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FLIGHT SIMULATORS. PART I: PRESENT SITUATION AND TRENDS PART II: IMPLICATIONS FOR TRAINING

D. Hass and W. Volk

Translation of "Flugsimulatoren. Teil I: Stand und Entwicklungstendenzen. Teil II: Auswirdung auf die Ausbildung," Deutsche Gesellschaft Guer Ortung und Navigation, Nationale Tagung Ueber Simulation im Dienste Des Verkehrs, Bremen, West Germany, April 15-17, 1975, Paper 3.4, 34 pages

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16. Abstract

The present situation and developments in the technology of flight simulators based on digital computers are evaluated from the standpoint of training airline flight crews. Areas covered are minicomputers and their advantages in terms of cost, space and time savings, software data packets, motion simulation, visual simulation and instructor aids. Part II evaluates the division of training time between aircraft and simulator training and the possible advantages from increased use of simulators.

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D. Hass

Part I. Present Situation and Trends

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FLIGHT SIMULATORS. PART I: PRESENT SITUATION AND TRENDS
PART II: IMPLICATIONS FOR TRAINING

D. Hass and W. Volk

1. Introduction /2*

Flight simulators are used for research, test and instruction purposes. The demands on simulators to be as realistic and as widely developed as possible, however, are greatest in the case of instructional simulators which are used for training crews. With these simulators what is important is that all sense impressions which might be encountered by pilots in piloting an aircraft are imitated for them as realistically as possible. It is indeed the task of the instruction simulator to replace the aircraft as a training tool.

The pressure to produce realistic sensations in all areas has caused industry to make use of the latest technology. Here in particular it is the development of electronics and digital techniques which has made possible the current level of simulation techniques and which permits us to expect further basic improvements for the future.

2. Breakdown of Areas Covered by the Technique of Digital Flight Simulators

The different areas covered by simulation techniques are shown in Fig. 1 by means of a block diagram.

In the center is the computer in whose storage mechanisms are stored data and programs for the solution of simulation tasks. The following sections can also be seen:

* Numbers in the margin indicate pagination in the foreign text.

- Rudder pressure simulation
- Simulation of cockpit instrument readings
- Noise simulation
- Movement simulation
- Visual simulation
- Extra apparatus for the instructor.

In the following discussion of the present situation and trends of simulation technology I would like to restrict myself to the digital computer, motion and sight simulation and instructional aids because the greatest changes have occured in these areas in recent years and it is here -- in particular one thinks of motion and sight simulation -- where decisive improvements are indeed still desirable.

3. Present Situation and Trends of Simulation Technology /3

3.1 Digital Computers - Hardware

Digital computers for flight simulators must operate in rapid, complicated processes in real time. Therefore their predominant characteristic is high calculating speed. Fig. 2 shows some information on the latest digital computers presently offered in connection with flight simulators. For purposes of comparison the Mark I was included in the last line. This computer controled the first digital flight simulator for a passenger plane in 1963, a Boeing 727 simulator of Eastern Airlines.

As a measure of the speed of the computer the RAM memory access time is given in the table. Depending on the type of storage mechanism used -- core storage or semi-conductor storage elements -- these times range between 1.3 and 0.3×10^{-6} seconds. If one uses a representative instruction cross-section for the simulation task then a rough estimate for the computer listed gives a processing speed of $0.5\text{-}1.0 \times 10^{6}$ instructions per second.

The Mark I handled only 0.16×10^6 instructions per second, hence was 3-6 times slower than today's computers.

This first digital computer for a passenger plane simulator was specially built for simulation purposes, since no computers with sufficient speed were available on the market in the required order of magnitude. In the meantime all purpose computers have prevailed against such "special purpose" computers, since computers suitable for simulation purposes are offered on the market today in larger numbers. Thus simulation technology, which indeed in terms of size represents an insignificant market for data processing machines, has the possibility of profiting from extensive developments and the thus continually improving characteristics of all purpose computers.

Out of this group of so-called "general purpose computers" minicomputers today are increasingly being used for simulators. These are computers with word lengths of 24 bits and less, whose basic equipment without peripheral equipment costs U.S. $20,000-25,000. In terms of performance these minicomputers are "small giants." The integration technique of modern semi-conductor development (MSI, LSI) has created for us such a large reduction in space requirement for a large number of logical components along with a simultaneous increase in the data rate that minicomputers which can fit into half an electronics cabinet 4
today are comparable in terms of performance with computers which just a few years ago took up several electronics cabinets and cost many times more. Credible predictions of the electronics industry say that in 5 years it will be possible for a few hundred U.S. dollars to purchase a complete minicomputer on the order of a PDP 11 which consists of only one circuit board [1].

A PDP 11 computer today controls Boeing 727 simulators used by Lufthansa. In this area smaller, faster and less expensive computers already seem to be quite within the realm of possibility.

Shortly after the introduction of the first digital computer for flight simulators the concept was applied of allowing two simulator cockpits with the same or even different flight patterns to be controlled by a central computer. The computer employed was fast and large enough in terms of its storage capacity to simultaneously process two mutually independent real time processes. This concept did not prove successful and today is outmoded, as logical and cost-saving as it might have appeared at first glance. The computer for a long time now has not represented a sufficiently large part of the overall cost of the simulator for it to be worthwhile to put up with the numerous operational disadvantages of such a solution. If the central computer breaks down both of the flight simulators are out of commission. Program changes for one of the two simulators can only be performed if the computer is fully available, i.e. when no instruction is taking place on either simulator.

The inexpensive computer -- the minicomputer--- allows current developments to go in the opposite direction. Instead of a central computer for several cockpits or a medium general purpose computer for one cockpit, the manufacturers allow 2-3 small computers working in parallel to control one cockpit. With further decreasing computer costs this direction, in my opinion, has two large advantages. The computer console of the simulator is now fast and large enough in terms of responsive storage capacity to be able to carry out in parallel the calculation of the real time simulation problem and the working in of program changes (reassembly). This is of interest, since flight simulators are being used 16-20 hours per day for instruction as meanwhile indispensible substitutes for aircraft and therefore the digital computers are available only a few hours during the night for necessary program changes.

Thus the working time of our simulator technician can thus /5 even better be taken advantage of.

The second advantage is due to the susceptibility of the digital flight simulator to computer breakdown. Digital computers occasionally break down and with redundancy in the computer complex -- which is becoming an increasingly good value -- the availability of the simulator should increase further beyond the current 98%.

3.2 Digital Computers - Software

Here we will not discuss computer oriented software nor the mathematical methods of simulation. First of all we are concerned with the data required for the simulator on flight characteristics and flight performances of the aircraft to be simulated which are supplied by the aircraft manufacturer. The quality and completeness of this data are decisive factors in the choice of simulation methods.

Based on our experinece the data released on flight characteristics for the construction of simulators up to about the early 1960's were by-products of the preliminary calculations and flight tests of aircraft manufacturers in order to obtain air worthiness certificates for new flight designs. The result of this cost-saving method was that extensive data were available on marginal flight conditions but only a little data was available on normal flight conditions which are much more important for instruction purposes.

