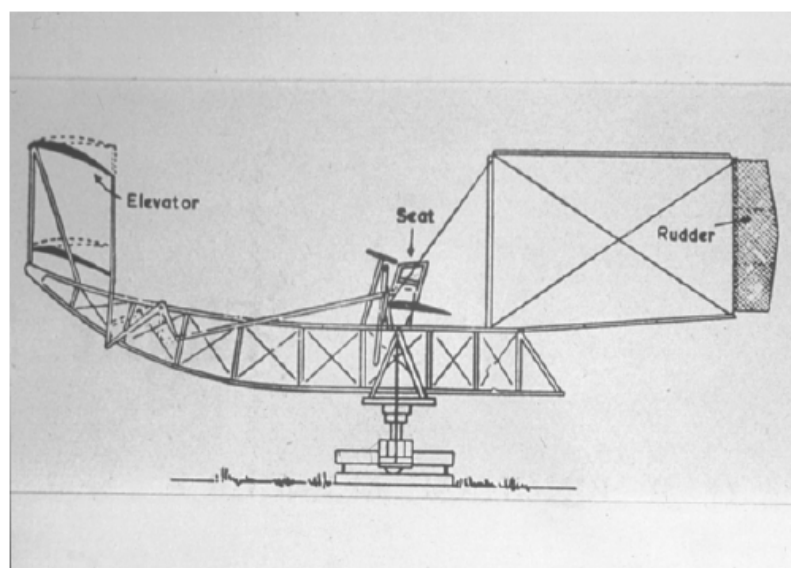


Figure 4. First proposals for truly ground-based trainers. Source- Brief History of Flight Simulation, Ray L. Page, R.L. Page and Associates.

One such device was the Sanders Teacher. Flight in their December Issue of 1910 stated: “The Invention therefore of a device which will enable the novice to obtain a clear conception of the workings of an aeroplane and conditions existent in the air without any risk personally or otherwise is to be welcomed without doubt. Several have already been tested and the Sanders Teacher is the latest to enter the field.”

The Teacher was constructed from actual aircraft components and in reality became an aircraft mounted on a universal joint in an exposed position and facing into the prevailing wind. Other examples of this type of training simulation were those of Eardley Billings which was made available for use at Brooklin Aerodrome as well as the Italian Gabardini “Captive Monoplane” illustrated in the 1910 edition of Janes Aircraft.

Unfortunately as was the case with many of these devices, they proved not to be successful without doubt due to the unreliable and irregular nature of the wind. It is interesting to reflect on this irregular and unreliable nature of the wind which some sixty years later drove the requirement for increased fidelity so that complete crosswind training could be successfully carried out in the modern flight simulator.

Also in this period was one of the first truly synthetic flight training devices as shown from a photograph published in the 1910 Antoinette catalogue (Figure 5).



Figure 5 One of the first truly synthetic flight training devices. Source- Brief History of Flight Simulation, Ray L. Page, R. L. Page and Associates.

This consisted of two half-sections of a barrel, mounted and moved manually so as to represent the pitch and roll of an aircraft. The prospective pilot sat in the top section of this device and was required to line up a reference bar with the horizon.

The need for the training of large numbers of aviators during World War 1 encouraged the development of the new discipline of aviation psychology and tests were introduced for pilot selection. Many devices were invented to aid in the assessment of the aptitude of potential airman. In 1915 such a device was proposed for the measurement of reaction times in correcting disturbances; this was to consist of a rocking fuselage fitted with controls and an electrical recording apparatus with the response of the student being recorded to tilting which was manually produced by the examiner.

The next step in the evolution of the flight trainer was the replacement of the human operators in Antoinette type machines with mechanical or electrical actuators linked

to the trainer controls. The aim of these now automatic devices was to rotate the trainee pilot's fuselage into an attitude corresponding to that of the real aircraft in response to his control inputs. Provision was usually made for an instructor to introduce disturbances in attitude to simulate the effects of rough air and to present control problems to the student.

An example of this technique is the family of devices described by Lender and Heidelberg of France in 1917. One of these consisted of a pivoted dummy fuselage with pitch, roll and yaw motions produced by compressed air motors which introduced, probably for the first time, variations of response and feel with simulated speed. Engine noise and a rudimentary visual presentation were also described. Another version used air flow from an attached propellor to produce tilting of the fuselage in response to balancing flaps and rudder. (This has an obvious similarity to the Sanders Teacher) An electrical version of this type of trainer was patented in the USA in 1929 by Buckley.

The most successful and well-known of this type of trainer was of course the LinkTrainer (Figure 6).

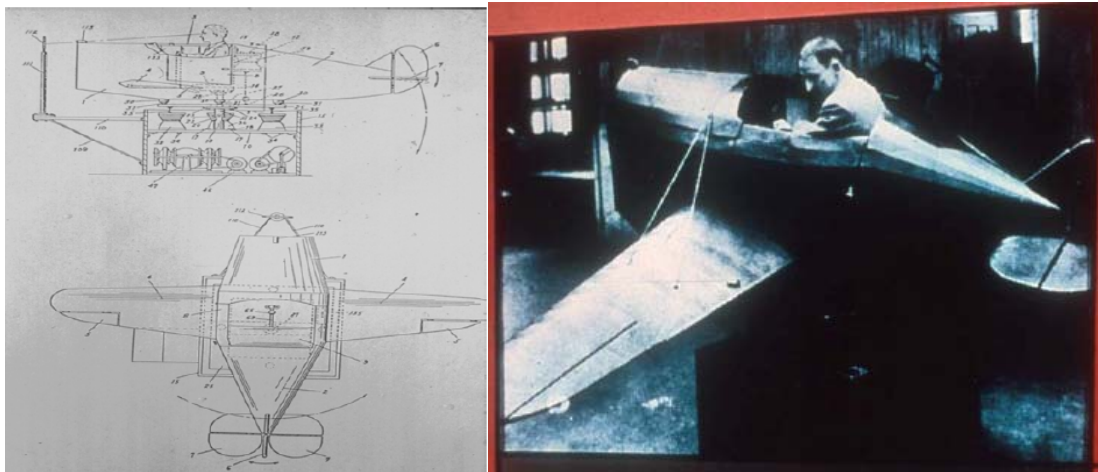


Figure 6. The Link Trainer. Source- Brief History of Flight Simulation, Ray L. Page, R.L. Page and Associates.

Edwin Link gained his early engineering experience with his father's firm the Link Piano and Organ Company of Binghamton New York and in fact Link's first patent was granted for an improvement in the mechanism of player pianos. The Link Trainer was developed in the period 1927-1929 in the basement of the Link factory and made use of the pneumatic mechanisms from the player pianos and organs. The first trainer was patented (9) in 1930 and advertised as "an efficient aeronautical training aid and a novel, profitable amusement device".

An electrically driven suction pump mounted in the fixed base fed the various control valves operated by the stick and rudder, while another motor-driven device produced a repeated sequence of attitude disturbances. In common with other trainers of the time the performance was adjusted by trial and error by the designer until the correct "feel" was obtained.

However despite twenty years of inventiveness, synthetic flight trainers had not caught on and simulation was not seen as a substitute for actual flight and acceptance of simulated flight had to wait for further developments in the science of flying.

SIMULATION FOR INSTRUMENT FLIGHT TRAINING

In the late 1920's a new stream of development began as the need became recognised for effective training of pilots in the skills of "blind" or instrument training (Figure 7).

