HELICOPTER TESTING USING THE PC-BASED MFI 90 FLIGHT TEST INSTRUMENTATION SYSTEM.

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ABSTRACT

DLR realizes flight testing under the rough environmental conditions on board of helicopters. Beside the necessary data about the behavior of the base helicopter the main interest concerns information about the rotor system.
After explaining the measuring technique the computer integrated Rotor data acquisition system is presented which communicates with the Central computer inside the helicopter via serial data line.
The Central computer that has to gather and process also the signals from the base is a modified PC-type computer. It is demonstrated how to use office PC components for this purpose. These have the advantage to be inexpensive and always and everywhere available. The Central computer is a 486er type now. Necessary modifications for airworthy certification are explained. This technique includes on board recording and telemetry.
An intelligent LC display is presented which gives the test pilots the necessary information about their tasks. It is a simply modified notebook controlled only by handling cursor keys. In addition pilots have the chance to fly "head up" by using an LC display which origins from an LCD projection panel.

INTRODUCTION

For DLR's helicopter investigations concerning handling qualities, rotor system identification and noise a flight test instrumentation was designed and tested which combines

* High Performance
* Best Flexibility
* Low Cost.

The system must work under rough environmental conditions (high vibrations and others) and it includes data acquisition, on board recording, telemetry, ground equipment and pilots displays.

The main philosophy is: Never allow the test instrumentation to be responsible for the failure of flight tests because these are growing more and more expensive and are often not repeatable.

High performance means to be able to solve present and calculable future demands. Here the Quantity of signals is about 120, Accuracy 10 bits or better and Sample frequency < 3000 Hz.
The abbreviation MFI means Modular Flight-Test Instrumentation. Many years of experience in this field proofed a modular design to guarantee best flexibility.
PC technology has become the most common computer standard. Best flexibility can be achieved if the FT instrumentation uses its components originally as available at the PC shop next door. If there is some trouble with the instrumentation one should be able to get and replace the necessary parts within hours and wherever the tests may be done. The office PC industry also offers very low prices because of the enormous volume of production and world-wide competition for their components. Using these components leads to get a low cost system. As a result again best flexibility will be achieved because due to low price some sufficient stock of spare components can be available during test campaigns.
The mentioned aspects are true for hard and software. This last item may be even more important. Many intelligent people are working on similar problems with the same tools and may have solved many problems. The rest can be done easily by using any computer language. For PC standard all compilers are available. The resulting EXE files are also generated from inexpensive systems, compilers and programs.
One important aspect should not be forgotten. This technology helps to find solutions that are handy and not too complex and therefore useful not only for a few specialists. This avoids failures.

HELICOPTER TESTING AND MEASURING TECHNIQUE

To understand which tasks this data acquisition system has to fulfil some remarks are made about the problems in this field. In the background of the first picture a vehicle is symbolized drawn, for which the system was developed. It shall show one of DLR's helicopters, a BO 105. In the foreground some results are drawn, which other departments or institutions are expecting for further evaluation. If the pilot, e.g. gives a stick input the instrumentation has to record, transmit and show the reaction of the vehicle (attitudes, rates, accelerations etc.). But more important is what special parts do (mast, blades, tail rotor . . .).

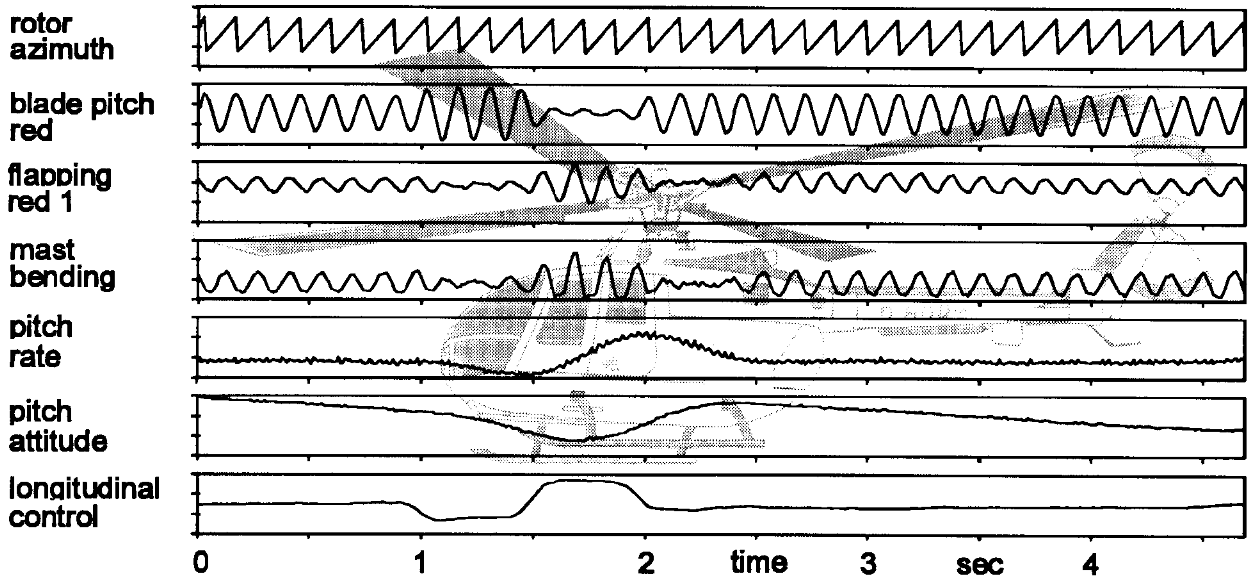


Figure 1. Rotor Response = f (x-Input) of BO 105.

