THE ROLE OF IN-FLIGHT SIMULATION FOR THE DEFINITION OF SIMULATION FIDELITY CRITERIA

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Abstract

In the introduction some of the reasons, which led to a programme where flight simulators were to be compared, are given. A particular kind of simulation technique, namely in-flight simulation, will be explained briefly. With the help of a typical flight task, an ILS approach, problems of post flight-data conditioning will be discussed. Two methods showing how the quality of a model following system can be determined, are presented. This is firstly the statistical evaluation and secondly an approach called Delta Rating. It is based on the ratio of model following error to the desired state of the test-bed to be controlled. Three typical examples of the past experience concerning investigations of the man-machine interface will be given. A reproducible pilot task based on a synthetic navigation system will be presented. It has been flown on the simulators to be compared by several test pilots. The simulators used were a ground based and an in-flight simulator. The same wide-body transport aircraft has been modelled on both simulators. Some of the results, gained in the first phase of the programme, are discussed.

1. List of Symbols

f	frequency
n	number or load factor
p	roll rate
q	pitch rate
s	standard deviation
t	time
x	flight state
z	vertical direction
α	angle of attack
Δ	difference
Θ	pitch angle

Subscripts

H	Host aircraft
M	Model aircraft
SP	Short-Period Mode

Abreviations

a/c	aircraft
CRT	Cathode Ray Tube
DME	Distance Measuring Equipment
DoF	Degree of Freedom
FL	Flight Level
IFS	In-Flight Simulation
ILS	Instrumental Landing System
INS	Inertial Navigation System
MFS	Model Following System
PIO	Pilot-Induced Oscillations
PSD	Power Spectral Density

2. Introduction

2.1 General Remarks

The safety concept of today's airborne transportation of passengers is mainly based on the following two factors:

- The high grade of qualification and experience a crew flying a transport a/c must have.
- The high technology which is available in a *state ot the art* airliner, giving a pilot the necessary support.

However, the existence of distance between commercial pilots and their aircrafts is an actual phenomenon. Several incidences and also accidents during the last years have shown this (see e.g. Enders (1989)). Problems in the field of man-machine interfacing have obviously still not been solved. One actual example is given by N.N. (1994), where the accident of China Airlines Airbus A300-600R at Nagoya Airport, 26 April 1994, is described. This new article is based on a further analysis of the digital flight data recorder and a better transcription of the cockpit voice recorder. It shows that the cockpit crew engaged, disengaged and then reengaged the takeoff/go-around (TOGA) switch before the a/c crashed. The recorded confusion in the cockpit illustrates that the crew members were not *in the loop* and did not understand the reactions of the systems.

Tragedies like the one mentioned above are making it obvious, just how necessary it has become to, not only improve the cockpit design, but also to educate the pilots. An increase of flight hours on certified moving-based simulators is expensive and not necessary in all cases. On the other hand it is not possible to model all effects adequately. The limits of fixed-based and moving-based flight simulators must be investigated systematically. Flight-test results play an essential role in these studies.

2.2 Deficiencies of Flight Simulators

How realistic a flight simulation is, depends on the quality of the simulator. Fixed-based simulators are useful if the pilot has to perform tasks where the motion cue has minimal importance. Typical start or landing procedures under IFR-conditions with minimum external disturbances can be easily performed.

Moving based simulators give a pilot a realistic impression of a flying a/c on the ground if they are additionally equipped with a good visual system.

However, deficiencies of ground based simulators are well-known (see e.g. Harper (1991)). Some of them are as follows:

- In the case of a fixed-based simulator there are no proprioceptive cues.
- A motion-system has physical limits and therefore some cues are more or less suppressed (i.e. only 10-15% of the real roll acceleration $\dot{p}$ are available).
- Some cues, such as the load factor n_z, are missing.
- Because of washout filtering, some cues are generated which never appear in a real airplane. The design of washout filters is still a kind of *black art*.
- The harmonization between a/c motion-system and visual-system dynamics is a problem area.
- The workload of the pilot in a simulator and in real flight is generally different. Investigations concerning PIO-effects, for instance, have shown this.

All above mentioned aspects led to a programme termed AIDA at the DLR Institute for Flight Mechanics, where some particular aspects concerning simulation fidelity are being investigated. AIDA is an acronym and stands for ***A**irborne **I**dentification and **D**evelopment of simulation fidelity criteria using **A**TTAS*. The central tool in this case is the airborne simulation, represented by the flying testbed ATTAS of the DLR (Figure 1).

Figure 1: DRL In-Flight Simulator VFW 614 ATTAS

3. Nonlinear In-Flight Simulation Technique

The aim of in-flight simulation is to imprint the characteristics of a vehicle to be simulated on an airborne simulator. The technical solution to realize this approach is an explicit model following system.

Figure 2 contains the block diagram of the control system which is in use on ATTAS. The *Pilot* has only control of the model a/c to be simulated. He has no influence on the host a/c, which is observed by a safety pilot.

The *Nonlinear A/C Simulation* is based on the differential equations of a 6-DOF rigid body a/c model. The kind of a/c which is simulated usually only depends on the describing database. This database can be changed, thus leading to a flexibel approach.