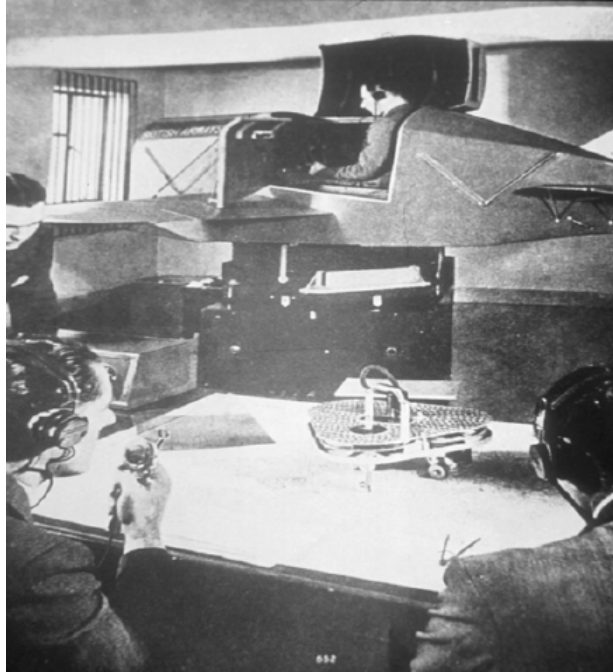


Figure 7. Simulation for Instrument Flight Training. Source- Brief History of Flight Simulation, Ray L. Page, R.L. Page and Associates.

Two approaches were adopted: Firstly the existing moving trainers, such as Links, were fitted with dummy instruments with a means for their activation; Secondly, non-moveable devices were invented specifically for the task of instrument flight training.

Blind flying training was started by the Links at their flying school in the early 1930's and the importance of this type of training was recognised, notably by the US Army Air Corps, and a contract was awarded to carry the mail. This was the start of recognition of simulation for pilot training and the sale of the Link Trainers commenced in earnest.

A further increase in usefulness of the trainers was achieved with the addition of the course plotter, where a self-propelled crab was able to remotely trace the position and track by means of an inked wheel, and communications between pilot and instructor were now made via simulated transmissions which also provided radio beacon signals to the trainer.

The 1930's were indeed the years of the Link Trainer and this device was produced in many versions and sold to many countries such as England, Japan, France, Germany and the USSR. In 1937 American Airlines became the first world airline to purchase a Link Trainer for their Pilot Training.

From the late 1930's onwards, however, the majority of advances in flight simulation technology were based on the application of electrical and electronic methods. Two of the first electrical flight trainers both still based on empirical designs were

Dehmel's Trainer and the Travis "Aerostructor". Dr. R.C. Dehmel, an engineer with the Bell Telephone Laboratories, became involved in the development of synthetic radio signals for a Link Trainer which was a significant development providing a positive simulation of the behaviour of radio navigation aids. The Aerostructor, developed by A.E. Travis also in the USA, was a fixed base electrically operated trainer with a visual system rather than an instrument presentation. The visual system was based on a loop of film and simulated the effects of heading, pitch and roll movement. This trainer was never commercially produced although it was used by the US Navy in a modified form as the "Gunairstructor".

WORLD WAR TWO AND SIMULATOR TRAINING

At the start of the Second World War the need arose for the training of very large numbers of pilots and other skills involved in the operation of various military aircraft with basic pilot instruction being performed in part on Link Trainers both in the USA and Britain.

Developments in aircraft design such as variable pitch propellers, retractable undercarriages and higher speeds made sound training in cockpit drill essential, and the fuselage mock-up was introduced to assist with these procedures. One such device was the Hawarden Trainer made from the centre section of a Spitfire fuselage which enabled training in the procedures of a complete operational flight. The Links too were developed to incorporate the instrument layout and performance of specific aeroplanes such as the U.S. Army-Navy Trainer Model 18.

In 1939 the British requested Link to design a trainer which could be used to improve the celestial navigation capabilities of their crews who were ferrying "surplus" U.S aircraft across the Atlantic. Ed Link together with aerial navigation expert P. Weems designed a massive trainer suitable for use by an entire bomber crew and which needed to be housed in a 15 metre high silo- shaped building. The pilot flew the trainer, while the bomb aimer's station provided the appropriate sight and targets over which the trainer was flying. The navigator was provided with all the radio aids as well as a very elaborate celestial view from which he could take his required astrosightings. The stars, of which an adequate number were collimated, were fixed to a dome which was given movement to correspond to the apparent motion of the stars with time and changes in bomber longitude and latitude.

The first Celestial trainer was delivered in 1941 and while only a few of these devices ended up in England hundreds of these devices were installed and operated in the USA for war time training.

In 1940 Rediffusion (later to become Redifon) built a direction finding trainer for ground operators which simulated the Bellini-Tosi goniometer DF equipment, whereby two stations could take a fix on aircraft transmissions. Redifon produced a number of trainers of which the C100 DF and Navigational Trainer was certainly the most important in the training of air crews in the skills of navigation using ground beacons. These were known as Crew Procedures Trainers and some installations were equipped with sound effects and epidiascopes so that pictures of target areas and other landmarks of importance could be projected in front of the 'planes.'

One of the great technological successes of the war was the part played by the trainer group at the Telecommunications Research Establishment (TRE) in the design of synthetic radar trainers for all the new radars developed during the war years. Many trainers were designed and built for specific training during the war

years usually by adding extra features to the basic link trainer and indeed the need for training and the use of simulation had now been well established and the benefits proven beyond any doubt.

THE ELECTRONIC FLIGHT SIMULATOR

The major advances in electronics during World War Two and the development of analogue computers now made the technology available to solve the flight equations of motion of the aircraft thereby allowing simulation of the response to aerodynamic forces rather than empirical duplication of their effects. Many of the early generation analogue devices actually contained both forms of simulation; however certain devices were indeed true analogues and these were certainly the direct ancestors of the modern flight simulator.

The first known discussion of the computer method of simulation is believed to be that of Roeder in his 1929 German Patent Specification where his outline of the task to treat the general problems of instrument control and free movement in space could well refer to the modern simulator. As an example of his technique, he described the dynamic simulation of an airship height control system using a fluid operated analogue computer; however, no successful training devices are known to have resulted from this work.

With the now proven ability of the flight simulator to provide meaningful training and the technology flowing from the developments of electronics in World War Two, many simulation devices were constructed which would be well beyond the space available to attempt to describe in any detail. Three major manufacturers emerged during this period and must be credited with the development of the flight simulator.

Dr Dehmel from the Bell Laboratories had continued with his interest in simulation and through his work on Bell's M-9 anti-aircraft gun directors, applied this knowledge to the design of an instrument flight trainer and in 1943 was able to convince the Curtiss-Wright Corporation to manufacture these devices. Curtiss-Wright continued their interest after the war and contracted to Pan American Airways to construct a full simulator for the Boeing 377 Stratocruiser (Figure 8) which became the first full aircraft simulator to be owned by an airline.



Figure 8. Full simulator for the Boeing 377 Stratocruiser.

Source- Brief History of Flight Simulation, Ray L. Page, R.L. Page and Associates.

In 1947 BOAC decided to buy Boeing 377 Stratocruisers and knowing of Redifon's work on synthetic trainers, requested a proposal from this company to construct a device similar to that being used by Pan American. This resulted in an agreement being entered into between Redifon and Curtiss-Wright with work commencing in 1950.

These devices used the a.c. carrier method of analogue computation with contoured potentiometers and 400 Hz synchros for aircraft instrument drives. The control loading unit used variable levers, servo controlled as a correctly computed function of airspeed with springs to provide the required forces. This simulator was completed in 1951 at a cost of £120,000. Prior to completion of this simulator, Redifon gained another contract from BOAC for the Comet 1 which was to become the first jet transport simulator to be constructed. A number of airlines throughout the world purchased REDIFON simulators including QANTAS to simulate their L1049 aircraft.

After the war, competition from Curtiss-Wright stimulated Link to develop their own electronic simulators using analogue computation and this was used in their C-11 Jet Trainer for which a contract was awarded by the U.S. Air Force in 1949. Over a thousand of these were produced. Link moved from a.c. to d.c. for the analogue computation which was a far more demanding technology but capable of far greater precision, and in the mid 1950's, Pan American and QANTAS became the first airlines to place into service simulators for the B707 aircraft (Figure 9) which at that time would have then been the world's most sophisticated simulators ever produced.