The simulators which were built on the basis of these data packets, e.g. for the first generation of jet passenger planes, not least of all for this reason showed considerable differences in piloting characteristics in comparison with the actual aircraft.

With the increasing importance which airlines attached to their flight simulators manufacturers were forced to introduce special methods to obtain data for the construction of simulators in order to improve the quality and extent of the data. To begin with test flights were performed especially to improve data records for the construction of simulators.

Understanding on the part of aircraft manufacturers was also improved by the fact that the manufacturers themselves now began to purchase simulators for their aircraft designs for instruction purposes.

I would like breifly to describe how one aircraft manufacturer /6
provided the data on flight characteristics for a new large aircraft.

On the basis of wind tunnel measurements and calculations the departments responsible provided the so-called predicted aerodynamic design data from which was calculated the predicted performance data on a large computer using their own program. With these two data documents the simulator manufacturer began work, for in this case the simulator had to be ready for use as early as a few months after the initial flight of the prototype by the first airline which had purchased the aircraft. After the conclusion of test flights and receipt of the air worthiness certificate the aircraft manufacturer reduced the flight test data and provided the flight proven aerodynamic design data document. Using the above mentioned computer program the final performance data document was then produced. In the numerous graphs of this data the aircraft manufacturer plotted the flight test points for verification. At this point training on the simulator had long been underway and in a modification program after completion of the first training period the simulator programs were worked over according to the new data.

So much for the method of producing a consistent data document for the construction of a simulator.

Unfortunately the data on flight behavior produced in this way are almost exclusively of a static nature and much too little aircraft data on dynamic processes are included in the data packet.

The extensive check lists of simulator manufacturers in many cases contained test data calculated on the basis of the simulation model where results of in-flight measurements made by the aircraft manufacturer himself would inspire more confidence.

As a result of this data situation, which only on the part of the aircraft manufacturer can really systematically be improved by still greater efforts, we see ourselves forced to perform our own test flights. This is a costly process and in view of the high prices for existing data packets it is also especially unsatisfactory.

The accuracy of qualitative data on flight characteristics from our own test flights leaves much to be desired.

In many cases the data was obtained using primitive means; /7
film cameras must replace data recorders. The data obtained in such a complicated manner must now be reduced and integrated into an existing simulation system in such a way so that the desired improvement is accomplished without undesirable side effects.

As long as data packets for flight simulators do not get better each final test of an instruction simulator in the last analysis will not be completely free of subjective adjustements. As encouraging as the prospects for the development of digital computer hardware might be, it is regrettable that we still do not have a completely satisfactory mathematical description -- the optimal data packet -- for our simulation object.

3.3 Motion Simulation

Among the airlines there is agreement on the fact that motion systems are necessary for instruction simulators. The American Civil Aviation Board requires functional motion systems for flight simulators which are used in the instruction and routine testing of crews [2].

Finally, in the relevant literature there is also agreement on the fact that for the instruction of flight manuvers, in which impressions of motion occur as a warning or disturbance variable, motion simulation is very desirable [3].

So today simulators are no longer supplied for commercial airplanes without a motion system.

Thus the question of whether the existence of motion simulation is justified in thus clearly answered, whereas it still seems to be unclear which of the three types of motion systems should be selected: a system with 3, 4 or 6 degrees of freedom. Fig. 3 presents a table of the essential characteristics of typical representatives of the 3 systems, whereby 1 system with 6 degrees of freedom in the most favorable case costs 3.5 times as much as the system with 3 degrees of freedom and 6 times as much in the most unfavorable case. Figs. 4-6 illustrate how these systems operate.

Starting from the desire to be able to imitate motion impressions as realistically as possible one is inclined to decide on the system with 6 degrees of freedom.

The larger possibilities for movement seem to qualify this system from the outset. It is the only one which affords all the physical prerecquisites for imitating by way of suggestion all accelerations occuring in normal and abnormal flight conditions as well as movements caused by atmospheric disturbances. However, for realistic motion simulation within physical limits there comes along with the kinematic system a computer program as well which makes optimal use of and controls this system with its motion possibilities. /8

The pressure to buy the "newest" and "best" -- not least of all in order to be able to have something to show to the inspecting authorities -- but certainly also the justified hope of coming a little closer to reality has today resulted in the fact that systems with 6 degrees of freedom have become standard.

These systems were first offered by industry in 1967 in conjunction with Boeing 747 simulators. Today they are also used in conjunction with Boeing 727 and Douglas DC 9 simulators.

The systems with 6 degrees of freedom offered today possess a large potential which is really not yet fully taken advantage of. In the first exchange of practical information on these systems at an IATA meeting in Dublin in 1971 uncertainty prevailed among the duly qualified representatives of the airlines when it was supposed to be specified what savings in terms of flight time were due to the large motion systems of the B 747 simulators.

Exhausting the motion possibilities of systems with 6 degrees of freedom can, in my opinion, only be managed in experimental programs under the cooperation of research institutes, manufacturers and airlines. For such programs, which in the last analysis improve the cost effectiveness of our motion systems, we are prepared to cooperate.

3.4 Visual Simulation

Visual simulation systems in conjunction with flight simulators for passenger planes have found ever increasing wide-spread use in recent years. Visual systems consist of 3 system components:

1) an image storer in which 3-dimensional data on the area being flown over, in general the closer surroundings of one or several airports, are stored. /9
2) An image producer which extracts the data from the storer and taking into consideration the perspective of the pilot transforms it in such a way that it corresponds to his view of the area being flown over.
3) An image presentation unit by means of which the synthetic image is made visible in front of the windows of the simulator cockpit.

At the present time three types of visual systems operating according to different principles are being used by the airlines. The principles of these three types of systems are compared in the table in Fig. 7.

In the case of television systems, the oldest and today wide-spread group represents the image storer, as Fig. 8 shows -- a 3-dimensional landscape model, e.g. on a scale of 1:2,000 with dimensions of 12 x 4.5 m. A television camera with an optical probe place in front of it moves in front of the model by means of a lift system guided on tracks corresponding to the 3 translatory movements of the simulated flight. The optical probe contains servosystems for control corresponding to the 3 rotatory movements of "flight" and permits atmospheric effects such as the underside of clouds and flight visibility to be faded in by means of a filter in the path of the light rays. The camera and optical probe represent the image producer.

Image representation takes place selectively using a television projector which is installed on the simulator cockpit and which allows the image to be projected on a projection surface or in front of the front panes of the simulator by means of shadow masks on the picture tubes. In many cases today optical systems are inserted between the image plane and the pilot. These systems consist of spherical mirrors and so-called bean splitters which produce a collimated image. Figs. 9 and 10 show two image representation devices in use today. The display of Fig. 9 covers both front panes, while the display in Fig. 10 covers only 1 front pane of the cockpit. The latter display is therefore installed twice, one unit per window.

