

Brief History of Flight Simulation

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ABSTRACT: *Simulation today is a multi-million dollar industry and its application has spread to a vast number of training and analytical requirements. Many of those now involved with this industry have little concept of its origins and the efforts involved to gain recognition and credibility for simulation as a training tool. The use of Simulation for training now dates back over seventy years and as we now enter a new century, it seems appropriate to take a brief look at the history of this Industry.*

The origins of the Simulation Industry were generated from the use of flight training devices. This paper briefly outlines the evolution of the flight simulator and the efforts involved to gain recognition for its use, the establishment of standards and the constant demands of matching ever increasing technology.

Without doubt the technology available for the simulation task to day and for the future is unbelievable by comparison to that of the past seventy years; however many of the problems such as data, parts and standards which have plagued this industry from its inception, are still evident today. Perhaps, therefore, as we enter this new century, it is appropriate to reflect on our history, so that organisations such as the SIAA can carry on the tradition.

1. Introduction

This presentation is based on a simulation industry that grew from commercial aviation and the space programmes and while the use of simulation for military applications generated many developments, the role of the flight simulator has only really gained acceptance for military training in many countries during this last decade. By comparison, the use of the Flight Simulator became an integral part of all commercial airline operations in the 1960's, and for both safety and training effectiveness, it became no longer practical to train in the actual aircraft. With the space programmes it is of course well recognised that it would not have been possible for man to have set foot on the moon without the training provided by simulation, and the use of simulation to assist the problems with the Apollo 13 Mission is now legendary.

The basis of this presentation relating to early flight training devices ⁽¹⁾ comes from an historic event which took place in April 1979 when the Royal Aeronautical Society and The American Institute for Aeronautics and Astronautics hosted a conference in London to commemorate fifty years of simulation from the date Edwin Link made a patent application for his pilot trainer. The guest of honour for this conference was Edwin Link, and the significance of the event was marked by the presence of His Royal Highness, the Duke of Edinburgh at a number of the conference sessions and social events.

The role of the company which Edwin Link founded must be credited with much of the major development and progress of simulation and the short video shown with this presentation was produced by LINK to commemorate their role in the first fifty years of simulation.

2. Origins of Simulation

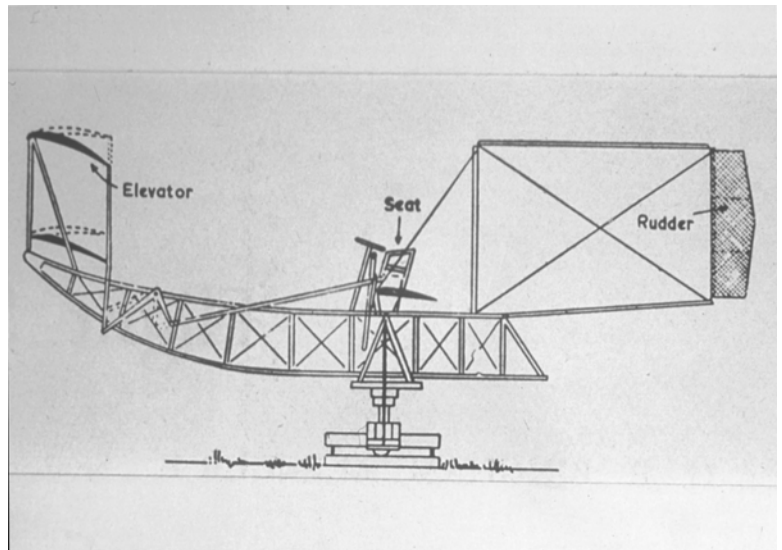
The importance of training has been recognised since the inception of manned flight. The mythical story of Icarus and Daedalus is usually related to a warning about flying too high because the heat of the sun would melt the glue used to hold together the feathers of the wings - this is probably not a 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 ⁽²⁾. 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 ⁽³⁾ 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 ⁽⁴⁾. 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. One such device was the Sanders Teacher ⁽⁵⁾. 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. 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.