The Model Following System consists of a *Linear PI-Controller* and a feedforward controller. In the different segments of a flight (start, climb, cruise, approach, landing, etc.) the pilot has to change the configuration of his a/c. Those configuration changes are no problem in a simulation, if a nonlinear real-time model is in use like on ATTAS. The difficulty is to adapt the model following system to the actual reference flight state of the host a/c. Otherwise the airborne simulator cannot follow the model. In the discussed case of the ATTAS-MFS the relevant parameters of the *Nonlinear Feedforward Controller* are adapted using a real-time interpolation algorithm based on *Configuration Data Processing* (see Heutger (1990), Bauschat (1991)).

The most important part of this scenario is the *Flying Test-Bed ATTAS*. It is equipped with a fly-by-wire/light system. A very flexible onboard experiment computer allows this nonlinear in-flight simulation to be performed with a cycle rate of 40 Hz. Information needed by the pilot are attained from an electronic flight information system (EFIS). Hanke et al. (1991) have described the main features of ATTAS in greater detail.

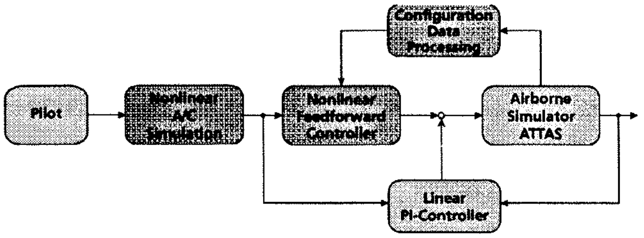

Figure 2: Blockdiagram of the Nonlinear In-Flight Simulation

4. Evaluation of Model Following Control Results

The comparison of the real-time simulators is based on the in-flight simulation, which delivers a basis of reference data. This is the reason why the level of quality of the model following control has to be evaluated. Adequate methods will be discussed in this section.

4.1 A Typical Flight-Test Example

Figure 3 shows typical flight states of the longitudinal motion, which were recorded during a standard ILS-approach simulated in flight. The simulated a/c was a nonlinear model of a wide-body transport a/c (two engines, 115 tons). The testpilot performed the landing approach as follows:

Flying straight at a level of about 820 m (2690 ft) the pilot captured the localizer of the particular airport. At a time of t = 100s of the time-axis given in the figure, the pilot reached the glidepath of the ILS. He changed the configuration of the model and the host a/c to landing configuration. The landing gear was extended and the simulated a/c as well as ATTAS began the descent. The change of the configuration can be seen very clearly in the diagram of the angle of attack (α_M). It decreases from about 4° to 1.8°, increasing then again when the pilot stabilizes the a/c. Below 600m (1970 ft) the in-flight simulation came into significant external disturbances. These were caused by thermic flows. The traces of α_M and α_H also show, that only the host a/c is influenced by these external weather conditions.

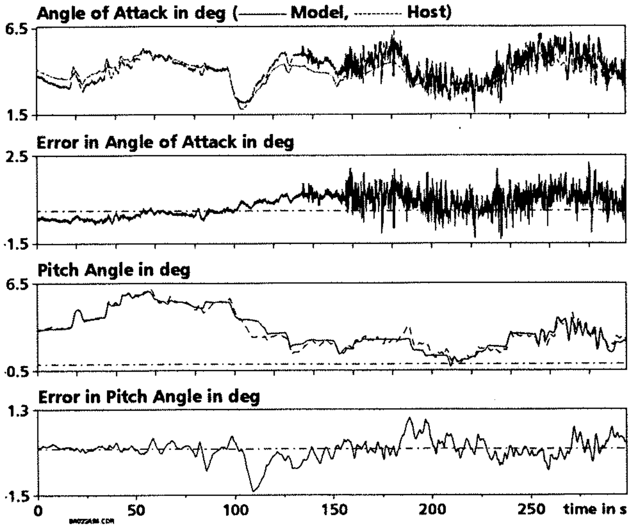

Figure 3: Selected flight-states of an ILS-approach

The sensor for the signal α_H is a flightlog at the tip of a noseboom. The plotted signal is the result of a calibration of the raw signal and a transformation in the centre of gravity of ATTAS. The pitch angle Θ_H is sensored by the INS, which has a low-pass filter characteristic. High frequencies which are measured by the flightlog are suppressed here.

The problem is now to make a statement concerning the quality of the model following. One typical method is illustrated in Figure 3 - flight states of model a/c and host a/c are plotted in one diagram. It is then possible to see how well the two curves match. This more quantitative method based on an optical check can be supported by an additional error curve given with equation (1):

$$\Delta x(t) = x_H(t) - x_M(t) \tag{1}$$

Those error curves are also given in Figure 3.

The next step should be now to think about a more analytical way for the quality rating. In the given case of in-flight simulation, additional data preparations might be necessary before the evaluation. This fact is briefly discussed in the following section.

4.2 Post Flight-Data Conditioning

The flight states of model and host recorded in one simulation cycle Δt, for instance, should not be compared (see e.g. Bauschat (1990)). Different signal source characteristics exist. The main problems are particular time delays, which occur in a real a/c system. This kind of time delay results in a time shift between the flight states of model and host a/c. It is important to know the value of this delay because then it can be taken into account during the data evaluation process. Concerning the ATTAS IFS the flight states of the model a/c must be shifted +0.15 s on the time axis to make them comparable with the state variables of the host.