Visual systems in which film techniques are used have been /10 in operation since 1968 among airlines. A 70 mm wide screen film is used as the image storer. The film is taken by a helicopter, for example, performing an ILS approach for landing. The image is produced by means of a film projector fitted with a distortion lens system. Changes in the perspective of the pilot due to control inputs of the simulator during flight are simulated in this optical system through parallelogram distortion of the projected film image by means of anamorphic components. Changes in flight speed are simualted by controlling the image speed of the projector between 0 and 32 images per second. The projected film image is created on two spherical projection surfaces and is transmitted via an image representation unit -- similar to televisions systems -- in front of the front panes of the simulator cockpit.

Since 1972 airlines have also been using visual simulation systems which are based on the principle of computer generated images. Computer generated image (CGI) technology has become surprisingly widespresd in a very short period of time. Already about 25% of all instruction simulators operated by IATA companies are furnished with CGI systems. Core storage or semiconductor stroage of digital computers serve as the image storer. A numerical model for example of the stylized surrounding of one of several airports is stored in these computer storage systems. In the simplest case the store contains the geographic positions of all the lights in the lighting system of the airport as well as a few peripheral lights such as of street lighting systems and of nearby localities. This numerical model of the airport and its surroundings is continuously being transformed with respect to perspective in real time and the position of each point of light is determined on a selected image plane by a computer program which obtains input information from the simulator computer on the position of the simulated aircraft. In the sense of the definition given above the computer program represents the image producer, the image is produced by means of cathode ray tubes which, in contrast to shadow masked picture tubes, permit considerably more accurate beam control, so-called beam penetration tubes.

The image of these cathode rat tubes is again made visible on the front panes of the simulator via a collimating reflecting optical system. It is the image of a night scene. CGI systems which produce daylight images are presently being constructed. The first simulators for passenger planes will be furnished with daylight CGI systems in late 1975.

In general, visual systems can be judged on the basis of the following criteria:

- image quality and image content,
- manuver range and
- "flyability."

Along with light intensity, contrast and color the decisive characteristics of image qulaity are resolution and horizontal image field. Fig. 11 shows the ranges of these characteristics for 3 types of sytems. Television and film systems have a rather similar horizontal visual field, but film systems offer 3-4 times better resolution, not least of all because of the information content of the film image which is 2 orders of magnitude greater than that of a television image with 625 lines. By expanding to additional channels for the side windows and by means of series connected image representation units CGI systems permit considerable extenstion of the horizontal visual field while the good resolution quality remains unchanged.

Even taking into consideration the 2 systems under development which are listed here for purposes of comparison, Fig. 11 clearly shows how far visual simulation systems are still removed from real flight visibility.

In terms of image content television systems and film systems are superior to CGI systems. The quality of the image content is the same only in the area of the night time image which, because of its largely discontinuous image content (points of light, few surfaces), is particularly well suited for representation by means of so-called computer graphics. Computer generated daylight images raise many new problems. For example, for reasons of perspective concealed surfaces must be suppresed and the image content must be stylized for reasons of cost.

The technology of impecable daylight images, which in terms of content hold their ground in comparison with film images, is currently available, although at present numerous digital computers operating in parallel would be required for the real time generation of such images. As a result we must patiently await development in the field of digital technology before computer generated daylight images become cost effective for use in instruction simulators. The image content of the most advanced daylight CGI system, which so far has been ordered for an airline's instruction simulator, is still restricted to 1,000 corners and 2,000 light points at an image computing frequency of 30 Hz.

The manufacturers of night time image CGI systems today offer, in addition to approximately 2,000 light points, a lightening of the landing path surface and of the horizon.

The maneuver range of visual simulation systems is under- /12
standably most restricted in the case of the film systems and in our opinion these systems, primarily for this reason, don't stand a chance anymore for the future. With respect to the maneuver range for reasons of space the television is subject to qualifications which, however, are to be made consistent with training demands.

In principle the CGI system has no limits. Of course and image can actually be seen only in the proximity of the airport.

Now let us turn to the last criterion, the "flyability" of the systems.

The "flyability" of a visual system is primarily a problem of tying in with the flight simulator, i.e. the mutual co-ordination of different simulation programs. An important factor here is the behavior of the different visual systems in terms of control engineering, in particular behavior with respect to system inherent distortions. A comparison shows that the response behavior of the servosystems of television and film techniques is just as limited ast the image calculating speed and the printing rate of the representation tubes of the CGI system.

The distortions in the 3 systems are comparable and otherwise are far smaller than those which occur in the piloting of an airplane. The speed of the position and attitude control of the 3 systems is likewise very similar and completely satisfactory for the motion of passenger planes. Thus the prerecquisites for the system hardware are presently the same for the problem of "flyability." In Part II of this presentation this decisive criterion will be gone into in greater detail.

In the diagram in Fig. 12 we have tried to plot the present situation, trends and limits of the 3 methods discussed above. The cost of the systems -- simply the procurement costs -- was plotted along the ordinate axis and the output of the systems -- the training value -- was plotted along the abscissa. The diagram presents our view with respect to the use of visual ssytems for passenger plane instruction simualtors.

No further development can be expected of the film systems. This is because of their limited range of maneuver -- the preliminary programing of maneuver sequences on the film -- and the high costs due to wear on the film. Their training value is limited.

Television systems will be further developed to be sure. One manufacturer claims to be putting the same amount of money into the development of these systems as into CGI systems.

However the development possibilities are very limited. At present experiments are being carried out in the following areas: electronic distortion of the television image close to the ground in order to prevent depth of field problems, improved horizon simulation (so-called electronic sky) and development of new optical probes. There is hardly any possibility of obtaining a wider visual field. In addition there are high extra installation expenses, such as carrying off the heat created by the model illumination, and high maintenance costs.

The CGI systems still require an enormous increase in expenditure in making the transition from a night time to day time imgae. However with further development in the sector of electronic components the procurement costs will drop sharply. Since these systems at the same time make possible an enlargement of the horizontal image field and, on the basis of initial practical experience, require considerably smaller maintenance costs, they will be the systems of the future.

3.5 Instructor Aids

To conclude our discussion of simulation techniques we will here present devices for use by the simulator instructor. These so-called instructor aids are united in the instructor panel which in passenger plane simulators is always located in the interior of the simulator cockpit. Along with the normal control elements for putting the simulator into operation, which basically as far as the cockpit is concerned are independent of the group of controls for keeping the simulator in service, the following adjustment functions are present on the instructor panel:

- Input of surrounding conditions
- Check of load and fuel condition

- Input of errors -- arranged on the basis of communication systems -- with error preselection dependent on various parameters
- Plotting of deviations during instrument approach
- Position indication of the simulated flight
- Plotting and reporduction of the last 5-10 minutes in each case of the training run
- Devices for simulated radiotelephone communications.