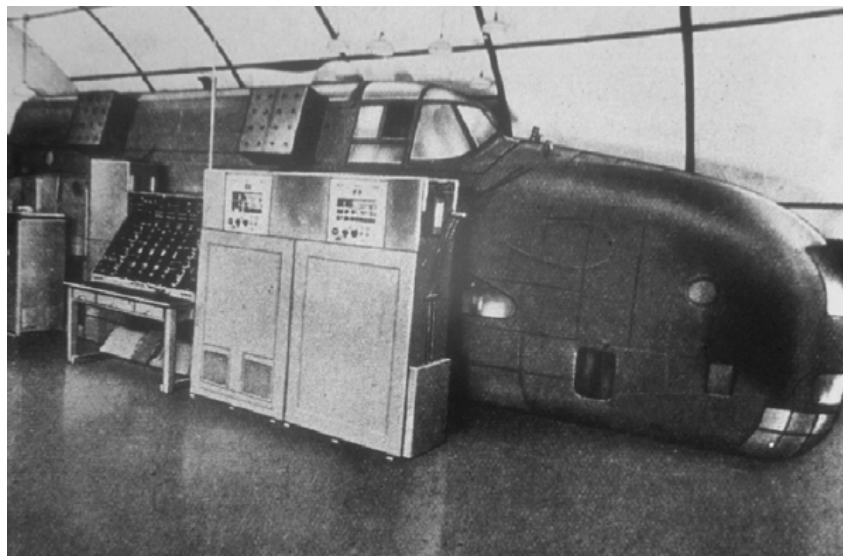


Figure 9. B707 aircraft simulator. Source-
Brief History of Flight Simulation, Ray L. Page, R.L. Page and Associates.

One of the major limitations up to this time had been the lack of accurate performance data for both airframes and engines, and simulator manufacturers were therefore committed to ad-hoc methods to achieve desired performance. This changed with the arrival of the large sub-sonic jet transport aircraft where airframe manufacturers began to produce more complete data and to perform more extensive flight testing and development programmes. Together with requirements for driving motion and visual systems then being introduced, and pressure from operators to improve accuracy and thereby, they hoped, better transfer of training, significant increases in the amount of analogue computer hardware became necessary. At this

point, the law of diminishing returns began to operate and the cumulative errors caused by the additional hardware exceeded the improved accuracy which should have resulted from more extensive aircraft data which demanded the hardware.

DIGITAL SIMULATOR

Even with improved hardware and design, the reliability of the large analogue simulators of the day began to fall and despite continuous efforts by large maintenance teams, reliable utilisation of 10-12 hours a day appeared the maximum achievable. It became obvious that the demands for increased fidelity and reliability could no longer be achieved with the analogue computer.

The general purpose digital computers of the day could not be used for real time flight simulation due to their poor arithmetic and input /output capabilities and it was indeed fortunate that a second generation of digital computers was then being developed which appeared able to satisfy the speed and cost requirements of flight simulation. A research programme was initiated by the University of Pennsylvania in 1950 which resulted in a special purpose device being designed at the University which was named UDOFT (Universal Digital Operational Flight Trainer) which was actually manufactured by the Sylvania Corporation in 1960.

In the early 1960's Link developed their own design for real time simulation - the Mark 1 - which used three parallel processors for arithmetic, function generation and radio station selection. This device also used a drum memory for the programmed instructions to augment the storage capacity (10K) and speed limitations of the core memory available at that time. It was without doubt the most successful breakthrough and these simulators were purchased by most of the world's major airlines and the U.S. Military. There was now a total swing to digital computation by all the manufacturers of the day, however many hybrid devices were also produced which in some cases proved as unreliable as the analogue devices they were replacing.

By the 1970's the general purpose computers had improved to the extent that some of these could be considered for flight simulation and from this time onwards the selection of the computer has been a major issue for each and every simulator manufacturer. It is interesting to note that not all these decisions have resulted in good simulation and many lessons have been learned along the way in terms of resolution and speed and capacity requirements.

MOTION SYSTEMS

Apart from the very rudimentary motion system of the early Link Trainers, simulators produced up to the mid 1950's had no fuselage motion systems. This was often justified by the statement that pilots no longer flew "by the seat of their pants"; however the fact remained that the simulators did not completely feel like the aircraft they simulated. It was found that handling improvements could be introduced by empirical adjustment of the simulator control loading and aircraft dynamics which in part gave some compensation for the lack of motion.

In 1958 Redifon received a contract from BOAC for the production of a pitch motion system as part of the Comet IV simulator (Figure 10).



Figure 10. Comet IV simulator. Source- Brief History of Flight Simulation, Ray L. Page, R.L. Page and Associates.

More complex motion systems followed with two, three, four, five and finally six degrees of freedom which was considered essential to provide the lateral acceleration required for aircraft such as the B747. The need for extended motion cues has always been recognised and many innovative designs have appeared which often required massive structures and hydraulic systems which became a maintenance nightmare and in many cases actually produced incorrect cues.

A great deal of research on motion systems has been carried out by NASA and of course the landing of the Lunar Landing Module presented an unusual challenge and one which had to be trained for with simulation. From their research, NASA produced a set of motion equations which have been used by most of the simulator manufacturers.

The need for the use of motion systems for flight simulation has over the years generated quite some controversy; however, many of the experiments used to argue the case against motion systems have used very early motion systems, which without doubt, provided many false cues and certainly may have even provided some negative training. While it is well understood that motion systems may be ineffective in the simulation of highly maneuverable military fighters, there is little doubt in the view of the training captains from the world airlines and the world regulatory authorities that motion systems are essential for commercial aircraft flight simulation.

VISUAL SYSTEMS

Systems for providing the out of window visual scene have been proposed and constructed since the inception of the flight simulator with some of the early Link Trainers being mounted inside a panoramic display to give the illusion of flying high.

It is well beyond the scope of this paper to even attempt to address the many concepts for visual systems that have been tried over the history of the flight simulator and therefore only some of the more successful ones have been addressed.

The point-light source projection or shadowgraph method enjoyed some popularity in the 1950's, especially for helicopter simulators. A series of simulators using this method of visual display were produced by Giravions Dorand in France and even by Shorts of Belfast in 1955. Simulators using this method were also constructed in the USA, however the shortcomings of the shadowgraph seem to have limited the success of this system. During this period another method of visual presentation was developed by Link using film and an anamorphic optical system known as VAMP which, while producing a good quality picture, was very limited due to the inability to fly outside the area of interest contained on the film strip (Figure 11).



Figure 11. Visual simulator. Source- Brief History of Flight Simulation, Ray L. Page, R.L. Page and Associates.

Development of closed circuit television systems commenced also in the 1950's where the scene was contained on a moving belt and viewed by the camera through an optical probe which allowed for pitch roll and rotation, and which was then projected on a flat screen mounted in front of the flight simulator cockpit. Initially these were monochrome systems and were produced by Curtiss-Wright and Link at the Link Division of General Precision in England (formerly Air Trainers Link Ltd). The first colour system was produced by Redifon in 1962. The belt model was then replaced with a Rigid Model and the camera moved over the terrain which was now capable of containing models of town and country with even lighting for realistic night time simulation. These systems usually operated with a scale factor of 2000:1 and remained in service well into the 1970's.

The first computer image generation (CGI) systems for simulation were produced by the General Electric Company (USA) for the space programme. Early versions of these systems produced a patterned "ground plane" image while later systems were able to generate images of three dimensional objects. Progress in this field was rapid and closely linked to developments in digital computer hardware with a parallel development taking place in night-only computer image generation systems using

calligraphic or stroke writing rather than a raster scan, which enabled a superior reproduction of lightpoints. These systems were initially developed and marketed by McDonnell-Douglas Electronics Corporation with VITAL and Evans & Sutherland / Redifon with NOVOVIEW. Link soon followed with a system developed by its English operation Link Miles known as the IMAGE Visual Systems.