The reason for the noise in the signal of α_H, which is plotted in Figure 3, has been explained. If the influence of turbulence on the in-flight simulation is not a subject of the investigation, it might be disturbing. In such a case the signal has to be lowpass filtered. First the correct value of the lowpass filter cut-off frequency has to be investigated. The frequency of the short-period mode f_{SP} could be used to guarantee that only those frequencies are taken into account which are caused by this natural mode. The value of f_{SP} for the VFW 614-ATTAS is about 0.2 Hz in the discussed approach configuration. Figure 4 shows that this would be a critical value.

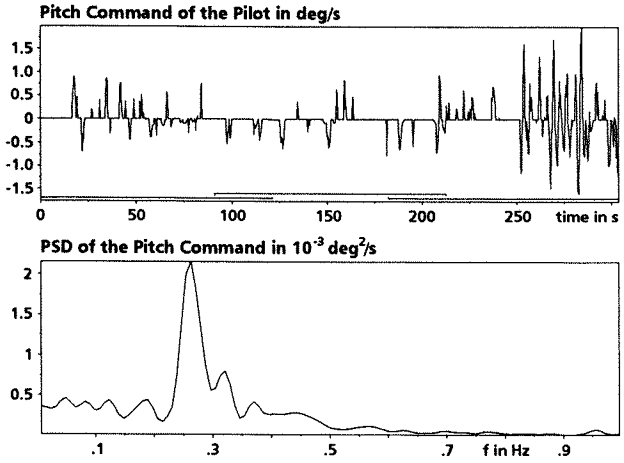

Figure 4: Pitch Command of the Pilot and its PSD

In the first diagram the pitch command of the pilot during the above-mentioned ILS approach (Figure 3) is plotted. The second diagram shows the PSD of the command, which makes it obvious that a significant influence of the pilot lies below 0.5 Hz. Using f_{SP} as cut-off frequency of the filter would lead to a suppression of the main part of the pilot command. The result of the low-pass filtering with 0.6 Hz cut-off frequency is illustrated in Figure 5.

The filtered signal is easier to compare with the angle of attack of the model a/c. It can be seen that there are still distubances on α_H. The source is gust influences which are not filtered.

In the next sections two methods will be shown, as to how the model following quality, based on the post conditioned data, can be evaluated.

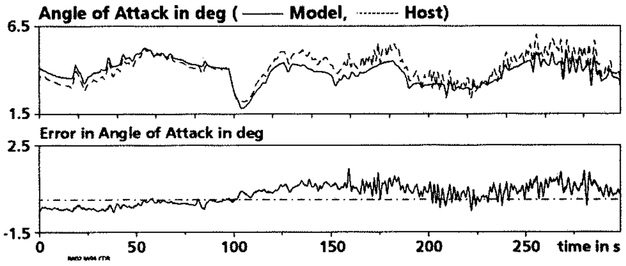

Figure 5: Low-pass filtered α_H and the comparison with α_M

4.3 Statistical Evaluation

The result of equation (1), the error $\Delta x(t)$, can be used for statistical data evaluation. The determination of the *Standard Deviation* $s_{\Delta x}$ of the error can be determined.

Standard Deviations for the error curves of the above discussed ILS approach:

- in Figure 3
  - $s_{\Delta\alpha} = 0.493°$
  - $s_{\Delta\Theta} = 0.344°$
- of the angle of attack computed with low-pass filtered α_H (Figure 5)
  - $s_{\Delta\alpha} = 0.435°$

It was expected that the deviation between the angles of attack of host and model on the basis of a filtered α_H is smaller. The difference between the standard deviations is 11.76 %.

4.4 The Delta Rating

At the beginning of this section, it was described how the engineer usually evaluates the result of a model following control: He tries to find out how

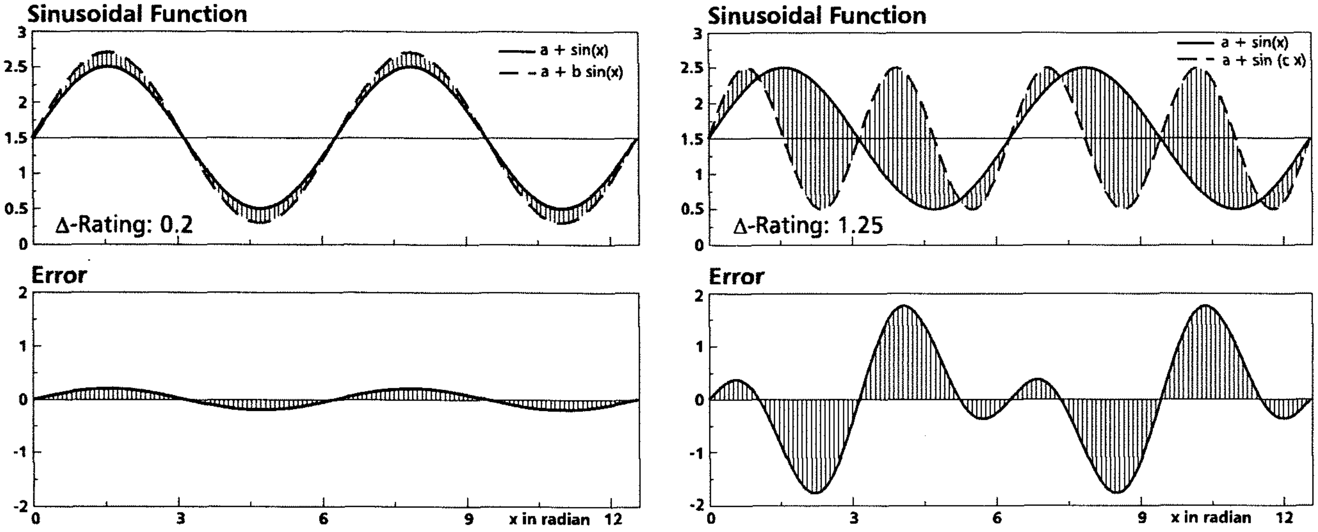

Figure 6: Examples for the Application of the Delta Rating

well the signal generator input (model a/c) and the output of the system to be controlled (host a/c) match. This way is supported by the following approach which is called Delta Rating ($\overline{\Delta}_R$). It is defined by the ratio:

Delta Rating =
Model Following Error / Desired Signal

The mathematical description is based on the following assumptions and equations:

- The states of model and host are given in a time interval $[t_1, t_2]$.
- The reference states in the time interval can be determined.

It is now essential for the idea of the Delta Rating, that the deviations from the given reference state of the model a/c are evaluated. These deviations are integrated using the following equation:

$$X(t) = \int_{t_1}^{t^2} | x(t) - x_{Offset} | \, dt \tag{2}$$

In the case of a flight state, which has to be integrated with equation (2) x_{Offset} is the constant reference flight state of the actual flight segment. Its value has to be found out in advance.

The model following error (equation (1)) is integrated in the following way:

$$\Delta X(t) = \int_{t_1}^{t^2} | \Delta x(t) | \, dt \tag{3}$$

With the integrals (2) and (3) a mathematical interpretation of the Delta Rating can be given:

$$\overline{\Delta}_R = \frac{\Delta X(t)}{X(t)} \tag{4}$$

The simple nature of $\overline{\Delta}_R$ provides a direct impression of the model following quality. Two limiting values can be distinguished in an exemplary way:

- $\overline{\Delta}_R = 0$: The two curves which have to be compared are identical.
- $\overline{\Delta}_R = 1$: The plane under the error curve is equal to the plane under the curve of the desired signal. This would be an example of a bad ratio.

Figure 6 illustrates an example with the help of three sinusoidal functions. The constants are selected as follows:

$a = 1.5 = x_{Offset}$
$b = 1.2$
$c = 2$

With equation (2) one arrives at:

$$Y_1(x) = \int_0^{4\pi} |\sin x| \, dx = 8$$

$$Y_2(x) = 1.2 \int_0^{4\pi} |\sin x| \, dx = 9.6$$

The error between $Y_1(x)$ und $Y_2(x)$ has to be calculated with equation (1):

$$\Delta Y_{21} = Y_2(x) - Y_1(x) = 1.6$$

The rest of the necessary results of the example in a shorter form:

$$Y_3(x) = 8, \; \Delta Y_{31} = 10$$

With these calculated values, two Delta Ratings can be determined:

$$\overline{\Delta}_{R,\,Y21} = \frac{\Delta Y_{21}}{Y_{21}} = 0.2$$

$$\overline{\Delta}_{R,\,Y31} = \frac{\Delta Y_{31}}{Y_{31}} = 1.25$$

In Figure 6 the curves can be seen, which are represented by the equations of the example.

This approach can now be applied to the the flight-test results at the beginning of this section. First Figure 3, the Delta Rating for the model following quality for the angle of attack (α_H unfilterd) and the pitch angle:

$$\overline{\Delta}_{R,\alpha} = 0.86$$

$$\overline{\Delta}_{R,\theta} = 0.37$$

Taking the low-pass filtered α_H into account (Figure 5):

$$\overline{\Delta}_{R,\alpha} = 0.82$$

The improvement in the Delta Ratings of the angle of attack model following is 4.7 %. Compared with the Standard Deviations given above, it can be seen that the Delta Ratings indicate a good model following for the pitch angle. The error between α_M and α_H is obviously more significant related to the desired signal and in particular related to the Standard Deviation.

The Euler angles play a dominating role in the in-flight simulation, because they are controlled directly by the pilot. They are modelled adequately in this case and not only in the longitudinal motion, which is presented here, also in the lateral motion (see e.g. Bauschat (1991)). During the last five years, numerous flight-test hours with about fifteen experienced test pilots have been performed. They all gave this in-flight simulation only good or excellent ratings. Based on the given analytical and subjective evaluations, the data base, which is gained with the airborne simulation, is a good reference for the comparison.

5. The Comparison of two Real-Time Simulators

The two real-time simulators, which were compared in the first phase of the AIDA-programme, are:

- ATTAS ground-based simulator

  The real-time simulation of ATTAS on ground simulates the a/c as well as it is possible to do without a motion cue. The onboard data-processing system consists, as in the real a/c, of MIL-specified computers. An original ATTAS-cockpit belongs to the simulator. The standard of the ATTAS ground-based real-time simulator allows the realization of typical experiments concerning simulation technique (see e.g. Saager (1990)).

- ATTAS in-flight simulator

  The main features of this flying test-bed were described above.

5.1 Past Experience

'The comparison of ground-based and in-flight simulation techniques makes it necessary to perfom demanding and reproducible piloted tasks. The decision, which kind of task should be selected, must be the result of thorough investigations. During the last two decades a lot of papers have been published dealing with man-machine-interfacing in combination with real-time simulation or flight-tests. Three examples of studies where valuable experience has been gained are most interesting for this work.