Digital flight simulators make it possible for these functions to be automated to a large degree for the purpose of freeing the instructors from having to make adjustments and thus be able to devote as much undivided attention as possible to the crew under instruction. /14

The simplicity of operation of the instructor panel is a crucial requirement, since our instructors do not spend all of their time only performing instruction sessions on the simulators and when the simulator is used they must quickly familiarize themselves once again with its operation. Therefore it is also important that the principles on which the controls and dials are based, and which, after all, are used in the aircraft cockpit, are consistently carried out on the instructor panel.

4. The Importance of Reliability

Instruction simulators used by airlines are in use 6-7 days a week 16-20 hours a day. Such a high work load can be planned only if the equipment is highly reliable, since practically no cushion of time is left to allow for breakdowns.

So a technical failure which shuts down the simulator can cause large consequential costs, for example by increasing the number of unproductive use days of crews, increasing non-sellable aircraft time etc. For this reason in judging the suitability of new technical devices for instruction simulators an important factor, alnog with what they contribute to increasing the realism of the simulation, is their effect on the reliability of the total system. Therefore in the field of simulation technology for our use progress means an increase in realism while maintaining or improving reliability.

Figures for Part I /15

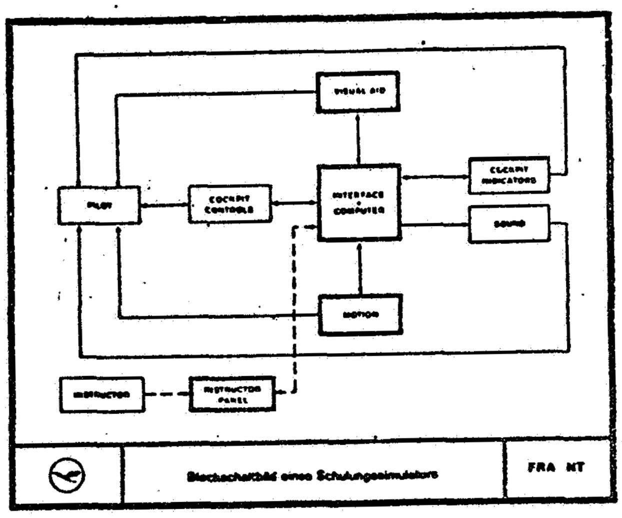

Fig. 1. Block diagram of an instruction simulator

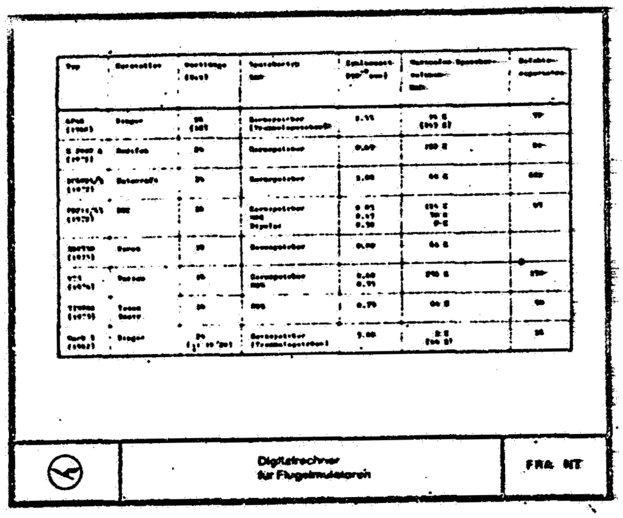

Fig. 2. Digital computer for flight simulators. /16

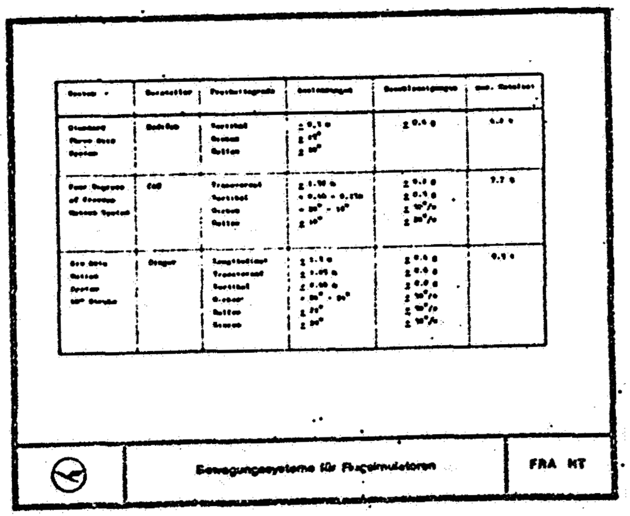

Fig. 3. Motion system for flight simulators

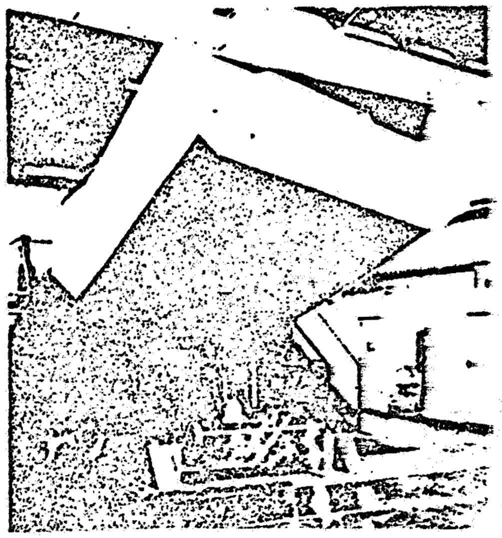

Fig. 4 Motion system with 3 degrees of freedom.

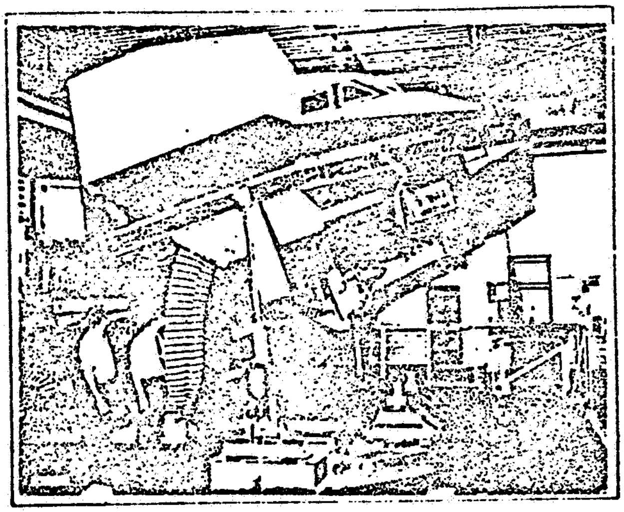

Fig. 5. Motion system with 4 degrees of freedom.

