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ABSTRACT
Flight simulation can be divided in two main areas: flight simulation for training air crews and flight simulation for research purposes. In this paper an overview of research flight simulation specific technology is illustrated by some examples from the Research Flight Simulator (RFS) of the National Aerospace Laboratory NLR. Then from these examples a common characteristic feature is presented which can serve as a guideline for research flight simulation technology.

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THE 'SMART SOFTWARE - SIMPLE HARDWARE' CONCEPT

FOR MAXIMUM FELXIBILITY IN RESEARCH FLIGHT SIMULATION

by

J.M. Hoekstra

This paper has been presented at the American Institute of Aeronautics and Astronautics (AIAA) Flight Simulation Technologies Conference, August 1-3, 1994, Scottsdale, AZ, USA.

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THE 'SMART SOFTWARE - SIMPLE HARDWARE' CONCEPT FOR MAXIMUM FLEXIBILITY IN RESEARCH FLIGHT SIMULATION

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Abstract

Flight simulation can be divided in two main areas: flight simulation for training air crews and flight simulation for research purposes. In this paper an overview of research flight simulation specific technology is illustrated by some examples from the Research Flight Simulator (RFS) of the National Aerospace Laboratory NLR. Then from these examples a common characteristic feature is presented which can serve as a guideline for research flight simulation technology.

RESEARCH VS TRAINING FLIGHT SIMULATION

Below (figures 1 and 2) two simulator cockpits are shown, representing the two main areas where flight simulation is exploited: research and training. Most uses of flight simulation can be placed under one of these two headers. The military mission rehearsel for example is a form of training, while some tactical evaluations can be regarded as research.

A third category form simulators built for entertainment. Because the technology of these simulators is still very different, this category will not be discussed here.

Though the two simulator cockpits in the figure resemble each other, the technology of research simulators and training simulators is quite different. This is due to the different purpose of these simulators, leading to different requirements.

WHY FLEXIBILITY?

Table 1 shows some requirements that are specific to research simulators and training simulators. In this paper the specific technology for a research simulator will be discussed. Typically a research simulator cockpit is being rebuilt and modified several times a year. To minimize this effort, a high degree of flexibility is essential for a research flight simulator. One should be able to modify, replace, expand and adjust all systems in the cockpit and often even be able to simulate different aircraft types.

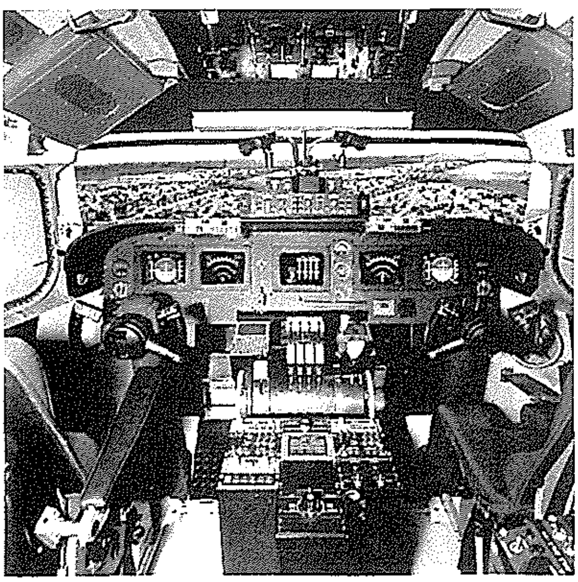


Fig. 1 Research flight simulator cockpit

Fig. 2 Training flight simulator cockpit

TRAINING SIMULATORS:	RESEARCH SIMULATORS:
- degree of realism depending on nature of training	- degree of realism depending on nature of research
- failures should be simulated realistically	- different aircraft types have to be simulated
- hardware & software represent one specific aircraft type	- experiment scenario's have to be simulated realistically
- user friendly instructor-station	- hardware & software should be easy to modify
- should comply with regulations	- extensive real-time data recording
	- ....? (any experiment dependent requirement)

Table 1 Requirements for training and research flight simulators

Furthermore, research flight simulators require not only 'basic' flight simulation but also special features, such as extensive data recording, sometimes even physiological measurements.

Realism is an important aspect in flight simulation. The degree of realism is largely technology driven. There are two different aspects to the realism of a good simulation: realistic models, which ensure the behaviour matches the reality, a realistic environment, ensuring a realistic feel and look. Realistic models are not only dependent on the available data but also on the computing power available. The realistic environment is more easily realised by using similar devices in the cockpit or copying the real devices enhanced with simulation specific options.