There maybe primary on-line calculations like some filtering. Sometimes a result must be calculated from other signals because this is needed on-line. Normally each signal shall be brought to the ground in original state.

Flight tests with helicopters have one advantage. Often the helicopter can land near the ground station. So on board recorded data are available directly after landing. This circumstance avoids the necessity to record via telemetry on the ground. Only a quick look information about the success of a manoeuvre must be on-line displayed on board and on the ground. For this purpose the test engineers need Time History plots, Fast Fourier analysis, Min/Max or Least Square value information etc.

A problem that can be heard is the noise of helicopters. It is disturbing passengers and people on the ground. Therefore, at many places efforts are made to reduce it by different tricks. To know where to begin, it is necessary to investigate the areas on the blades where the largest amplitudes of the higher harmonic frequencies of the rotor rpm are produced.

Another problem is the high vibration level on board of helicopters. It makes helicopter flying not only less comfortable, but also acts on the materials and last not least it wastes energy. This is caused by the flapping and bending of the blades during the rotation of the rotor.

Fig. 2 shows some examples of the measuring technique that is applied to get the described information. Blades are shown in length and cross-section and on them the places are marked where strain gauges or pressure transducers plus temperature sensors are installed. The installation technique is highly sophisticated because it cannot be allowed to disturb the airflow around the blades by the necessary cables or the transducers themselves. This would lead to wrong results. Another problem is the

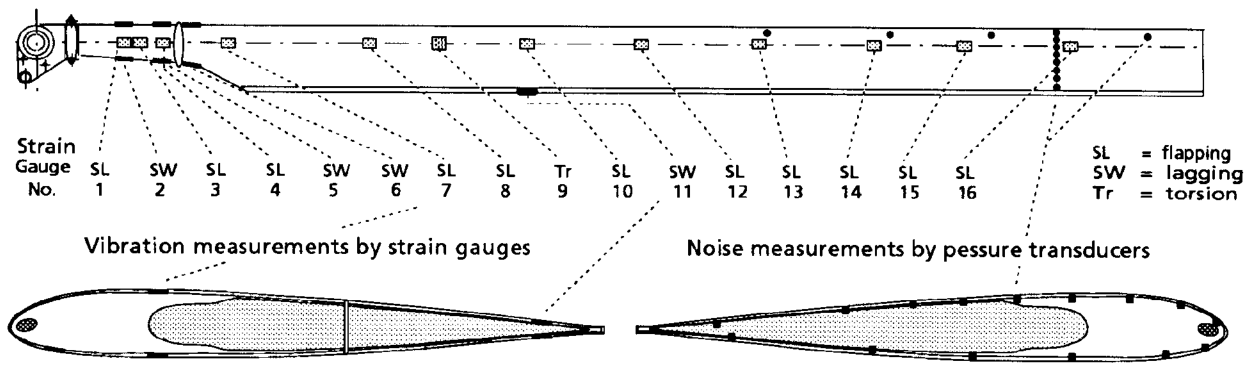


Figure 2. Rotor blade Measuring Technique

lengthening of the blades due to centrifugal forces and the bending. This requires special cable rooting techniques.
Vibration's investigation can be done with a sampling frequency of 300 Hz. The noise detections by pressure transducers (acoustic investigations) need sampling rates of more than 2000 Hz. The result is a large amount of data in a short time. Fortunately the measuring time can be very short (some Rotor RPM's) because data give only reproducible information if the helicopter is in a steady state flight configuration.
It would exceed this report if only some possible measuring failures would be discussed. One point is true, early digitization avoids failures.

THE MFI 90 SYSTEM

Since some years the MFI 90 system was developed to be a flexible tool for variable flight test tasks. The main aspect is to bring more intelligence to the transducers. Transducer groups that are at the same place or can be concentrated there and are producing similar outputs are seen as modules. After a minimum of analog preconditioning, the signals of such a module is A/D converted there, put in a frame and sent to the Central computer as a serial data stream. For synchronisation the measured voltages are stored simultaneously in Sample + Hold's and then digitised one by one to build the frame. Serial transport maybe done by different protocols and depends on data rates according to signals' bandwidth. Sometimes the data rates and protocols are determined by the availability of suitable modules and processor boards. Often it is given by the manufacturer of the certain module. (Some output RS232, like GPS systems, many work with the ARINC protocol, like Strap down systems and Air data computers.) If the Central computer cannot understand the protocol it can be converted there or in the module without any loss of information.
One advantage of these transducer modules system is the possibility of easy exchanging or combining according to different tasks. This saves time because the principle is always the same. Only the program in the Central computer has to be