5.1.1 Flared Landing Approach Flying Qualities

The aim of this programme was to investigate what

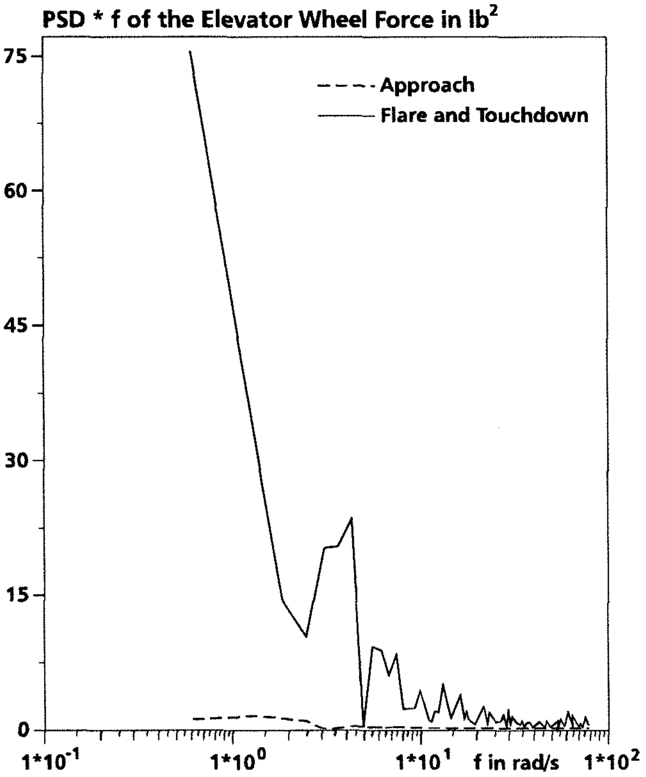

Figure 7: Example for a Smooth Piloting Technique

kind of command response (angle of attack or pitch rate) and its characteristics were prefered by the pilots. Weingarten et al. (1986) have summarized the results.

The NC-131H TIFS (Total In-Flight Simulator) was used and seven evaluation pilots with different experience were involved. They had the task to intercept an ILS glide slope. In addition to this pitch task the experiment started with a lateral offset. In order to further assure the pitch task activity, a (1 - cosine) angle of attack gust was fed to the model during the approach. A desired touchdown area was defined on the runway. The pilots gave Cooper-Harper ratings for the different control systems.

One result was very interesting in connection with investigations concerning the man-machine interface. The individual piloting technques affected the pilot ratings of a configuration. Two typical flight-test results prove this. Figure 7 shows the PSD of the elevator wheel force of a pilot who exhibited a smooth technique with minimum stick activity.

A completely different control technique is illustrated in Figure 8. The PSD shows that this pilot was constantly pumping or *dithering* the stick during the approach.

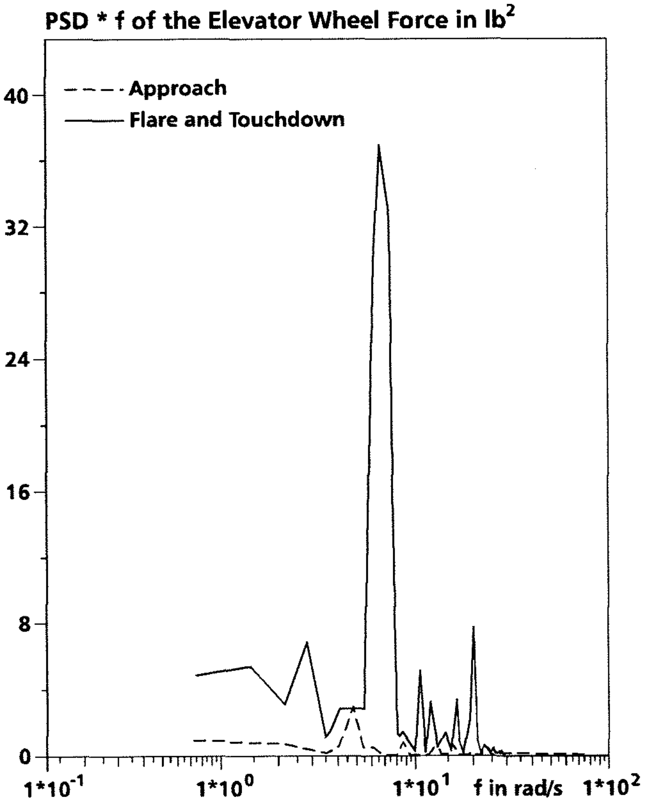

Figure 8: Example for High Stick Activity During an Approach

Both pilots flew the same configuration simulated in flight. However, during this particular programme they flew several different configurations and tended to prefer those, which supported their individual technique.

This result influences in general the design of a task, which will be flown by different pilots during an investigation. It must be demading enough for pilots with a wide variety of backgrounds. In addition, the task should accomodate the widest possible range of piloting technique.

5.1.2 Analysis of Shuttle Orbiter Handling Qualities

Ashkenas et al. (1983) summarize a study of the Shuttle Orbiter approach and landing conditions. Deficiencies caused by pilot-induced oscillations (PIO) were observed during a manually flown landing.