All of these CGI systems were displayed on a picture tube and viewed through a beam splitter from a mirror mounted in front of the display. While the quality of the displays were quite acceptable, there were limits to the size of the scene able to be produced and displays were mounted in juxtaposed locations in an attempt to improve the pilot's field of view (QANTAS, for example, installed a six window, six channel system). The final development, which is still in operation to-day, then moved to a projected picture (though now produced on a curved screen) allowing for continuous viewing in excess of 180 degrees thereby enabling training for a circling approach. In addition, the quality and content of the displayed picture improved to such an extent that route familiarisation was now possible using the flight simulator.

There have been many other developments such as domes and area of interest visual systems, however, these have specific applications and have not been part of the main-stream development for the flight simulator which has provided the credibility for the use of simulation for training.

FLIGHT SIMULATION STANDARDS

The basis for the credibility that the Simulation Industry enjoys today is due to the efforts of a relatively small number of airlines to establish common standards for flight simulation, which led to the granting of training credits by regulatory authorities for use of a flight simulator for the training and licensing of aircrew. Apart from the enormous cost savings so generated, training aircraft accidents were eliminated and today, the task to instill in crew-members the instinctive and correct reaction to failures as well as emergencies, has passed beyond the economic and practical use of the aircraft for training.

In the beginning there were no standards and each simulator manufacturer proposed what they believed was desirable for the airline's training needs and it would be no exaggeration to say that no two simulators from the same manufacturer, representing the same aircraft, felt the same from a pilot handling perspective. This did little for pilot confidence in flight simulation nor did it provide any incentive for regulatory authorities to grant credits for the use of the simulator for training.

Airlines bought flight simulators in good faith finding they then had great difficulty in maintaining some standard or other which had never been defined as most of these devices were accepted based purely on subjective assessment by one or two of the airline's pilots.

In the early 1970's the simulator maintenance organisations of a small number of world airlines joined together to form an association to be known as IAFSTA (International Airline Flight Simulator Technical Association) and several meetings were held. These took the form of very open discussion of the various problems which they were experiencing with both flight simulators and their respective manufacturers. Needless to say some of the simulator manufacturers of the day did not react very well to this public criticism and law suits were threatened. The airlines re-grouped and after further discussion accepted an invitation from IATA (International Air Transport Association) to form a Technical Committee under the umbrella of its organisation and in October 1973 the first meeting of the Flight

Simulator Technical Sub-Committee (FSTSC) was held in Denver USA (Figure 12).

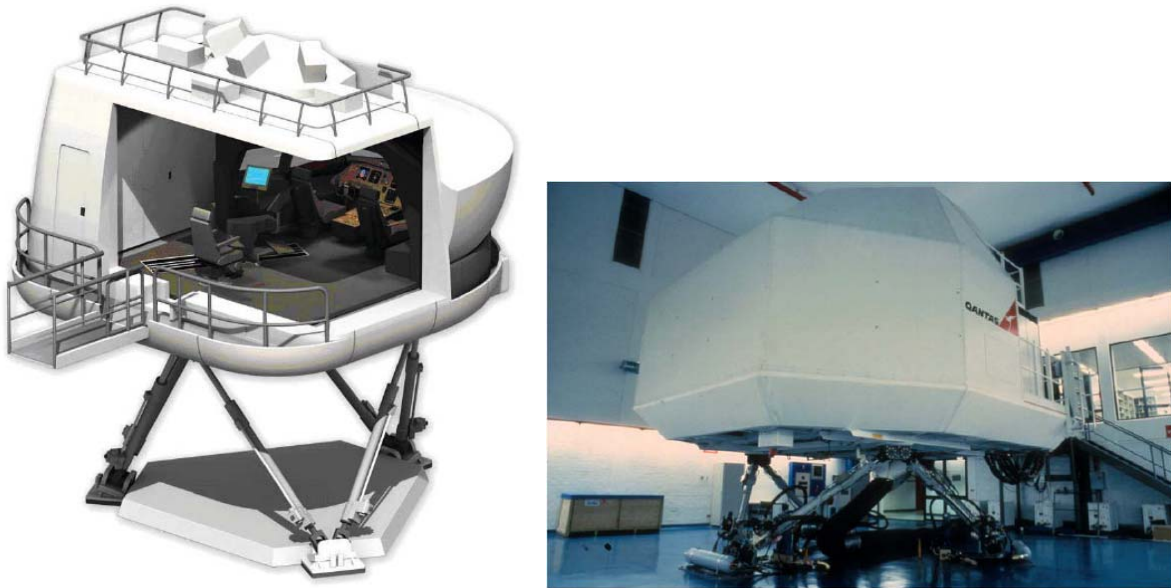


Figure 12. Example of modern simulators. Source: 07.10.2018

The IATA FSTSC now set about the task of developing standards both for simulation as well as data from the airframe and avionics suppliers. Through the power of IATA as well as the forces brought to bear by the individual airlines, simulation moved forward to achieve credibility both with the airline pilots and the regulatory authorities. Another major step by the FSTSC was the drive which led to the approval of ARINC 610 which then mandated the incorporation of simulation functions in aircraft avionics avoiding the problems known as “locks and freezes” which affected these devices when used in the flight simulator. With regard to the regulatory authorities, the FAA must be credited with the foresight with which in the 1970’s it established a programme to encourage the industry for improvements, leading to approval for the landing maneuver and eventually the complete transfer of training and aircrew checking from the aircraft to the flight simulator. International standards have now been agreed for flight simulators and a multi-million dollar simulation industry exists thanks to many individuals over the past seventy years who believed in simulation and especially to Edwin Link who has been called the “Father of Simulation”.

FIDELITY

The key to the value of the advanced simulators is system fidelity. This fidelity does not come cheaply. New simulators for large aircraft can cost \$15 million or more. The new cockpits with the requisite motion and visual performance extremely close the real aircraft in performance, sound, visual presentation and feel.

Fidelity has several definitions. The one most familiar to most people is simply “faithfulness” (Webster’s New World Dictionary), but the Fidelity Working Group developed the one for the DoD Simulator Interoperability Standards Organization (1998). This definition reads as follows: Fidelity. The degree to which a model or simulation reproduces the state and behavior of the real world, or the perception of a real world object, feature, condition, or chosen standard in a measurable or

perceivable manner; a measure of the realism of a model or simulation. Fidelity should generally be described with respect to the measures, standards, or perceptions used in assessing or stating it. See accuracy, precision, resolution, repeatability, model/simulation validation (SISO, 1998).

This definition conveys the message that when we speak of fidelity in relation to safety critical evaluation processes, we must be prepared to validate the stated fidelity in quantifiable and verifiable terms. To use a simulation to “prove” a concept, or to validate the operation of a new avionics system, we must be able to document and validate the supporting simulator in some manner, including the human-aircraft interfaces. The proper way is through the use of objective testing judged against real-world performance data, coupled with a subjective assessment by expert operators, or in this case, experienced professional pilots.

NON-APPROVED SIMULATORS

One of the primary reasons for establishing the advanced simulator approval program was to improve fidelity, improve maintenance programs, and ensure currency with existing aircraft configurations and performance in simulator equipment. Non-approved simulators do not meet the same stringent oversight requirements, so are limited in training credit allowed by the authorities. The fidelity levels achieved and quality maintained varies widely between operators on non-approved equipment. Software programs are often changed considerably from the original loads. Similar problems can occur with cockpit hardware. Not all non-approved simulators suffer from these problems, of course, but it is difficult for an operator to maintain software and hardware configuration control without a formal process in place. Many of the non-approved devices are in use by educational establishments and smaller training centers that find it difficult to justify the cost of maintaining certification status. NASA and some educational institutions, such as Embry-Riddle, have obtained FAA Level C or D approval on newer devices to receive added credits from their use, and to ensure fidelity. The general aviation (G/A) community has also been slower to move into the approved simulator arena. In many cases for G/A training, an actual aircraft can be much cheaper than an advanced simulator. But as costs come down on simulator equipment, the market is expanding. Some operators, such as Flight Safety, have sizable simulator operations for G/A training.