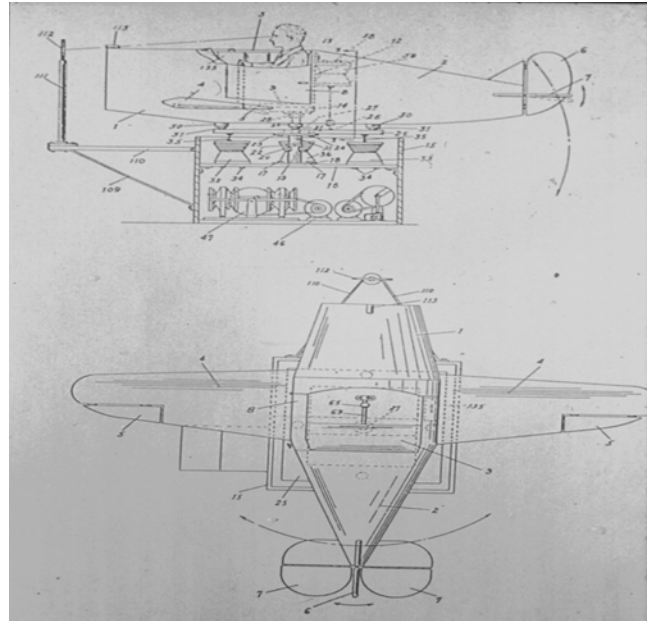


The need for the training of large numbers of aviators during World War 1 encouraged the development of the new discipline of aviation psychology and tests were introduced for pilot selection. Many devices were invented to aid in the assessment of the aptitude of potential airman. In 1915 such a device 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⁽⁶⁾ 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⁽⁷⁾.

The most successful and well-known of this type of trainer was of course the Link Trainer⁽⁸⁾. 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.

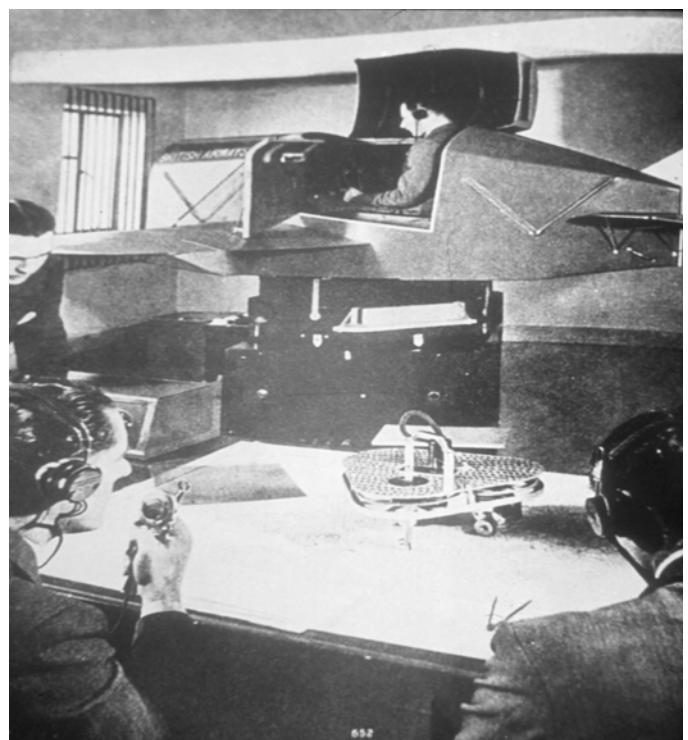
However despite twenty years of inventiveness, synthetic flight trainers had not caught on and simulation was not seen as a substitute for actual flight and acceptance of simulated flight had to wait for further developments in the science of flying.

3. 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. Two approaches were adopted:

Firstly the existing moving trainers, such as Links, were fitted with dummy instruments with a means for their activation, and 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

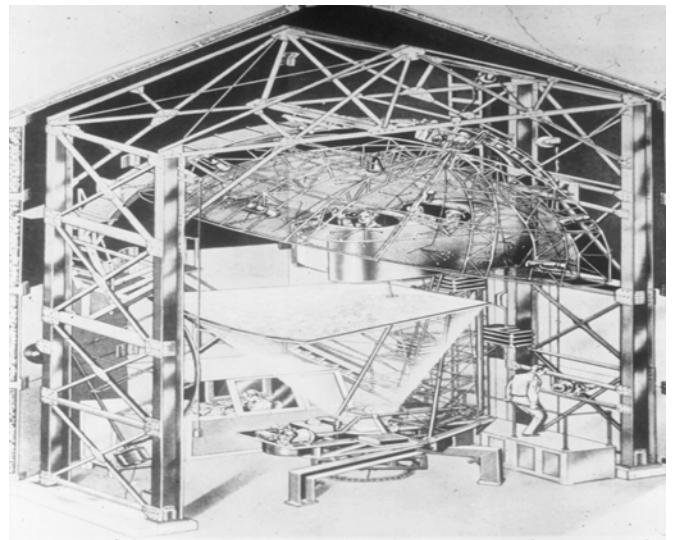
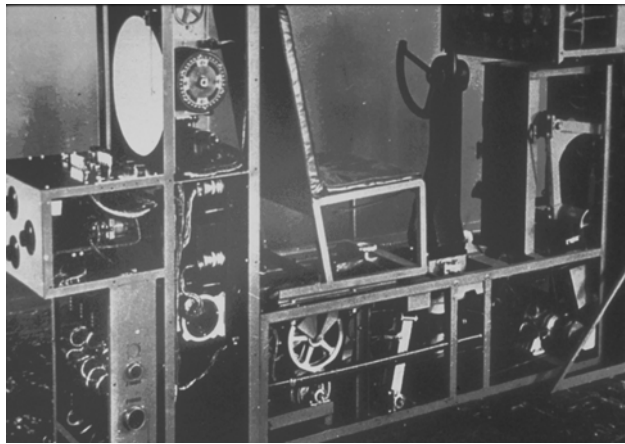