During the investigation the pilot control characteristics of the Orbiter were compared with a YF-12. This a/c flew the Orbiter approach and landing task without problems.

An exploratory piloted simulation was devised to confirm that analytically exposed differences were operationally significant. A simple fixed-based simulator was used, which is normally not PIO sensitve. A task was defined, based on a particular CRT symbolism. It gave the pilot a sense of urgency and a need for fast response.

The selection of an adequate flare and touchdown task made reproducible real-time simulation results possible, which intern show the typical handling quality charateristics of the two vehicles. As inflight, the pilots had no problems in controlling the YF-12. In the Orbiter simulation, large attitude excursions occurred and both attitude and altitude traces were oscillatory.

5.1.3 Flight Simulator Motion and Pilot Performance

A study was conducted to determine the effects of alterations in flight simulator motion upon pilot performance and opinion (Bussolari et al. (1986)). Eighteen airline pilots were given a series of flight scenarios in a Phase II Boeing 727 simulator under varying conditions of simulator motion. Three motion platform conditons were compared: full six DOF motion, vertical and lateral translational motion and small amplitude vertical translation motion commonly called *special effects*. The scenarios were chosen to reflect the flight manoeuvres that these pilots might encounter during a routine pilot proficiency check (engine flameout, typical airwork, approach and landing), which are usually not aggressive.

The subjective and objective data collected in the study suggest that large, complex motion platform systems may not be necessary for either reasons of pilot acceptance or performance. It was found out that the presence of a wide field-of-view visual scene and sufficient *special effects* may be adequate for the investigated type of a/c under normal training operations.

5.2 The ILS-Tracking Task

A tracking task, in general, causes the pilot to compensate generated offsets (see e.g. Koehler et al. (1988)). Programmable CRTs allow it to generate a symbol, which indicates to the pilot an offset from a given fixed reference. This can be a special symbol depending on the particular experiment. But it is also possible to use the indications the pilot is familiar with. These are, for instance, the flight director bars, which the pilot needs to perform an ILS approach (see section 4). These bars are in use for the AIDA-programm. The basis is a synthetic navigation system, which is computed in real-time. All typical elements of a navigation system are available and can be combined as desired.

For this tracking, a glidepath-, a localizer transmitter and a DME are necessary. The cone effect is also simulated. The designed task is shown in Figure 9.

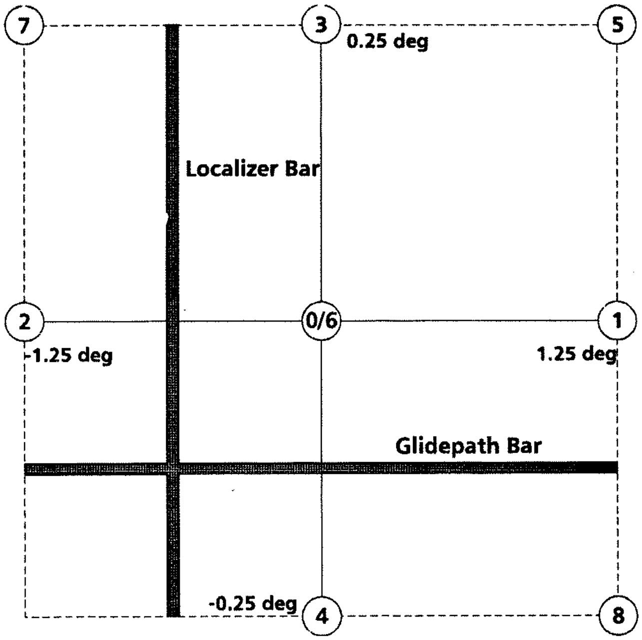

Figure 9: Offset Sequence of the Flight Director Bars

In all cases, which will be discussed, the experiment started between FL 180 and FL 200. Most of the flights had no or light turbulence, so it was not a factor. Some flights were performed with a constant headwind. The pilot had to stabilize the a/c in a given configuration and a given speed with a climb angle of -1.5°. The flight-test engineer started the tracking with a switch. At that moment, a short initialization process was started. Based on actual flight states (heading, altitude, position) the simulated ILS was located 55 kilometres in front of the a/c and 1440 m below it. The data on the CRTs of the testpilot, like heading, altitude, speed and distance were related to the simulated ILS.

The tracking had 9 phases (Figure 9) and began with both bars in the middle (Nº 0). It was found out that it makes sense to halve the normal maximal deflections of the bars of a real ILS. The used values were:

- Glidepath: ± 0.25°
- Localizer: ± 1.25°

After a given time (60 s) the Localizer bar jumped to the right (Figure 9, Nº 1). That indicates that the a/c is left of the localizer beam. The pilot now had again 60 s to compensate this offset and so on.

Coming nearer to the transmitters, the degree of difficulty of the task increased because of the cone effect. The indication became more and more sensitive.

5.3 Familiarization Flights

A pilot, who has perhaps never flown the a/c to be simulated, must have the opportunity to familiarize himself with the particular type. Especially if he has never flown an in-flight simulator. On ATTAS, the pilot has to perform tasks which are representative for the longitudinal- and the lateral motion. These tasks are usually flown in a test-area and at a safe altitude. The reason therefore is that the pilot must have the opportunity to concentrate on the a/c to be simulated. Typical tasks are:

- Descents and climbs
- Changes in the heading
- Turns
- and a combination of the three mentioned tasks

Each run on the particular simulator had the same task sequence. The evaluation pilots first flew the familiarization tasks and then they flew the tracking experiment.