ADVANTAGES AND DISADVANTAGES OF APPROVED SIMULATORS

The most obvious benefit from using the approval process is the documented fidelity, as compared to the actual aircraft, that leads to the additional training credit allowed. System performance is assured within defined limits leading to more consistent results that help considerably with validating equipment performance. There are normally built-in diagnostics that allow one to easily check performance and integrity to ensure continued fidelity.

The approval process has built-in provisions for tracking changes and modifications, and maintaining configuration control. As practiced, this is not as onerous as you might expect. In most cases changes can be evaluated on-line before being permanently installed for use. Most hardware changes are driven by update

programs to the aircraft and do not effect flight performance, so have limited impact on the approval process beyond initial evaluation after installation. Research specific hardware can be installed for use and then removed to return to training status.

The credibility of using approved simulators for top-end man-in-the-loop evaluations cannot be ignored. The time saved in system development, procedural development, training requirements assessment and risk assessment on safety issues is difficult to achieve in any other way.

Disadvantages of the approval process include cost and time requirements. The manpower needed to maintain daily checks and repairs can be considerable. Likewise with spare parts, and in-house technical talent. To justify the overhead of maintaining an approved simulator program, an operator must get maximum utilization from the equipment. There are situations with smaller operators where the burden of the approval process is not needed, nor desired. In most of these cases they buy simulator time from larger operators.

Zero Flight Time Training (ZFTT) refers to the training given on an aircraft type rating course that is carried out entirely in a simulator. This method of training is not available for every pilot; the entry requirements are contained in PART-FCL, SUBPART H, Section 2, especially FCL 730.A, and it is the training organization's responsibility to ensure that only qualified pilots start it.

In order to be eligible to conduct ZFTT, the training organization (TO) concerned will need to comply with the following requirements: 1. It must have a specific approved arrangement with an Operator. 2. It shall ensure that the student pre-requisites are met before starting the course. (see PART-FCL quotes above). 3. The type rating will be restricted to that particular Operator until line flying under supervision has been accomplished. 4. A specific simulator session including a minimum of six additional take-offs and landings shall be conducted according to EU 1178/2011, EU 965/2012. 5. The Flight Simulator(s) must be suitably qualified in accordance with EASA-FSTD and approved (for ZFTT) by their CA and/or the Agency.

Approval for zero flight-time training (ZFTT), as specified in Part-FCL, shall only be given to ATOs that also have the privileges to conduct commercial air transport operations or ATOs having specific arrangements with commercial air transport operators. For an approval to conduct ZFTT, the Operator shall have had at least 90 days of operational experience on the aeroplane type. The "90 days" requirement will not apply, (in the case of ZFTT provided by an ATO having a specific arrangement with an Operator), when the type rating instructor (TRI(A)) involved in the additional take-offs and landings, as required in Part-ORO, has operational experience on the aeroplane type. (ORA.ATO.330 General).

INITIAL APPROVAL: For an initial approval to conduct ZFTT, the operator should have held an air operator's certificate for commercial air transport for at least 1 year. This period may be reduced where the operator and the ATO have experience of type rating training. (AMC1 ORA.ATO.330 General).

Instructors for the ZFTT session must be qualified as a TRI, and those instructors completing the first four take-offs and landings (Aeroplane) of the Line Flying Under Supervision must also be TRI(A) qualified (TRI) with aircraft privileges, or TRI restricted to simulator only, who has received additional training in accordance with AMC1 FCL.930.TRI, (k) and (aa). (TRI FFS/LIFUS)).

ZFTT may be conducted only in EASA-FFS qualified to level CG, C or interim C and FFS qualified to level DG or D. Evidence specifically permitting ZFTT for each FFS will be required.

In the case of aeroplanes, pilots that have been issued a type rating based on a zero

flight-time training (ZFTT) course shall: Commence line flying under supervision not later than 21 days after the completion of the skill test or after appropriate training provided by the operator. The content of such training shall be described in the operations manual; Complete six take-offs and landings in a FSTD not later than 21 days after the completion of the skill test under the supervision of a type rating instructor for aeroplanes (TRI(A)) occupying the other pilot seat. The number of take-offs and landings may be reduced when credits are defined in the data established in accordance with Regulation (EC) No 1702/2003. If these take-offs and landings have not been performed within 21 days, the operator shall provide refresher training. The content of such training shall be described in the operations manual; Conduct the first four take-offs and landings of the LIFUS in the aeroplane under the supervision of a TRI(A) occupying the other pilot seat. The number of take-offs and landings may be reduced when credits are defined in the data established in accordance with Regulation (EC) No 1702/2003.

Advantages of Flight Simulator Training Devices (FSTDs) Flight Simulator Training Devices (FSTDs) are without doubt great tools to significantly improve the training benefits and efficiencies with the various capabilities and specific benefits they bring.

Flight Simulator Training Devices offer various advantages compared to real planes, including:

- Safety
- Extended training scope compared to actual plane
- Special manoeuvres training capability
- 24 hour availability, all weather conditions
- Progressive and pedagogical learning
- High availability (> 96% field proven)
- Cost-effectiveness
- Environmentally-friendly

SAFETY

The first and obvious benefit of using an FSTD for training is the safety of the training operation itself. In the FSTD, the training environment is designed and controlled to avoid any real hazards for the trainees and instructors. In this safe environment a trainee can make mistakes and errors and learn from them, perform and repeat normal and abnormal procedures which may not be considered appropriate or safe when performed in a plane. Whilst the benefits of training in an FSTD are well known, it is important that FSTD training does not replace, but rather complements live flight training.

EMERGENCY AND PROCEDURE TRAINING

In addition to the normal operations and procedures that can be performed in planes, the training program utilising an FSTD offers opportunity to further develop more complex scenarios. For instance, a typical training program approved for the issue of a type rating utilising a plane is not suitable for the training of certain emergency procedures on safety grounds whilst no such restrictions apply to FSTDs. In addition to the procedures outlined in the flight manual, the FSTD can be used to practice various flight regimes such as LTE, Vortex Ring, DVE, dynamic roll-over, etc.

REALISM IN FSTD TRAINING

For safety reasons, when performing an abnormal procedure or a failure in the plane, the malfunction is simulated either by pretending or by reproducing the effect of the malfunction. For some critical scenarios trained on the plane such as engine failure during take-off, the element of surprise is often missing because of safety considerations. This denies the pilot the opportunity to experience failures as they would happen in real life thereby greatly diminishing the diagnostic element of the training exercise. These considerations don't apply when performing this training on an FSTD. This allows the pilot to experience more realistic training which includes a surprise element, the diagnostic process and the ability to learn from errors made in a safe environment. The use of FSTDs offers further benefits to a training organisation, for example:

- No delays due to traffic congestion,
- In flight conditions: VMC /IMC and Day/Night, icing condition, selection as required regardless of the prevailing conditions,
- Recognised high average FSTD serviceability (typically around 96-98%).

ECONOMICAL BENEFITS

There are economic benefits from using FSTDs in training. The savings made when compared with actual flight time can be quite significant for complex planes types in a multi-crew environment. Training in an FSTD is more cost effective. Additionally, whilst training in an FSTD, the plane is available to be used for revenue generating flights.

ENVIRONMENTAL BENEFITS

The environmental benefits of using an FSTD in place of a helicopter include lower emissions, a lower carbon footprint, zero noise pollution and minimal impact on the local area particularly during night time.

CONTROLABILITY, REPRODUCIBILITY, AND STANDARDIZATION

Behavior of virtual traffic, weather conditions, and the flights layout can be manipulated (offline or in real-time) as a function of the training needs or research aims. Purpose-developed scenarios enable trainees to practice a large number of dedicated options per time unit.

EASY OF DATA COLLECTION

Using Flight Simulator Training Devices can measure performance accurately and efficiently. With a real plane, it is far more cumbersome to obtain complete, synchronized, and accurate measurement data. It is a fundamental challenge to get an accurate recording of where a real plane actually is in the world.