the mail. This was the start of recognition of simulation for pilot training and the sale of the Link Trainers commenced in earnest.

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".



4. World War Two and Simulator Training

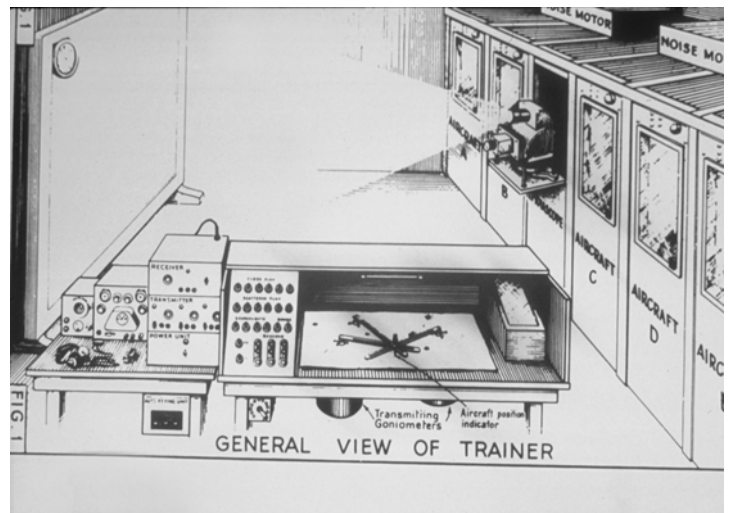
At the start of the Second World War the need arose for the training of very large numbers of pilots and other skills involved in the operation of various military aircraft with basic pilot instruction being performed in part on Link Trainers both in the USA and Britain⁽¹⁰⁾.

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 ⁽¹¹⁾.

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 ⁽¹²⁾ 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 ⁽¹³⁾ 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.

5. 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.

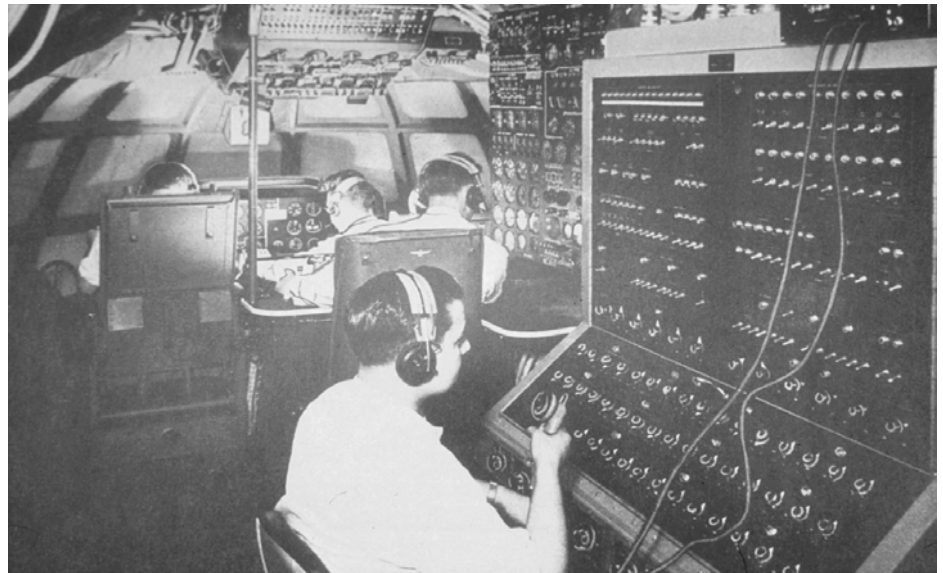


The first known discussion of the computer method of simulation is believed to be that of Roeder in his 1929 German Patent Specification ⁽¹⁴⁾ where his outline of the task to treat the general problems of instrument control and free movement in space could well refer to the modern simulator. As an example 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 which became the first full aircraft simulator to be owned by an airline.