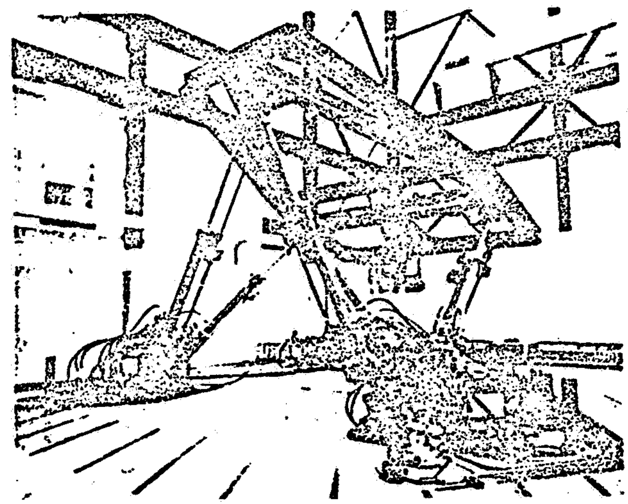

Fig. 6. Motion system with 6 degrees of freedom.

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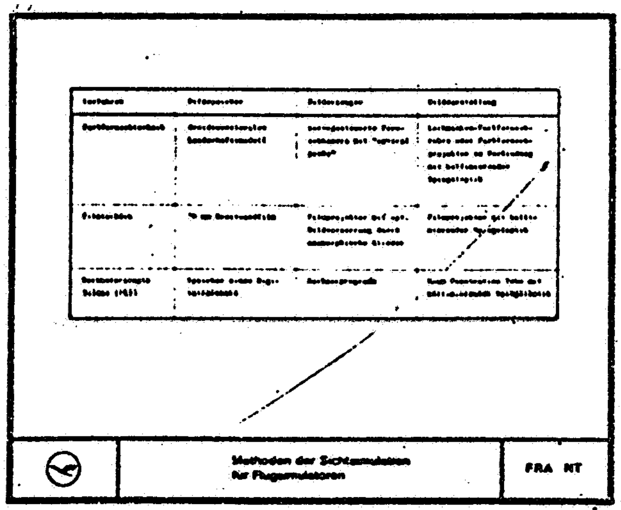

Fig. 7. Methods of visual simulation for flight simulators.

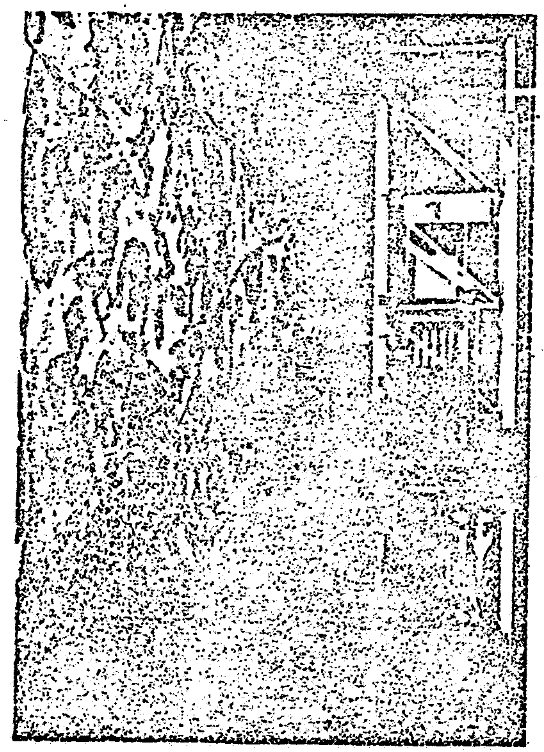

Fig. 8. Visual simulation based based on the television principle (image storer and image producer).

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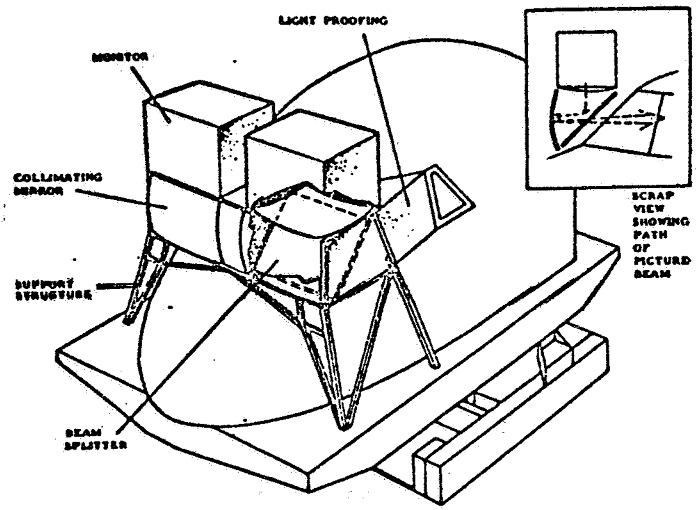

Fig. 9. Image representation device (monoview).

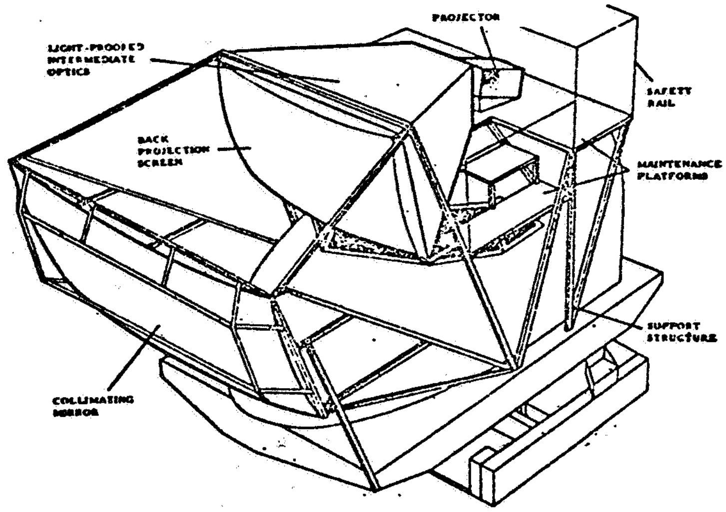

Fig. 10. Image representation device (duoview).

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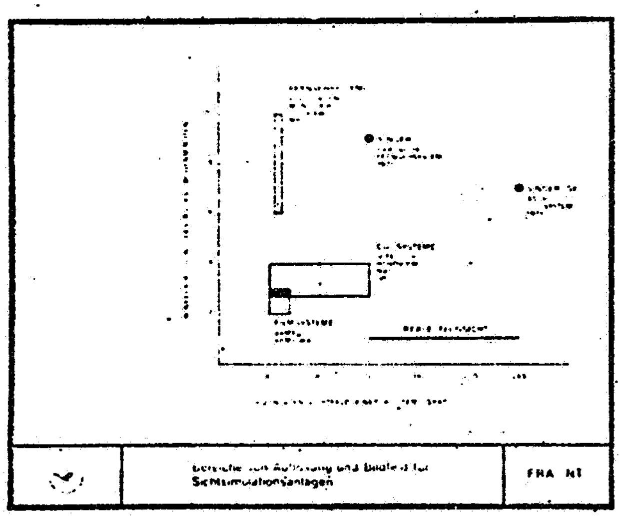

Fig. 11. Ranges of resolution and image field for visual simulation systems.