It is difficult to specify how realistic the simulation for an experiment should be, so a researcher often wants to be on the safe side and wants as much realism as he can get. This requirement for realism conflicts with the requirement for flexibility. As an example of this, for simulating analog flight instruments the most flexible, less realistic would be to draw the instruments on the screen of a graphics workstation, while the most realistic option, building the real instruments, is not very flexible.

When solving this contradiction one easily runs into the well known simulation vs. stimulation dilemma. Should we take the real system and fool it with simulated inputs (the stimulation option) or should we try to replicate the system adapted for the simulator (the simulation option)? To complicate things, in a research simulator one wants to be able to do both. Sometimes an easy-to-modify simulation of a system is used for conceptual design evaluation, and the real system is later 'stimulated' for final evaluation or certification.

Another feature of research simulators rarely found in training simulators is the ability to simulate different aircraft types. This is a second kind of flexibility that is required for research flight simulators. The NLR RFS is used to simulate Boeing 747-400/200, Fokker 100, Cessna Citation business jet, Swearingen Metro turboprop, a helicopter model and, with a fighter cockpit, the F-16.

How a high degree of flexibility is reached in the NLR RFS transport cockpit without sacrificing the realism, is shown in some examples, before a common concept or guide line for research vehicle simulation technology is defined.

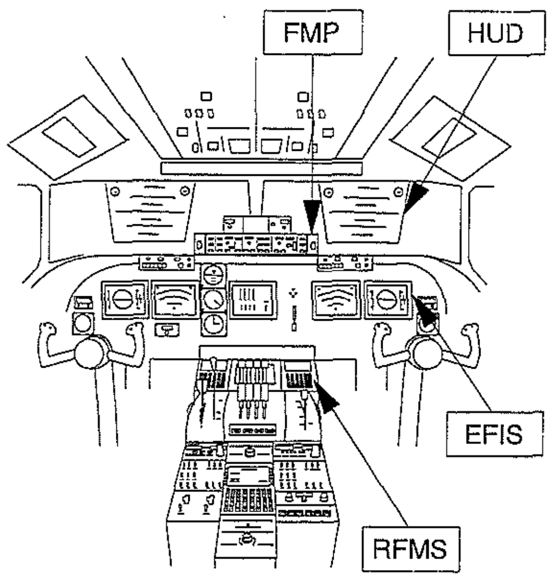


Fig. 3 NLR Research Flight Simulator Cockpit

EFIS

The EFIS in the RFS is generated by graphical workstations. Up to four displays are drawn on the screen of a workstation. A device called videosplitter converts the screen picture to four separate video signals, dividing the screen in four quadrants. These pictures are displayed on separate tubes in the cockpit. The program drawing the pictures was written by NLR and uses the graphical library of the workstation. This program has access to all variables of the main simulation program. This yields a high versatility enabling totally new displays to be used with new symbology and new information, such as enhanced vision (using IR/radar as sensors) or a tunnel-in-the-sky display.

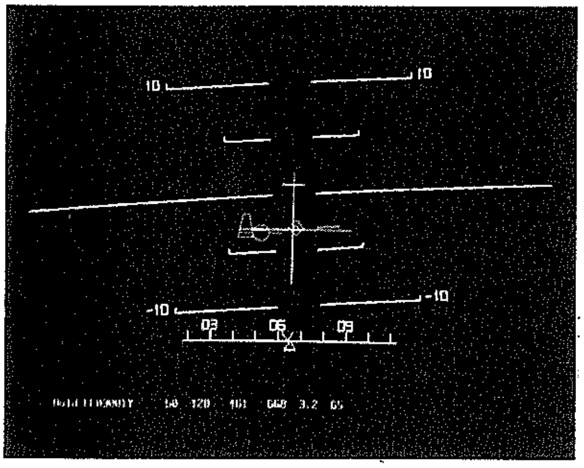


Fig. 4 Head-Up display of NLR RFS

A Head-Up-Display (HUD) is generated in the same way. The HUD is drawn on a graphical workstation. The resulting HUD video signal is mixed with the out-of-the window view video signal, producing a good simulation of an ideal wide-angle HUD[2]. Next to this flexible configuration, there is the alternative of using the actual EFIS displays, with the ARINC-interface in the simulator, for evaluation/ certification of real flight hardware. The Fokker 100 EFIS symbology was evaluated and certificated using this approach[3].