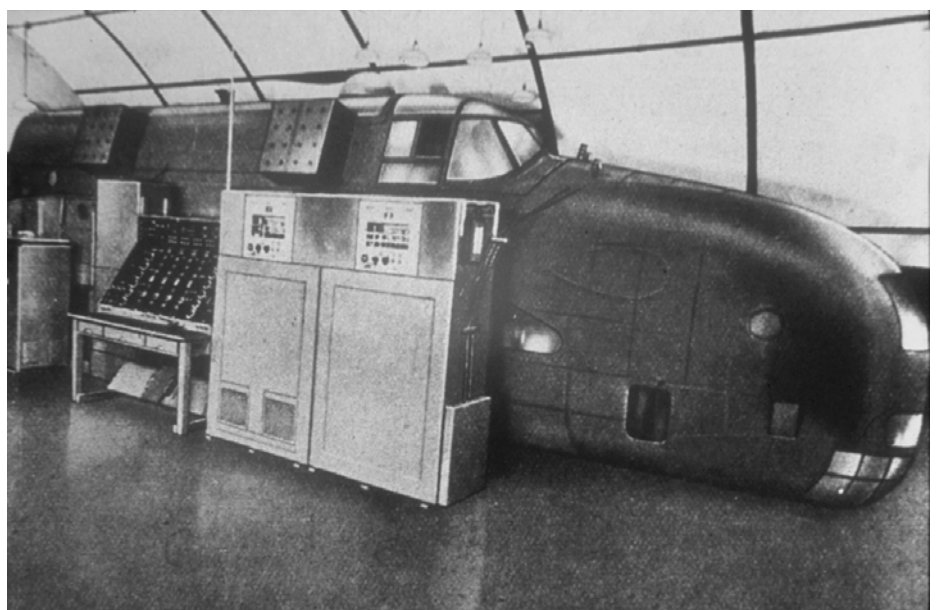
In 1947 BOAC decided to buy Boeing 377 Stratocruisers and knowing of Redifon's work on synthetic trainers, requested a proposal from this company to construct a device similar to that being used by Pan American. This resulted in an agreement being entered into between Redifon and Curtiss-Wright with 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 which at that time would have then been the world's most sophisticated simulators ever produced.

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.

6. The 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)⁽¹⁵⁾ 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.



7. 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⁽¹⁶⁾.

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

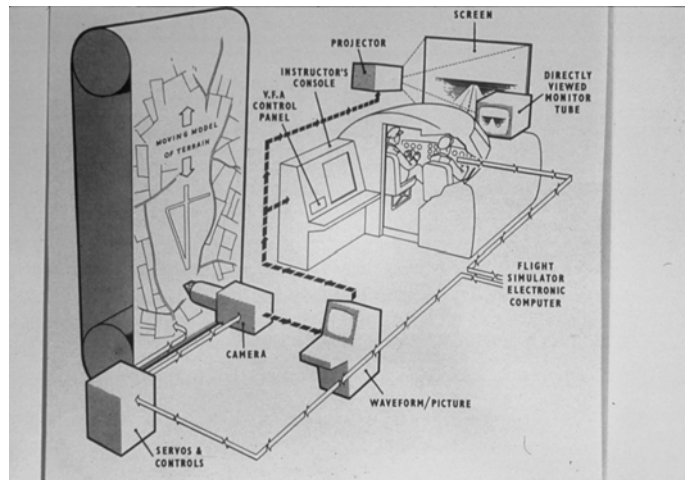
The need for the use of motion systems for flight simulation has over the years generated quite some controversy; however, many of the experiments used to argue the case against motion systems have used very early motion systems, which without doubt, provided many false cues and certainly may have even 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.

8. 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.