POSSIBILITY OF ENCOUNTERING DANGEROUS FLYING CONDITIONS WITHOUT BEING PHYSICALLY AT RISK

Simulators can be used to prepare trainees to handle unpredictable or safety-critical tasks that may be inappropriate to practice during real flight, such as collision avoidance, fire and other malfunctions. Furthermore, simulators make it possible to study hazard perception by exposing pilots to dangerous tasks, which is an ethically challenging endeavor in a real plane. Simulators “offer an opportunity to learn from mistakes in a forgiving environment”.

NOVEL OPPORTUNITY FOR FEEDBACK AND INSTRUCTION

Simulators offer the opportunity for feedback and instruction that is not easily achieved in real planes. For example, it is possible to freeze, reset, or replay a scenario. Feedback and instructions can be delivered in other modalities besides speech, such as visual overlays to highlight critical features in the environment.

DISADVANTAGES OF USING FLIGHT SIMULATOR TRAINING DEVICES

However, simulators have several known disadvantages and challenges, including:

- Limited physical, perceptual, and behavioral fidelity. Low-fidelity simulators may evoke unrealistic flying behavior and therefore produce invalid research outcomes. Simulator fidelity is known to affect user opinion. Participants may become demotivated by a limited-fidelity simulator and prefer a real planes instead (or a more costly high-fidelity simulator for that matter). Interestingly, while safety is often cited as an advantage of using simulation, sometimes this same feature is interpreted as a disadvantage.
- Real danger and the real consequences of actions do not occur in a Flight Simulator Training Devices, giving rise to a false sense of safety, responsibility, or competence. Simply investing resources to increase fidelity is not necessarily a desirable solution, as it adds to the complexity of the device and might hamper experimental control. In some cases, abstractions or deliberate deviations from reality yield valid results.
- Shortage of research demonstrating validity of simulation. A growing body of evidence indicates that Flight Simulator Training Devices measures are predictive for flying performance. However, only a few studies have investigated whether skills learned in a flying simulator transfer to the real flight. However in the field of aviation, studies on the transfer of training are far more common, but critical questions remain unanswered, for example whether a motion base provides added value for the effectiveness of flight training.

OTHER APPROACHES TO SIMULATION

There are a number of approaches to simulation including virtual and constructive simulations of varying degrees of fidelity, realism and complexity. In any constructive simulation you will be dealing with a physical representation of systems components or cockpit layout, possibly using actual aircraft hardware and software. These all have a valid role to play in program development. In fact, many part-task, limited simulation programs targeting specific systems, such as GPS, TCAS and CDTI, are an essential step towards final design and full integration that needs to take place in a full-mission simulator or aircraft.

VIRTUAL SIMULATION

The latest simulation technique is referred to as virtual simulation. A virtual cockpit is a representation of a single device with operational logic and graphical representations of cockpit components and controls. It allows a designer to dynamically interact with functional components and to evaluate, and refine, concepts within a short period of time. These models can then be integrated with other virtual models and functionally integrated prior to actually constructing a hardware-based system.

Virtual simulation has its place in the overall process of program design, but it also has very definite limitations. Through virtual simulation a designer can model, animate, operate and integrate a new system, such as a display, into a virtual cockpit on a computer. The skills required, and the process itself, are extremely complex, but the value of the model is only as good as the designer's input. It is essential that any flight operational evaluation ultimately be based on a pilot-centered design with a qualified pilot at the controls, and operating in a realistic environment. Even if you have a pilot "flying" the virtual model on a computer, it is still not a realistic environment. Virtual simulation is at its most valuable when used in the conceptual design stages, evaluating proposed changes, and for quick looks at "what if" scenarios with clearly defined variables.

It is possible today to link constructive simulators, such as approved pilot training devices, with virtual simulators where the constructive cockpit reflects the current technology or procedure, and the virtual simulator can be set up to reflect proposed design changes. Another use, and one used more often in technical evaluations and risk analysis, is to take actual flight test data from piloted approved simulators or aircraft, install it on a virtual aircraft model and run fast-time simulations for risk assessment or feasibility studies. These virtual aircraft models are very complex, in fact, can be similar to the sophistication of advanced simulator programs, representing specific aircraft models and performance. This enables one to get some of the data needed in spite of the limited availability of simulator and test pilot resources.

The value of virtual modeling for engineering design work and systems integration is without question. The results speak for themselves, but we need to remember that it is essential that we strive to keep the human in the process. Any tool is at its most valuable when used properly.

CONCLUSION

Flight simulation is a fast advancing set of technologies in a fast expanding area of aviation. As the cost of computers falls and their capabilities grow, the scope and application of flight simulation are also likely to expand at a dramatic rate. Significant technical advances will result in improvements in the quality of flight simulation systems.

To date, the acceptance of a culture of simulation applies to companies and organisations that have been using simulation across a range of applications in procurement, design, development and training. More organisations are starting to appreciate the benefits and, over the next ten years, flight simulation and flight training will play a major role in aerospace, possibly more significant than earlier developments in aerodynamics, propulsion and structures.

With the realisation of their potential benefits, synthetic training devices will become pervasive in many industries. Engineers have used computer-aided design tools for many years and in many areas the simulator will become an extension of these design tools. Simulation will become accepted as an effective method of system evaluation for designers, engineers and in the procurement of equipment.

The widespread use of simulation in airline training is now being extended to „ab initio” pilot training. A recent ICAO initiative, the Multi-Crew Pilot License (MPL), is likely to revolutionise the training of airline pilots, offering an alternative to the Air Transport Pilot License, where the MPL curricula will make extensive use of flight simulators.

Many of the technologies developed originally for flight simulation have been adopted in other industries and applied to a wide range of applications, such as the training of drivers of trams, cars, lorries, buses and armoured vehicles and ships' bridge and submarine crews. Similar developments are likely to extend to medical training, maintenance engineering and mission rehearsal for emergency services.

Companies that previously developed custom equipment to obtain a leading-edge product will rely more heavily on commercial off-the-shelf (COTS) and PC-based equipment developed for commercial markets where the benefits of customised equipment are far outweighed by the relatively low development costs associated with COTS systems. In particular, real-time simulation is well matched to a distributed architecture of processors connected to a high-speed local area network. COTS network cards supporting transfer rates in excess of 100 million bits per second are commonplace, providing the capability to add additional processors to increase overall performance.

Electrical drive systems have recently started to replace the hydraulic systems which simulate the forces felt by a pilot as the flight controls and engine levers are moved. The use of electrical drive system also extends to motion of the platform, where the previous hydraulic systems have been replaced with electrical motors, each controlled by a power amplifier to provide the accelerations to replicate the motion cues perceived by the pilot. These advances afford significant energy saving, where a small electrical motor for each actuator, combine with a mass compensation scheme (typically to support 10-12 tonnes) can reduce costs by as much as 80%.

With the rapid developments in light valve projection, LCoS (Liquid Crystal on Silicon) projectors offer a major improvement in image quality, in comparison with the traditional CRT (cathode ray tube) projection systems. In the past few years, advances in LCoS projection techniques have overcome the problems associated with

poor black levels, image lurring in dynamic scenes and a poor range of pixel visibility. In particular, LCoS projectors suport high contrast lights. With a substantial reduction in the cost of acquisition and maintenance combined with improved reliability and a redudation in power cosumption of the order of 75%, LCoS projection will become adopted throughout the simulation industry over the next ten years.

The computing requirements of flight simulation are becoming closely aligned with domestic markets, icludig computer games and virtual reality. Advances in terms of image quality of computer graphics, speed of processing and memory storage will fuel future developments in flight simulation.

With reducing costs of symulator hardware, univeristy departments have started to purchase or develop low-fidelity flight simulators to suport teaching on undergraduate and postgraduate courses (Figure 13).



Figure 13. A University flight simulator. Source-The impact of flight simulation in aerospace-Royal Aeronautical Society Flight Simulator Group, March 2009.

Flight simulation needs to be recognised as an established but still evolving scientific discipline, taught in universities and with an established track record of research, to provide the answers needed for the next generation of engineers and flight crew.