An interesting feature for display designers is the compatibility of the RFS with the DDF/NADDES display format[4]. This generic display format allows a display designer to specify and test a display in DDF format on eg. a PC on his desk. The resulting DDF-description of the display can directly be used in the simulator without any modification. This smooths the design traject enormously and thus enables the testing of display concepts in the realistic environment of the simulator.

FLIGHT MODE PANEL

The flight mode panel (or mode control panel) is used to control the autopilot and autothrottle functions. In the NLR RFS this panel is basically a panel with switches, dials, lights and digital displays. The logic of arming and engaging modes is very complex and dealt with by software. But simple logics such as the increase of the display value due to clicks of the dial is also performed by

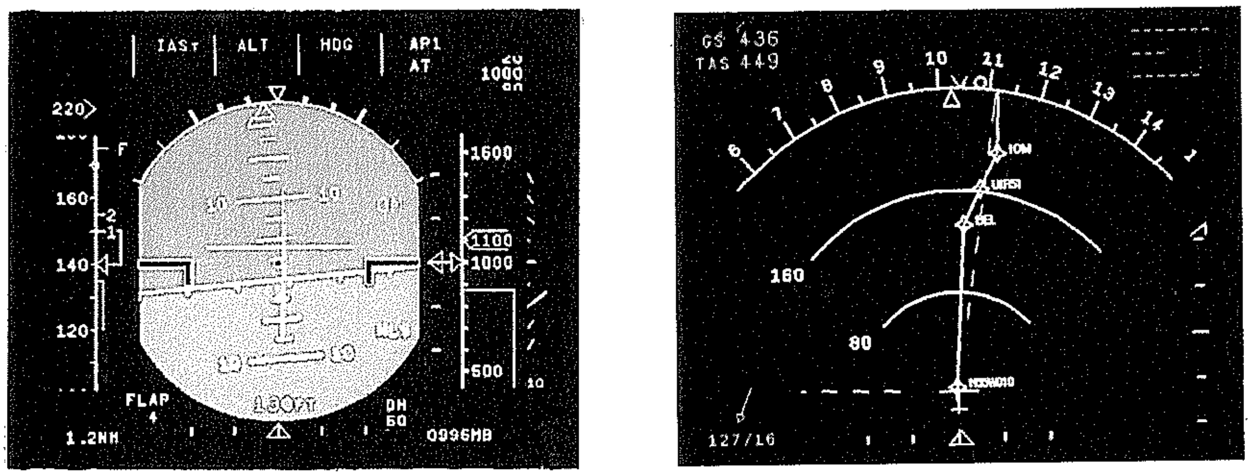
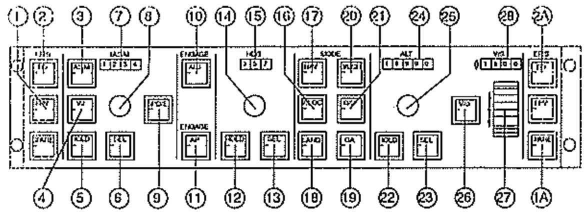


Fig. 5 Fokker Electronic Flight Instruments System (EFIS)

The figures above left and above right show the primary flight display and the navigation display in map mode, respectively. This EFIS lay-out is based on the Fokker 100 format. The Fokker 100 EFIS symbology was evaluated and certificated using the research flight simulators of Fokker and NLR in the period from 1981 to 1987. Several changes resulted from the experiments. The final result is a very neat EFIS picture. This EFIS symbology is used for several aircraft types in the NLR RFS. Pilots are always very pleased with this format, which is easy to learn and takes a very short time to adapt to. Sometimes for project dependent reasons, however, the EFIS symbology is changed to the actual format of the type of aircraft to be simulated. The EFIS program is easy to adapt to all user specified formats. In the certification phase of the Fokker 100, actual EFIS tubes were used in conjunction with the ARINC Bus Interface System of NLR's research simulator.

the software. So this is a good example where all the intelligence is in the software, resulting in very simple and straightforward hardware and maximum flexibility. It can easily be adpated for different aircraft types.