In the following section, some selected results will be discussed.

6. Flight-Test and Simulation Results

During the first phase of the investigation, three licensed testpilots were involved. Concerning the level of experience, the group was relatively heterogeneous.

All pilots first flew the experiment in the ATTAS ground-based simulation and then on the in-flight simulator. When it was possible, they performed it again on the ground after the flight-test. Every pilot flew the whole programme in a period of not more than three days.

The nonlinear simulated a/c was in all cases a wide-body transport a/c (two engines, 115 tons). The a/c was controlled in the pitch and the roll-axis with a sidestick and a rate command attitude hold system.

6.1 Investigation of the Effort to Solve the Task

A typical result is illustrated in Figure 10. The curves 1, 2 and 3 are the PSD of the pitch command of Pilot A flown in the fixed-based simulation. Number 4 and 5 are flight-test results. The numbering of the curves corresponds to the sequence of the runs.

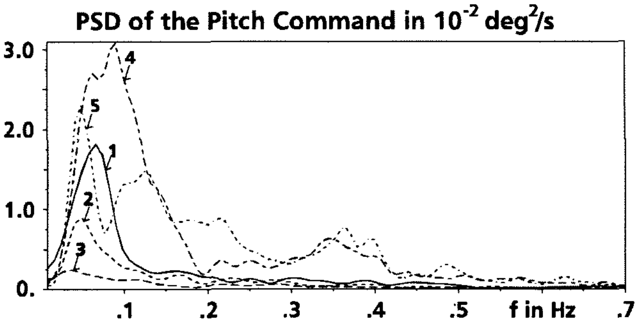

Figure 10: PSD of the Pitch Command and Standard Deviations (Pilot A)

First, the three runs performend on the fixed-based simulator: It can be seen that the effort to solve the task in the pitch axis decreases. The frequency of the maximum PSD value also decreases. It indicates that the pilot reduced his efforts by increasing his skill with every run.

With regard to the runs in the flight-test, it can be stated that the effort illustrated by the PSD curves 4 and 5 is significantly higher. It is also obvious that the range of the frequencies envolved is much higher.

The PSDs of the flight-test can be compared with the one given in Figure 4, where an ILS-approach under the influence of turbulence was performed. During that approach the peak of the PSD was at a higher frequency (f = 0.26 Hz) than during the tracking, but the introduced energy was at a lower level.

An interesting result is shown in Figure 11. A very experienced test pilot (Pilot B) performed these runs. Pilot B has a different control technique to Pilot A. His stick activity was much smaller. It is the same effect, which was discussed in the handling qualities programme mentioned in section 5.1.1.

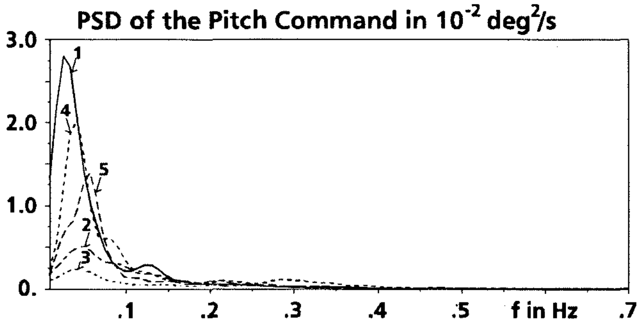

Figure 11: PSD of the Pitch Command and Standard Deviations (Pilot B)

There is a significant difference between run Nº 1 and 2 of Pilot B. Compared with the first try, the maximum PSD value was reduced by about 80%

during the second run. He minimized his effort to solve the task, which is a result of a fast learning process based on his experience.

In the flight-test, the almost same effect can be observed but with an increased PSD peak value. Pilot B performed the task again with minimum pitch command activity.

6.2 Rating of the Task Solution

For this investigation, it is important to know how well the evaluation pilots solved the task. An optimal result would be a fast compensation of the tracking error with respect to the dynamic of the simulated plant.

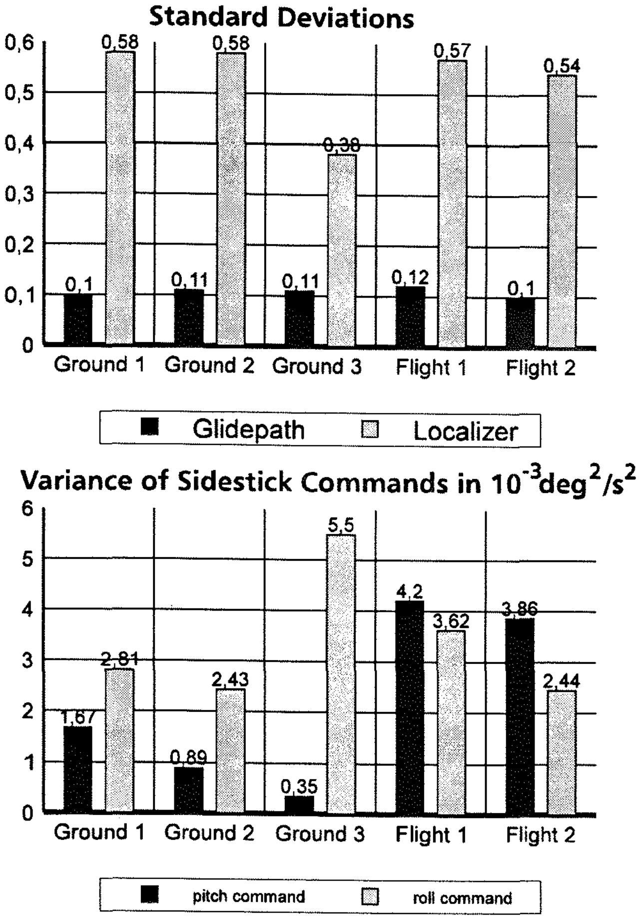

Figure 12: Standard Deviations and Variance Values (Pilot A)