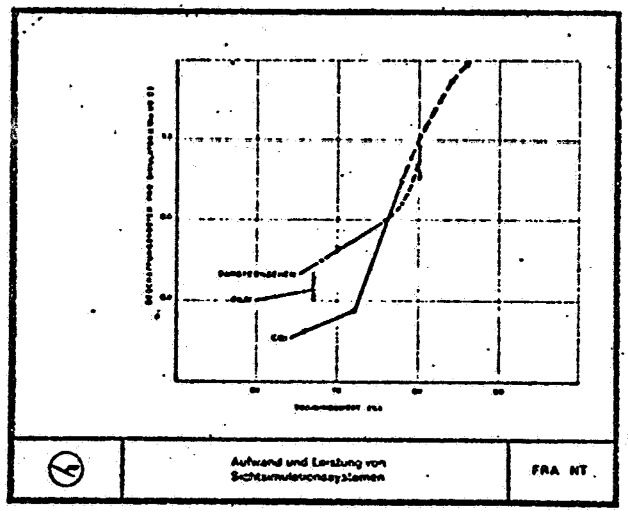

Fig. 12. Expenditure and output of visual simulations systems.

W. Volk

Part II Implications for Training

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1. Introduction

By way of introduction I would like to breifly comment on the importance of modern simulators in the instruction and testing of airline pilots from the standpoint of 4 criteria:

- Training Safety

It was not very long ago that in world wide air traffic a disproportionately large number of aircraft losses occured during training flights. Thanks to the use of simulators these figures have dropped sharply.

- Training Quality

The quality of training for certain flight maneuvers is higher in the simulator. For example: the failure of an engine is simulated in flight by pulling back the output to idle, whereas in the simulator the engine is actually shut off. Thus in an exercise for the failure two engines for the DC-10 the situation arose in which the remaining thrust of the two engines whose failure had been simulated was so great that the third engine also had to be cut back to idle in order to be able to begin the landing approach with landing gear and flaps extended. Thus the training aim, namely the exercise of approaches with asymmetric engine output is not obtained. So here the simulator is more realistic and qualitatively better. There are other flight maneuvers for which the same is true.

- Environmental Strain due to Training

The public is not fond of training flights. Repeated approaches with sharply different engine outputs are perceived as disturbing and therefore we also have difficulties in Germany finding training possibilities just for the prescribed test flights for extending liscenses. For the same reasons training in order to obtain the type rating has been performed abroad for years.

- Profitability of Training

In the time of a fourfold increase in prices, in which just to make a trafic circuit above an airport the resulting fuel costs range between DM 130.-- for the B 727 and DM 300.-- for the B 747, it is actually only a formality to point out the ratio of costs between a simulator hour and a flight hour for the same type of aircraft ranges between 1:6 and 1:20.

2. Stock Taking of the Division of Training Between the Simulator and Aircraft /22

In the first part of our joint presentation we have heard about the present state of development and tendencies in simulator technology. It is now time to take a closer look at their implications for the training of airline pilots. I would like to begin with a breif review of the current situation with regard to the division of training between the simulator and aircraft for obtaining type ratings for different types of aircraft as is found in our company in line use.

In Fig. 1 you see the trend which shows that a sharply decreasing amount of flight training is matched by an unchanging or slightly increasing need for simulator hours. A clear bend in the direction of fewer flight hours can be detected for all of our types with the hooking up of relevant simulators to our visual aid system. These hookups are made at different times.

A similar reduction is shown in the conversion of our 707 simulator training from a simulator type with analog technology of the 1960's to a type of digital technology with corresponding improvements in the fidelity of the total system and thus closer approximation to the flight behavior of the B 707. Since such investments in a company whose business goal of maximizing profit must always be taken into account can only be justified when corresponding savings are obtained, it was not easy for us to make the decision to purchase a new simulator in 1977 for the B 707. At the time the decision was made it was already possible to look ahead to the time when this aircraft would no longer be in operation in our company.

A recalculation over 3 years showed that savings of about 9 million DM were acheived by the purchase. The number of flight training hours was reduced by about half, the costs per simulator training hour for the better equipment have doubled at the same time, however they remain in the above mentioned relation to flight training costs.

From the same graph we also see, however, that with our input types B 727 and B 737, which have to handle both the initial training of new copilots from the Bremen flight school and the initial transition training of copilot to captian, the training times both in the simulator and in the aircraft are clearly greater than for the rest of the fleet.

- The Americans use just sticktimes as a reference, whereas /24[1]
in our data the figures contain all rolltimes on the ground (block time). An American article dating from 1966 [4] shows how the authors at that time imagined the development of the ratio of simulator training to flight training (see Fig. 3). For simulators based on 1975 technology they came up with a final value of 20 simulator hours as against 5 flight training hours.

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1. Not all of the pages are numbered and it is possible that p. 23 is missing.

We have plotted the currently valid values of large aircraft flown within the scope of ATLAS and we find extensive agreement with the assumptions made.

All thoughts of shifting more and more of the training from the aircraftt to the simulator in all considerations of profitability are always subject to the overriding factor that in making this transition the quality of the training may not be adversely affected. Apart from all other indicators which confirm the even higher quality of this combined training in the simulator and aircraft one can also refer to the number of total training hours. The figure for this is actually higher in 1975 than that given in 1966 for pure flight training not combined with simulator training.

A similar situations exists for the semi-annual test flights which are required by law for license renewals. After simulators were recognized for this procedure by the authorities these flights have largely been shifted to the simulator.

3. Effect of the Development of Separate Areas in Simulator Technology on Training

My statements up to now have taken stock of the use of simulators in the training of airline pilots.

Now I would like to take a detailed look at the different areas of simulator technology which permit us to expect further improvements for training and the solution of still existing problems.

This will either be done with possibilities already existing /25 in the total system or by further developments already spelled out by the existing technology. In particular the following sectors stand in the center of interest: motion and visual aid.

3.1 Motion simulation

The debate over the number of required degrees of freedom with motion simulation has still not be settled. A uniform viewpoint has not been formed among the airlines. Even today 3-axis motion systems are still being ordered. Moreover, the 4-axis motion system still has its supporters in England. With us, in the purchase of the latest 3 simulators for types B 707, 747 and 727, the 6-axis motion system was demanded by the pilots for the following reasons:

- in the intended training shift from the aircraft to the simulator the fidelity of this equipment must be as high as possible.
- In particular, during engine failure the yaw motion created by the loss of power must be easy to sense in order to give the pilots unimpaired information to react properly.
- Acceleration and deceleration processes (translatory motion simulation) are felt not only during takeoff and landing but are also an important aid during airwork training. This involves exercises which take place mostly in the range of low speed flight, i.e. stalls, slow flight, recovery from high-rate-of-sink, go-around etc.