1 FLIGHT PATH VECTOR
1A FLIGHT PATH VECTOR
2 FLIGHT DIRECTOR
2A FLIGHT DIRECTOR
3 IAS/MACH SELECTOR
4 V2 SELECT ON/OFF
5 SPEED HOLD
6 SPEED SELECT
7 SPEED DISPLAY
8 SPEED KNOB
9 SPEED ON ELEVATOR
10 AUTO THROTTLE ON/OFF
11 AUTOPILOT ON/OFF
12 HEADING HOLD
13 HEADING SELECT
14 HEADING KNOB
15 HEADING DISPLAY
16 VOR/LOC SELECT
17 LNAV SELECT (FMS)
18 LAND MODE
19 GO AROUND
20 VNAV SELCT (FMS)
21 GLIDE SLOPE
22 ALTITUDE HOLD
23 ALTITUDE SELECT
24 ALTITUDE DISPLAY
25 ALTITUDE KNOB
26 VERTICAL SPEED SELECT
27 VERTICAL SPEED WHEEL
28 VERTICAL SPEED DISPLAY

Fig. 6 Flight Mode Panel

FLIGHT MANAGEMENT SYSTEM (FMS)

Today's aircraft are equipped with a flight management system (FMS) for navigation, performance management and cost management. This 'brain' of the cockpit can be divided into two main systems: the Command & Display Units (CDU's) and the Flight Management Computers (FMC's). The CDU is the man-machine interface and is used by the pilot to enter data such as route changes. The FMC is the main computer of the system, performing all the calculations and autopilot guidance commands. Both contain some logic and communicate with each other. In the NLR RFS again the logic is in the software running on a workstation. This program contains both the FMC- and CDU-simulation. The contents of the CDU screens is drawn on a graphical workstation and sent to the CDU screens via the video splitter. The program reads the codes of the keys pressed on each CDU. Everything that happens in-between is dealt with in the simulation program, which was written in-house, based on information from the operations manual. The resulting possibilities are far more than with flight hardware. New experimental pages can be added very quickly. Graphical formats can be used on the screen of the CDU and the function of the keys is fully programmable.

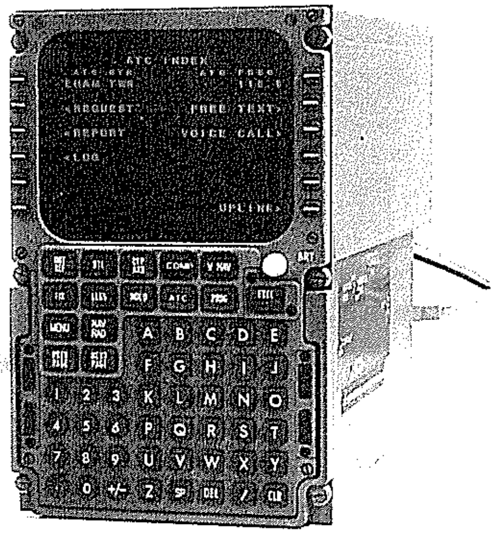


Fig. 7 Simulator CDU as used in RFMS

The first experiment utilizing the flexibility of this FMS simulation, also known as Research Flight Management System (RFMS), was the FAA Data Link experiment, where the CDU was one of the man-machine interfaces under investigation for operating the ATC Data Link[5]. For this experiment a complete ATC menu has been developed and implemented in the FMS software, linking FMS route data to the ATC datalink pages. The advantage of the in-house written Boeing 747-400 FMS simulation program is obvious: new data link pages are easily added. Also a new functionality, the data link interface, was added to the RFMS program. The interface has been expanded with another datalink protocol and a series of automatic functions to transfer ATC clearances to the FMC. In a follow-up of the first datalink experiment, the main topic was the human factors of the man-machine interface of the data link. The interface was more automated than in the first experiment. The RFMS is now a standard feature in the full glass cockpit of the NLR RFS and is used in every experiment and for different aircraft types.