Figure 12 shows, in the first diagram, the standard deviations of the error in the glidepath and localizer compensation of Pilot A. The values are nearly constant except ground-based simulation run 3 concerning the localizer.

A good additional impression is given in the second digram. It shows values for the integrals of the surfaces under the PSD-curves, the variance of sidestick pitch and roll command. It can be seen that the better compensation of the localizer error during ground-test 3 is caused by high roll command activity. During ground-test 1 and 2 and flight-test 1 and 2 Pilot A performed, as mentioned, the task with a constant quality (standard deviation). The variance values of the flight-tests, especially of the pitch command, indicate his significantly higher effort to achieve this result.

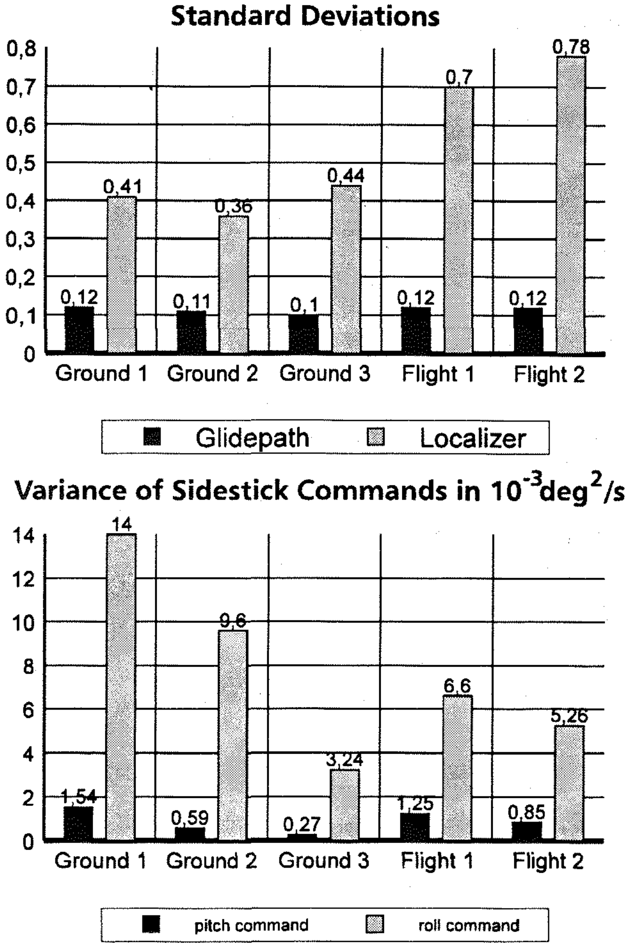

Figure 13: Standard Deviations and Variance Values (Pilot B)

Values of the standard deviation and the variance of the runs of the experienced pilot (Pilot B) is shown in Figure 13. The level of the standard deviations concerning the glidepath error is nearly the same and comparable to the results of Pilot A. There is again no significant difference between ground-based simulation and flight-test. In the flight-test, he obviously had more problems to compensate the localizer deviation than Pilot A. The values of the variance in the second diagram indicate, that a high stick activity in the roll axis was also necessary for Pilot B to solve the task adequately.

7. Summary and Prospects

It was shown that the in-flight simulation is suitable to deliver reference data as a basis for the evaluation of ground-based real-time simulators. With the help of a statistical evaluation and a rating method, the quality of the nonlinear in-flight simulation, which is in use on ATTAS, has been proved.

A particular kind of manoeuvre, an ILS-tracking, has been designed. It has been performed by several pilots in a fixed-based and an in-flight simulator. The results which have been gained show significant differences in the control behaviour of the pilots on ground and in the real a/c. The influence of the experience the pilot has can be investigated.

The given results show that an increased effort of the pilot is necessary, if the quality of the solution in-flight has to be the same than in the ground-test. It indicates the difference between the training situation on ground and the *real airwork*.

It was found that the experiment is adequate and delivers data, which are suitable for the comparison study. The evaluation pilot should still have to perform the task several times on one simulator. But with every run, the task should be more aggressive. The degree of difficulty can be increased by the following modifications:

- the time, which the pilot has to compensate the generated offsets can be reduced.
- a certain level of simulated turbulence can be introduced. It increases the stick activity (see Figure 4).
- the task should also be performed at lower altitudes
- it may increase the motivation of the pilot if the quality of the solution is indicated on a CRT during the task. For instance, with a symbol that changes the colour from green to orange and red in the case of decreasing quality and vice versa.

An additional aspect will be the investigation of the influence of a motion system. The research simulator described in N.N. (1992) will be used. This third simulator will be a good supplement to the systems which have been described in this paper.

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