There are still no studies which clearly indicate whether training is made more efficient by means of motion with more degrees of freedom. But in our subjective opinion each improvement even in this area brings with it a gain in credibility in the equipment among the pilots. This is quite an important point which will be discussed in detail later on.

3.2 Visual Simulation

In the training of pilots visual simulation has 2 main tasks. It should make it possible for the pilot:

- to practice final approaches and landings from instrument approaches with a cloud ceiling between 30 and 120 m and visibility ranging between 400 and 1200 m; /26
- to estimate and correct his deviations in relation to the landing path in the final approach on the base line. This phase is practiced in the traffic circuit above the airport under visual flight conditions between 3 and 4 NM on final up to and including the landing.

These requirements place partially different demands on the visual aid. for the instrument approach the following is required:

- good representation of the different weather conditions in terms of visibility and ceiling for the different approach methods. Here are a few examples as they were photographed on the visual aid on the Frankfurt base:

Position	Visibility (m)	Ceiling (m)	Exercise	Figure
Landing path start	200	Approaching	Start	4
Final approach 1 NM	1,200	120	non-precision approach	5
Final approach 200 base radio altitude on GS	600	60	ILS CAT I	6
Final approach 100 base radio altitude on GS	400	30	ILS CAT II	7

- realistic representation of approach and landing path lighting.

Both conditions are fulfilled by existing systems and are also formally accepted by pilots, since with these specific weather conditions even in the aircraft clear visibility is reduced and there is no demand for depth of field; peripheral vision is restricted and there is no necessity for lateral vision; and general distinctness is reduced due to mist and fog with the result that there are no excessive demands on resolving power.

By contrast, the demands for visual approach are considerably /27
more difficult to meet. These demands consist of the following:

- early recognizability of the landing path from a distance of 3-4 NM requires high resolution (Figs. 8 and 8a);
- uniform sharpness over the essential image areas requires great depth of field (Figs. 9 and 9a);
- high image content (detail) for estimating deviations requires that the model be highly accurate (Fig. 10);
- information for the pilot on the flight attitude in space requires peripheral vision through the side windows (Fig. 11).

The first two conditions are fulfilled by the new CGI systems better than by the television systems. For image content, however the latter are still better, since with them it is also possible to carry out very realistic training by day, twilight and night, whereas the CGI systems must primarily be restricted to night time representation (see Figs. 12-14).

With the already offered daylight representation, even with computer controlled systems, this may present a real improvement in training possibilities for visual approaches in the training of beginners and in making the switch to a new design type.

One unsolved problem for the time being is the demand of pilots for the greatest possible angle of sight. The existing systems with lateral sight, as they were studied by us, were unsatisfactory in so much as between the two view representations of the front and side window there remained a very disturbing gap of about 20° in the angle of sight and because the night time image of the CGI system the image content did not give sufficient infromation on slight attitudes of bank.

An optimal solution to the problem of over correcting bank attitudes by pilots in the simulator using the visual aid as a result of a restricted horizontal image field would be 180° /28 projection which is certainly technically possible, but the costs of which would be worthwhile only with the conversion of crew instruction to total simulation.

The high degree of reality of the bad weather representation brings with it large advantages, in particular during training for approaches after operating stage II and in part first makes efficient training for this possible (see fig. 15).

For to be sure with training in the aircraft one can simulate a cloud ceiling by removing a hood at a certain distance above the ground which up to that point had restricted vision to the outside. But the then existing conditions of unlimited vertical and horizontal visibility with a clearly defined horizon are so unrealistic for the actual problem of making the transition from instrument to visual flight that today the simulated world of the visual aid here produces greater training success because it is more realistic. For this reason this training is performed almost exclusively in the simulator.

If I have to say "almost exclusively," then that means that only because of existing statutory orders we have to continue testing a small part of the required exercises in the aircraft.

It is very valuable to be able to make a visual representation for different degrees of brightness with the simulation of day time, twilight and night time conditions in connection with the training of approaches as per operation stages I and II. In contrast to making an approach under visual flight conditions, with the simulator the day time approach is actually more difficult. Because the lights are less visible the contrast between the lighting and the surroundings is very low and in the overall very difusse illumination the recognizability of additional details on the landing path and adjacent areas remains low.

Still better results of bad weather representation are to be expected in part form CGI systems and the electronic sky with televisions systems, since in these cases, in particular the partial transparency of clouds and fog is very realistically represented. This we have seen in a few test representations of various manufacturers. The curtain effect of former days may thus finally have been overcome.

As always, however, difficulties still exist in the hooking up of visual aid systems to simulators. Since very many variables affect this adaptation, it is very difficult for pilots, who /29
fly the simulator during the acceptance, to make precise statements about where and what is to be changed in order to acheive a better representation. On the other hand, the data packets put out by the manufacturers on the flight characteristics of the aircraft type in question do not contain all of the information which is used in making the adaptation.

The Human Components of the Problem

With a certain input to the control surfaces of the aircraft via the control column the pilot, based on experience in handling his aircraft, exprects a certain reaction in relation to the environment in terms of rotary motions around the lateral axis of the aircraft (pitch), around the longitudinal axis (roll) and around the yaw axis (yaw).

If in the eraly state of adaptation this reaction in the simulator differs sharply from reality it is still relatively easy to obtain an improvement. In approaching the optimum this become increasingly more difficult, since the pilot very quickly "learns" to fly the simulator and visual aid in such a way that the required objective -- landing after an approach -- is reached. The memory value from the aircraft, which indeed is only supported by subjective experineces, is very quickly lost.

There are two possibilities to help remedy this:

1) Let the acceptance pilots very frequently draw comparisons with the aircraft or
2) Let aircraft pilots who have just returned from an extended mission fly certain exercises in the simulator and then by asking them specific questions obtain information on how realistic the representation is.

In this connection a relatively fine measure of the degree of agreement between reality and simulation is the center of equilibrium in the brain which even with relatively small deviations from synchronous operation becomes disturbed to the point of causing nausea.

The Technical Components of the Problem

It may have surprized you that in combining two technical systems data of such subjective origin has to be used. This is necessary simply due to the fact that the available objective data is not sufficient and does not supply ample information.

In particular we are lacking data from the aircraft manufacturers on the effect of small inputs to the control column on the order of ±5° and less on the roll motion of the aircraft. As has been found in the study of this problem, however, precisely these small imputs are used very frequeqtly, in particular for fine corrections in the final approach where they are made almost unconsciously by the pilot in order to remain on the approach base line.

Data for larger inputs of 20-30° are available, but since these processes do not proceed linearly they do not represent the flight behavior with sufficient accuracy and bring the pilot to the conclusion that the simulator just does not quite correspond to the aircraft, and this judgement in turn gives rise to a number of reservations.