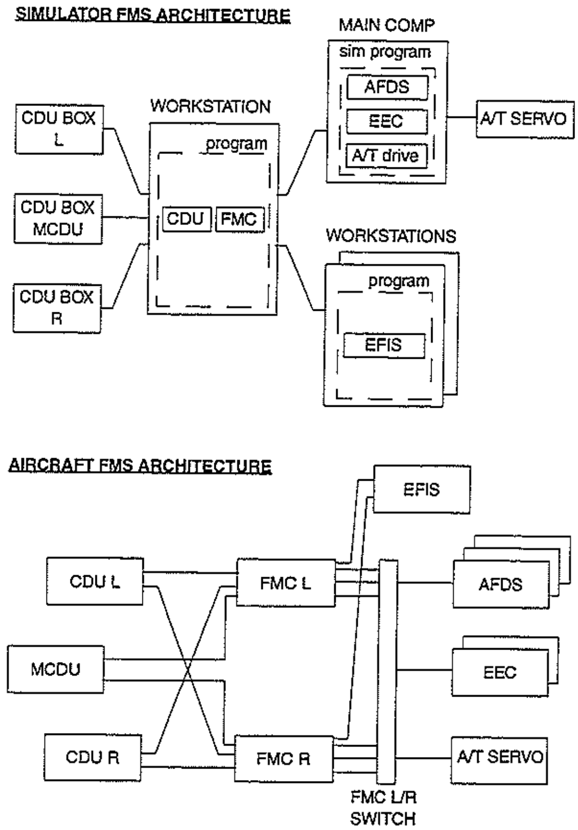


Fig. 8 Difference between aircraft and research simulator in architecture FMS

CONCEPT

In the example above there is one common characteristic feature, which is typical for a good research flight simulator. This is the so-called 'smart software-simple hardware' concept. This means that the complex functions and logics should be dealt with in the software as much as possible, in this way reducing the complexity of the hardware.

For example, in the case of the FMS, the CDU used in the RFS is nothing more than a display and switches. All the logic including scratchpad functions and the drawing of the characters is performed by the simulation software. The same goes for the other two examples: EFIS/HUD and Flight Mode Panel. In real aircraft, hardware units (incl. software) are more autonomous communicating via the ARINC bus.

The basic idea is that in general software is more flexible than hardware. Changing or expanding a program, recompiling and using it is easier, quicker and cheaper than 'bending metal'. This is especially true if the software is developed in-house.

CONDITIONS

Next to the simulation vs. stimulation dilemma, there now is the question: how much can be dealt with in the software? For flexibility as many functions as possible should be dealt with in the software. Doing this, attention should be paid to the following matters:

a. Is the program/computer speed sufficient?
b. Are the data available and are they sufficient?
c. Is the know-how to simulate this system with 'smart software' present?
d. Will the final result be realistic?
e. Is the 'simple hardware' available?

ad a. Is the program/computer speed sufficient?
One of the reasons software can now simulate a range of hardware systems is the enormous development of the processing power of today's computers. This enables the computer to perform complex functions in a small time span, enabling a loop frequency which makes changes appear continuous to the user. The speed requirements strongly depend on: how the simulation is sensed by the user, how fast is the real system to be simulated, how complex is the real system?

ad b. Are the data available and are they sufficient?
To build a software simulation of a hardware system, a lot of data including knowledge of the logic of the system is needed. Obtaining the data is always difficult. There are different ways of obtaining the required data: from the black box approach to a co-operating manufacturer. Sometimes even the manufacturer is not able to answer all questions that arise when a software simulation is designed, because he only builds the hardware solution.

ad c. Is the know-how present to build the software simulation?
A major research institute has the specialists

needed, it has the budget to do research in the area needed. If this is not possible, there are two solutions: choose the (flight) hardware or hire subcontractors to write the software. One should keep in mind that exploiting the main advantage of software, quickly and cheaply changable, could become difficult or impossible in the case of software written by subcontractors, even with proper documentation.

ad d. Will the final result be realistic?
The realism of the flight deck in the final solution should be as high as possible. This in case of the NLR RFS was often the main factor in determining the line between software and hardware functions. The advantage of modern, full glass cockpits is that they use the same technology as was already used in simulation. In the past, some simulators used to draw analog instruments on computer displays, while nowadays the same computer displays are used in the cockpit of the aircraft.

ad e. Is the 'simple' hardware available?
Though the functions of the hardware may be 'simple', the hardware becomes highly specialized. If this hardware cannot be purchased, it sometimes has to be developed by the research institute. This again is no problem for a major institute. The main issue here is: how to make it look realistic, while it is only a collection of switches, lights and/or computer displays. (see example of CDU)

If all these conditions are met, the 'smart software-simple hardware' concept results in a very efficient research flight simulator.

CONCLUSION

In the NLR Research Flight Simulator, where the 'smart software-simple hardware' concept has been in use for years now, we see the result: The simulator cockpit has evolved into a full-glass cockpit with all features of a modern aircraft cockpit: EFIS, Multi-Function Displays, FMS and an optional side-stick controller. The transport cockpit is not only up-to-date but even ahead of its time. It includes futuristic elements such as automated ATC Data Link interfaces, new fly-by-wire concepts, a head-up display, a Take-Off Performance Monitor (TOPM) display[6], and an Experimental Flight Management System for 4D guidance. All come together with the standard features of motion, two different visual systems, data recording, FMS, EFIS, touch screens, radio control panels, optional analog displays and physiological measurements. The application of the 'smart software - simple hardware' concept yields a flexible simulator. Increasing the versatility immediately broadens the scope of the research potential of the simulator. And only that determines the value of the flight simulator as a research tool.

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