ACRONYMS

Acceptable Means of Compliance; ATO Approved Training Organisation; ATPL Airline Transport Pilot Licence; CPL Commercial Pilot Licence; EASA European Aviation Safety Agency; EHEST European Helicopter Safety Team; FAA Federal Aviation Administration; FFS Full Flight Simulator; FNPT Flight and Navigation Procedures Trainer; FSTD Flight Simulation Training Device; FTD Flight Training Device; GM Guidance Materials; IMC Instrument Meteorological Conditions; IR Instrument Rating; LC Line Check; MCC Multi-Crew Cooperation; MET Multi Engine Turbine; MPH Multi Pilot Helicopter; NAA National Aviation Authority; OEB Operational Evaluation Board; OPC Operator Proficiency Check; PC Proficiency Check; PPL Private Pilot Licence; SEP Single Engine Piston; SET Single Engine Turbine; SPH Single-Pilot Helicopter; SRM Single (Pilot) Resource Management; TCAS Traffic Collision and Avoidance System; VMC Visual Meteorological Conditions.

REFERENCES

- Adorian, P., British Patent 572,508 filed 1940. P. Adorian, and R. P. Gabriel, British Patent 572,570 filed 1940.
- Adorian, P., W.N. Staynes, and M. Bolton. The Evolution of Flight Simulators. Presented at the Royal Aeronautical Society Conference 23-25 April 1979.
- Barr, Alphonso J., 1998. Analysis of All Weather Approach and Landing Visual Aids. Lighting Symposium, Arizona State University, Mesa, AZ, April 15-18, 1998.
- Benson, A. J. (1978). Spatial disorientation and spatial disorientation in flight. In G. Dehnin, G.R. Sharp, & J Ernsting (Eds.). Aviation Medicine (Vol. 1, pp. 405-467). London: Tri-Med. Books.
- Billings, C. E. (1991). Human-centered aircraft automation: A concept and guidelines (NASA Technical Memo. 103885). Moffett Field, CA: NASA-Ames Research Center.
- Billings, C. E. (1996). Human-centered aviation automation: Principles and guidelines, (NASA Technical Memo. 110381). Moffett Field, CA: NASA-Ames Research Center.
- Billings, C. E. and Reynard, W. D. (1984). Human factors in aircraft accidents: Results of a 7-year study. Aviation, Space, and Environmental Medicine, 960-965.



El Hindenburg en pleno vuelo

Bransford, J. D. and Johnson, M. K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal behavior*, 11, 717-726.

Buckley, J.P. U.S. Patent 1,865,828 Filed 1929.

Burki-Cohen, Judith, Soja, Nancy N., and Longridge, Thomas, (1997). *Simulator Platform Motion - The Need Revisited*. Department of Transportation, Volpe National Transportation Systems Center, Cambridge, MA, May 5, 1997.

Byrnes, R.E. and Black, P. (1993). Developing and implementing CRM programs: The Delta experience. In E. L. Weiner, B. G. Kanki, and R. L. Helmreich (Eds.), *Cockpit resource management* (pp. 421-443). San Diego, CA: Academic Press.

Characterizing the hazard of a wake vortex encounter. AIAA 97-0055, 35th Aerospace Sciences Meeting and Exhibit, Reno NV, January 6-10, 1997.

Cox, William J., (1993). Simulation of HUD evaluation of situation vs. command guidance symbology in hybrid landing system applications. SAE, G-10 HUD Subcommittee Report, July 31, 1993.

Curran, J. A. (1992). *Trends in advanced avionics*. Ames: Iowa State University Press.

Cutler, A. E. Environmental Realism in Flight Simulators. *The Radio and Electronic Engineer*, January 1966, pp. 1-12.

Dillard, Archie E., and Eberle, William R., (1991). Wake vortex program for crossing encounters at La Guardia airport. *International Wake Vortex Symposium*, Washington, DC, October 29-31, 1991.

Drummer, G.W.A. Aids to Training - The Design of Radar Synthetic Training Devices for the RAAF. *IEE Journal*, Vol 96, Pt. III March 1949, pp. 101-116.

Dunham, Earl R., Stuever, Robert A., and Vicroy, Dan D., (1993). The challenges of simulating wake vortex encounters and assessing separation criteria. AIAA 93-3568, AIAA Flight Simulation and Technologies Conference, Monterey, CA, August 9-11, 1993.

Dunn, W.H., C. Eldert, and P.V. Levonian. A Digital Computer for use in an Operational Flight Trainer. *IRE Transactions on Electronic Computers*, June 1955, pp. 55-63.

Durding, B. M., Becker, C. A., and Gould, J. D. (1977). Data Organization. *Human Factors*, 19, 1-14.

Eberle, William R., McCutcheon, William A., and Shrider, Ken R., (1988). *Wake Turbulence Investigation at New York's La Guardia Airport, Final Report*.

Lockheed Missiles and Space, Report LMSC-HEC TR F225747-B, April 30, 1988.

Eberle, William, (1991). Pilot response to wake turbulence encounters at New York's La Guardia Airport. Final report, Lockheed Missiles and Space Company Technical Paper LMSC HSV TR P038105, September 13, 1993.

Eberle, William, and Dillard, A. E., (1991). Simulation of Wake Vortex Encounters at LaGuardia Airport. Presented at the International Wake Vortex Symposium, Washington, D.C. October 29-30, 1991.

Edward, E. (1972). Man and machine: Systems for safety. In Proceedings of British Airline Pilots Association Technical Symposium (pp. 21-36). London: British Airline Pilots Association.

Edwards, E. (1979). Flight-deck alarm systems. *Aircraft Engineering*, 51 (2), 11-14.

Edwards, E. (1975). Stress and the Airline Pilot. Paper presented at British Airline Pilots Association Medical Symposium, London.

Endsley, Mica R., Farley, Todd C., Jones, William M., Midkiff, Alan H., and Hansman, R. John, (1998). Situational awareness information requirements for commercial airline pilots.

Fitts, P. M. (1951). Human engineering for an effective air navigation and traffic control system. Washington, DC: National Research Council.

Fuchs, A. (1962). The progression/regression hypothesis in perceptual motor skill learning. *Journal of Experimental Psychology*, 63, 177-192.

Goettl, B. P. (1985). The interfering effects of processing code on visual memory. Proceedings of the 29th Annual Meeting of the Human Factors Society. Santa Monica, CA: Human Factors Society.

Golaszewski R. (1991). General aviation safety studies: Preliminary analysis of pilot proficiency. Chevy Chase, MD: Abacus Technology Corp.

Greaber, R.C., (1986). Sleep and wakefulness in international aircrews. *Aviation, Space, and Environmental Medicine*, 57, (12 suppl.), B1-B64.

Hallock, J.N., and Burnham, D.C., (1997). Decay characteristics of wake vortices from jet transport aircraft. AIAA 97-0060, Proceedings of 35th Aerospace Sciences Meeting and Exhibit, Reno, NV, January 6-10, 1997.

Haward, D.M. The Sanders Teacher. *Flight Vol 2 No. 50* December 10, 1910 pp 1006-1007.

Hellings, G. and E.T. Emms. A Visual System for Flight Simulators. *British Communications and Electronics Vol 7 No. 5* May 1960 pp. 334-337.

Helmreich, R. L. (1982). Pilot selection and training. Paper presented at the Meeting of the American Psychological Association, Washington, DC.

Helmreich, R. L. and Wilhelm, J. A. (1989). When training boomerangs: Negative outcomes associated with cockpit resource management programs. Proceedings of the Fifth Symposium on Aviation Psychology. Columbus, OH: Ohio State University.

Hollister, K.M., Rhoades, A.S., and Lind, A.T., (1998). Airbus 320 performance during ATC directed breakouts on final approach, Project report ATC-265. Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA, November 20, 1998.

Hollnagel, E. (1993). Reliability of cognition: Foundations of human reliability analysis. London: Academic Press.