Remedies in this case can only come from test flights along the lines that we have performed in the past, and after a specified program they will also again be carried out this year. Of course it must clearly be stated that what is involved here is a problem of fine adjustment, as is necessary if one intends -- as we do -- to train the landing approach in the final phase with flare out to landing in the simulator with new pilots going for their type rating. The recurent training of experineced pilots who already have their type rating is not affected by this.

It is important however that aircraft manufacturers recognize these problems and obtain more data by flying and also make this available to the buyer in order that a simulation as near to perfect as possible can be acheived.

In order to obtain precise information on to what extent savings can be acheived in training pilots solely through the use of visual aid systems -- and indeed independent of other, for the most part simultaneously introduced improvements in simulators such as improved motion and more efficient computers -- we will set up a study in 1975, the essence of which will be a parallel experiment with a group of about 16 junior pilots at the same training level who will follow different paths to reach the same training objective.

The training will differ in so much as with 1/2 of the group another 4 hours in addition to the normal simulator training are planned for specific exercises in order to learn the final approach and landing phases in traffic pattern training sessions in the simulator fitted with visual aids. According to a set program the same instructor then takes over the group for flight training whose objective is "impeccable landings from visual and instrument approaches."

The possible saving results from the expenditure of the additional 4 hours in the simulator and the profits in terms of saved flight hours relative to the comparison group without additional training with the same quality demands. This experiment can then be repeated with a different number of additional simulated hours until one approaches a limit value where the number of simulator hours required to save a certain amount of flight training time becomes just so high that the number of hours spent in the simulator is no longer justified. /31

4. New Training Possibilities

From the standpoint of the computer a few possibilities are still to be found in the current simulator generation which have not yet fully been taken advantage of in the training of pilots. Among other things, this is so because enough is not yet known about effectiveness in the learning process. On the one hand this involves the possibility of allowing the computer to replay for purposes of demonstration, individual maneuvers flown by pilots, and on the other hand it involves the possibility of letting the student make a preliminary flight prior to his own excercise of a pre-programed maneuver as it should optimally be flown. Neither of these demonstration possibilities is without its critics, since many training captains are of the opinion that it is more efficient to let the student himself fly the suitable exercise to improve the routine.

Another method of using existing computer capacity is being prepared by us for refresher training. These refresher simulator preiods are independent of the liscense extension date and are also supposed to be carried out without the pressure of having to pass a test. Therefore a program is being set up which in the course of the flight poses different problems to the crew keyed in terms of time, altitude or speed. Solving these problems in the absence of a training captain makes it possible for the crew to test itself.

At the same time this acheives the following objective, namely that the crew, working as a team and responsible only to itself, exercises abnormal and emergency procedures without the positive or perhaps even negative support from an ever present instructor who recognizes and corrects at the outset mistakes which are about to be made and thereby prevents the crew from learning a very instructive lesson from the possible consequences.

In this area, however, developmental work really needs to be done and a general introduction of this method is conceivable only after certain experince with one type has been collected.

5. Relation of the Pilot to the Simulator

In these considerations however the "man-machine" problem or the human factor may not be ignored as I have reiterated a few times in the course of my discussion. The relationship of the pilot with the simulator is not an untroubled one and this is obvious since every 6 months he is required to undergo a test in the simulator which each time again makes a decision on his further professional life. The thought of this would also be certainly very uncomfortable for other professional groups. Therefore it is especially important, using suitable motivation starting with the training captains, to make sure that these training devices are fully accepted and in particular also to guarantee the highest possible degree of equality with airplanes by means of continual work on the technical quality of the simulators.

Figures for Part II[1]

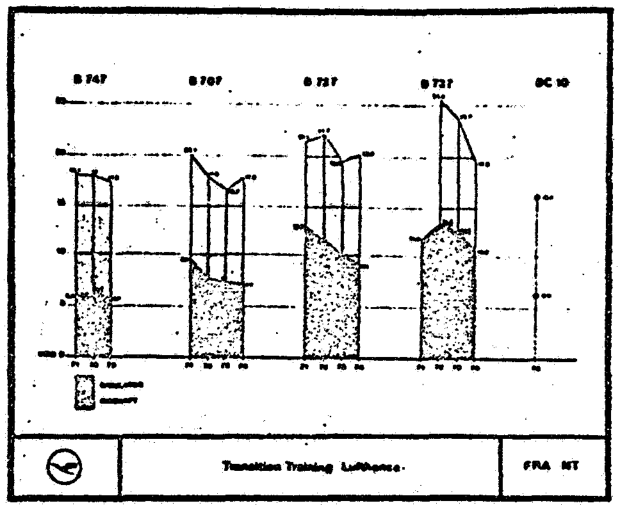

Fig. 1. Lufthansa transition training

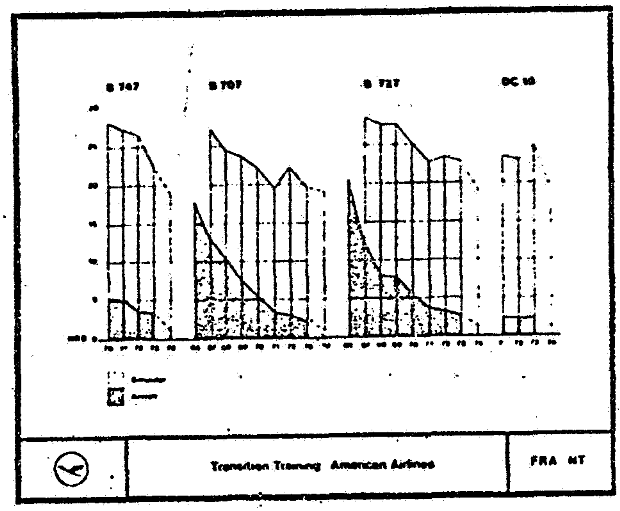

Fig. 2. American Air Lines transition training.

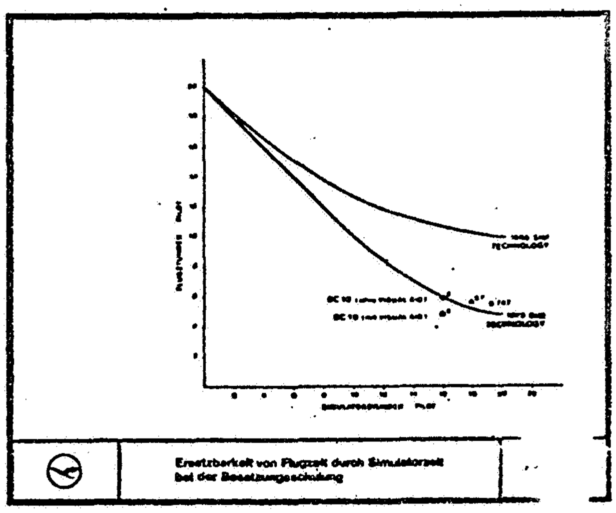

Fig. 3. Replacability of flight time by simulator time in crew instruction.

1. No other Figures are included in the text.