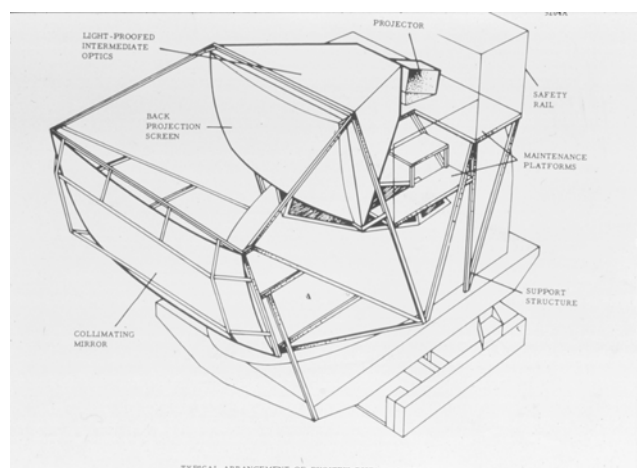
It is well beyond the scope of this paper to even attempt to address the many concepts for visual systems that have been tried over the history of the flight simulator and therefore only some of the more successful ones have been addressed.

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.



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) ⁽¹⁷⁾. 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 NOVOWIEW. 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 ⁽¹⁸⁾. 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.

9. Flight Simulation Standards

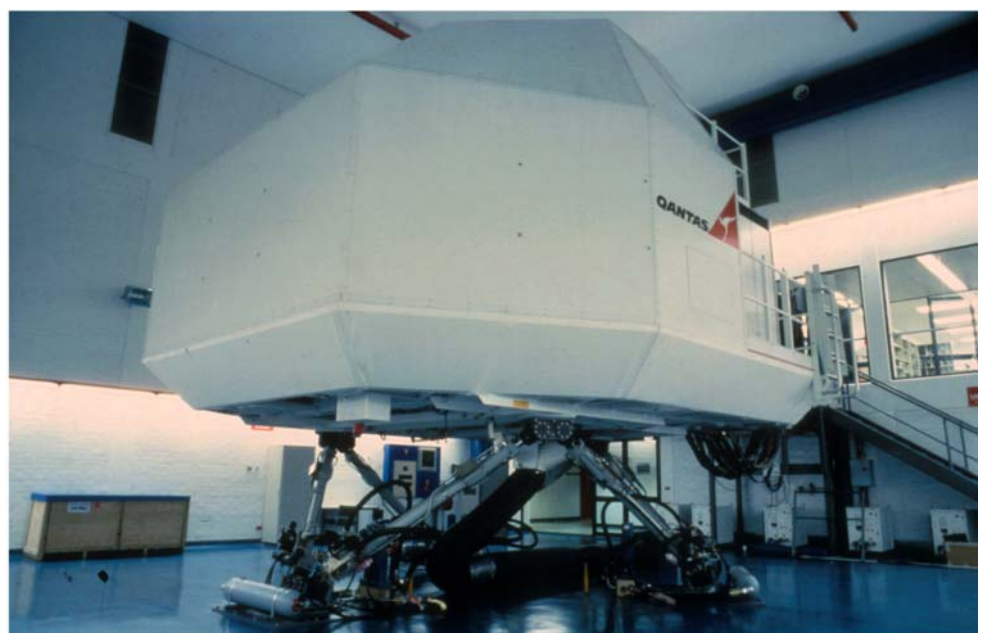
The basis for the credibility that the Simulation Industry enjoys today is due to the efforts of a relatively small number of airlines to establish common standards for flight simulation, which led to the granting of training credits by regulatory authorities for use of a flight simulator for the training 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 ⁽¹⁹⁾.

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.

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”.

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11. Author's Biography

Ray Page currently operates as a senior consultant to the Simulation Industry being able to offer the experience from an unparalleled background of forty years in the Simulation Industry with experience in all areas from maintenance development and procurement to management of QANTAS Simulation Services, Australia's oldest and largest simulation organisation. Over these years, Ray achieved International recognition for both his knowledge and role in the formation of industry standards. In this capacity he has authored numerous papers, served on international working groups and committees with two terms as the elected chairman of the IATA Flight Simulation Technical Committee. It was during this period under Ray's direction that the IATA FSTC developed and published the standards for the construction and acceptance of flight simulators which became mandatory contractual requirements in the purchase and acceptance of flight simulators and which are still used to this day.

Ray's expertise has been used by a number of International Airlines, RAAF, FAC, Australian Maritime College and the Australian CAA in the formation of their original simulator regulatory requirements as well as consultant to major Aerospace, Simulator and Visual Manufacturers.

In 1994 Ray was elected by the Australian Simulation Industry to Chair a committee seeking the development of a Co-operative Research Centre for Simulation and Training in Australia and in 1996 the SIAA was formed with Ray Page elected as the inaugural Chair of this organisation.