Jordan, N. (1963). Allocations of functions between man and machine in

- automated systems. *Journal of Applied Psychology*, 47(3), 161-165.
- Kelley, B. D., Greaber, R. C. and Fadden, D. M. (1992). Applying crew-centered concepts to flight deck technology: The Boeing 777. Paper presented at the Flight Safety Foundation 45th International Air Safety Seminar, Long Beach, CA.
- Kelly, L.L. *The Pilot Maker*. (Grosset & Dunlap, 1970, New York).
- Khatwa, Ratan and Helmreich, R. L. (1999). Analysis of Critical Factors During Approach and Landing in Accidents and Normal Flight. Flight Safety Foundation Task Force Report.
- Khatwa, Ratan, and Helmreich, (Eds.), (1998). Analysis of critical factors during approach and landing in accidents and normal flight. Final report. Flight Safety Foundation, Flight Safety Digest, November 1998.
- Kraft, C. L. (1978). A psychological contribution to air safety: Simulation studies of visual illusions in night visual approaches. In H.A. Pick, H. W. Liebowitz, J. E. Singer, A. Schneider, & H. W. Stevenson (Eds.). *Psychology: From research to practice*. New York: Plenum Press.
- Lender, M. and P. Heidelberg, British Patent 127,820 (First Filed 1917), British Patent 158,522 (First Filed 1917).
- Link, E.A. Jnr U.S. Patent 1,825,462 Filed 1930.
- Lyman, E. G. and Orlady, H. W. (1980). Fatigue and associated performance decrements in air transport operations (NASA Contract NAS2-10060). Mountain View, CA: Battelle Memorial Laboratories, Aviation Safety Reporting System.
- Maisel, A.Q. They Bombed Berlin in Binghamton. *Reader's Digest* April 1944, pp. 45-46.
- McCann, Robert S., and Foyle, David C., (1994). Superimposed Symbology: Attentional Problems and Design Solutions, SAE, Technical Paper 942111, October 3, 1994.
- McRuer, D. T., and Krendal, E. S. (1974). Mathematical models of human pilot behavior (AGARDograph No. 188). North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development.
- Miller, C. O. (1954). Applying lessons learned in accident investigations to design through a systems safety concept. Paper presented at the Flight Safety Foundation seminar, Santa Fe, NM.
- Miller, C. O. (1965). Safety and semantics. *Alumni Review*. Los Angeles: University of Southern California, Aerospace Division.
- Miller, C.O., (1988). U. S. civil aviation and system safety. In *Proceedings of the 7th International System Safety Conference*, San Jose, CA. MIT/ICAT, Document Number 98-1, Cambridge, Ma, September 1998.
- Nagel, D. C. (1986). Human Error in Aviation Operations. In *Human Factors in Aviation*, E. L.
- Notes on History of RAAF Training 1939-44 Air Ministry, Air Member for Training (Public Record Office Reference AIR 20/1347).
- Rasmussen, J. (1986). *Information processing and human-machine interaction*. Amsterdam: Elsevier North-Holland.
- Reid, D.D. (1979). The historical background to wartime research in psychology in the Royal Air Force. In E. J. Dearnaley & P.B. Warr (Eds.). *Aircrew stress in wartime operations* (pp. 1-8). London: Academic Press.
- Reimer, Heidi M. and Vicroy, Dan D., (1996). A preliminary study of a wake vortex encounter hazard boundary for a B737-100 airplane. NASA Technical Memorandum 110223, April 1996.

- Ringham, G.B. and A.E. Cutler. Flight Simulators. The Journal of the Royal Aeronautical Society Vol 58, No. 519, March 1954, pp. 153-172.
- Roeder, H.A. German Patent 568,731.
- Rossow, V.J., Fong, R.K., Wright, M.S., and Bisbee, L.S., (1995). Vortex Wakes of Two Transports Measured in 80 X 120 foot Wind Tunnel. AIAA 13th Applied Aerodynamics Conference, San Diego, CA, June 19-22, 1995.
- Rouse, W. B. and Rouse, S. H. (1984). Analysis and classification of human error. IEEE Transactions on Systems, Man, and Cybernetics, SMC-13, 539-549.
- Rouse, W. B. (1980). System engineering models of human-machine interaction. Amsterdam: Elsevier North-Holland.
- Sammends, Robert I., Stinnett, Glen W., and Larsen, William, E., (1976). Wake vortex encounter hazard criteria for two aircraft classes. FAA-RD-75-206 and NASA TM X-73, 113.
- Sekuler, R. and Blake, R. (1985). Perception. New York: Wiley.
- Senders, J. W. (1966). A reanalysis of the pilot eye-movement data. IEEE Transactions on Human Factors in Electromics, HFE-7, 103-106.
- Spooner, A.M. Collimated Displays for Flight Simulation. Optical Engineering, May June 1976, Vol. 15, No 3, pp. 215-219.
- Statler, I. C. (1984). Military pilot ergonomics. Proceedings, AGARD Aerospace Medical Panel Symposium on Human Factors Considerations in High Performance Aircraft (pp. 13-23).
- Stewart, C. B. (1965). Address before the graduating class. University of Southern California, Aerosp. Journal of Verbal Learning and Verbal behavior, 11, 717-726.
- Stewart, Eric C., (1998). A piloted simulation study of wake turbulence on final approach. AIAA Atmospheric Flight Mechanics Conference and Exhibit, Boston, MA, August 10-12, 1998.
- Symonds, C.P. and Williams, D.J. (1943). Clinical and statistical study of neurosis precipitated by flying duties (FPRC Report 547). London: Medical Research Council.
- Turner, L.W.F., Teaching Flying. Flight, Vol. 5, No 12, 22 March 1913, pp. 326-328.
- Vicroy, Dan D. and Nguyen, Truc, (1993). A Numerical Simulation Study to Develop an Acceptable Wake Encounter Boundary for a B737-100 Airplane. AIAA-96-3372-CP.
- Wiener, E. L. and Curry, R. E. (1980). Flight-deck automation: Promises and problems. Ergonomics, 23, 995-1011.
- Wiener, E. L. (1985). Human factors of cockpit automation: A field study of flight crew transition (NASA Contractor Rep. No. 177333). Moffett Field, CA: NASA-Ames Research center.
- Wiener, E. L. (1989). Human Factors of advanced Technology (glass cockpit) transport aircraft (NASA Contractor Rep. No. 177528). Moffett Field, CA: NASA-Ames Research Center.
- Wiener, E. L. (1993). Intervention strategies for the management of human error (NASA Contractor Rep. No. 4547). Moffett Field, CA: NASA-Ames Research Center.
- Wiener, N, (1948). Cybernetics. New York: Wiley.
- Wierzbicki, A. P. (1982). A mathematical basis for satisfying decision making. Mathematical Modeling, 2, 391-405.

Williams, Kevin W., (Ed), (1994). Proceedings of the joint industry-FAA conference on the development and use of PC based aviation training devices. Final report, Document number DOT/FAA/AM-94/25, Federal Aviation Administration, Civil Aeromedical Institute, OKC, OK, November, 1994.

Williamsburg, VA.: North Atlantic Treaty Organization.

Winslow, Carrol Dana. With the French Flying Corps. (Constable & Company Ltd., London).

Woods, D. D. (1996). Decomposing automation: Apparent simplicity, real complexity. In R. Parasuraman and M. Moulous (Eds.), *Automation and human performance: Theory and application* (pp. 3-18). Mahwah, NJ: Lawrence Erlbaum associates.

Woodson, W. E., Tillman, B., and Tillman, P. (1992). *Human Factors Design Handbook*, (2nd. Ed.). New York: McGraw-Hill, Inc.

Yates, R.J. *Management Problems With Simulators*. International Simulation Conference. Los Angeles March 1963.

Yeh, Y. Y., and Wickens, C. D. (1984). The dissociation of subjective measures of mental workload and performance (Final report EPL-84-2/NASA-84-2). Champaign, IL: University of Illinois, Department of Psychology, Engineering-Psychology Laboratory.

<i>Recibido el 30 de julio de 2018. Aceptado el 30 de diciembre de 2018</i>