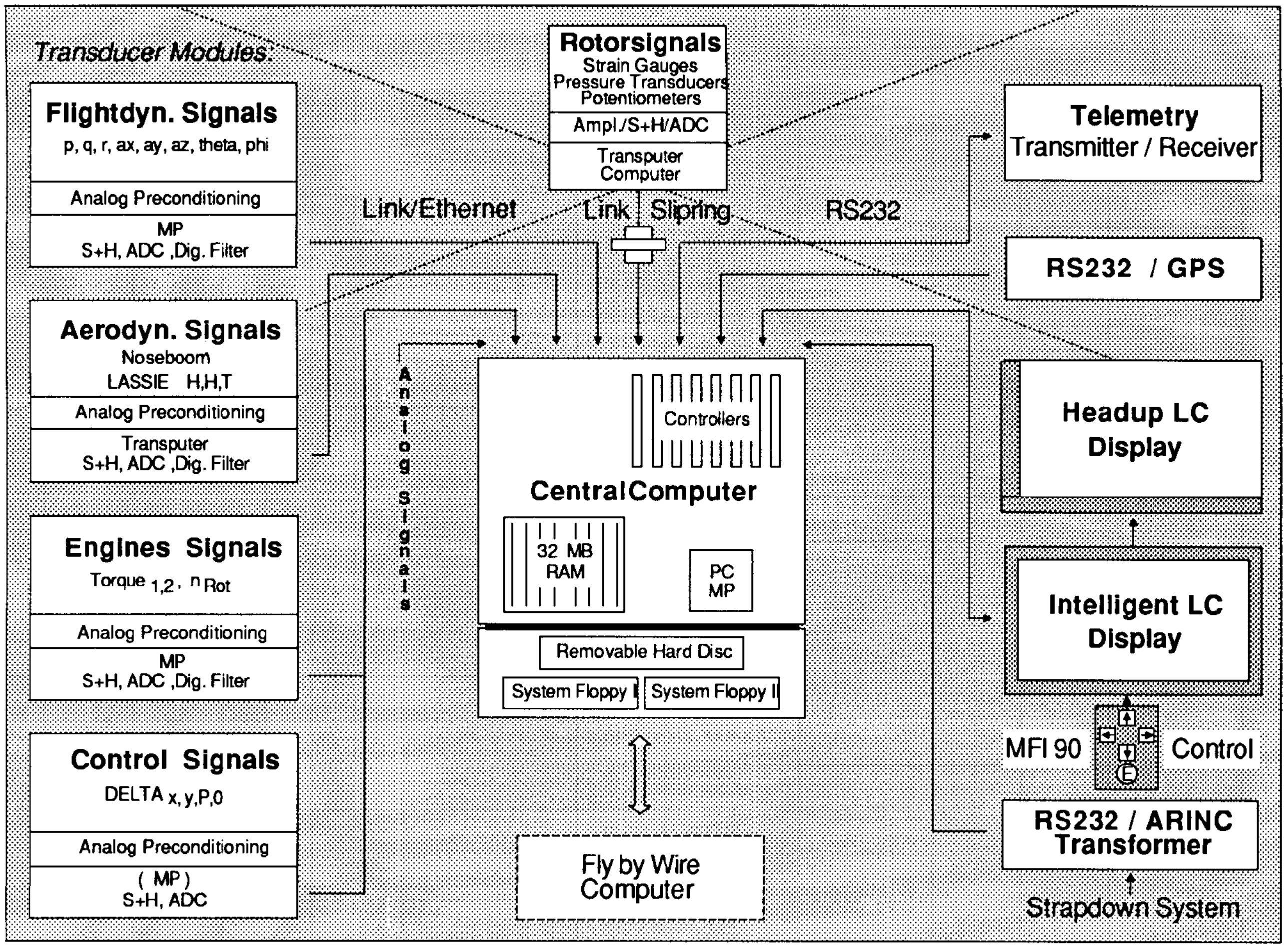


Figure 3. MFI 90 System.

modified. But after working some time with this system also software modules are available.
Another advantage is the avoidance of failures during data transport. Because these are serial digital data streams, also optical waveguides can do the jobs that have no active or passive electronic interference problems.

DATA ACQUISITION

The best example to demonstrate data acquisition is the Rotor module. To have a computer integrated data acquisition system on the rotor has many advantages. It is a complete system with high performance and was very new when it was developed. It can handle 40 signals with 12 bit resolution and a sampling frequency up to 3000 Hz. The principle is drawn in Fig. 4. On the rotor a cylindric case is installed with six inches in diameter and five inches in height. The dimensions should be as small as possible. It contains five boards for eight channels each with offset potentiometers, amplifiers, S+H's and one eight channel ADC. There are one computer board and one 1 MB RAM board. Beneath the motherboard is a board with voltage converters

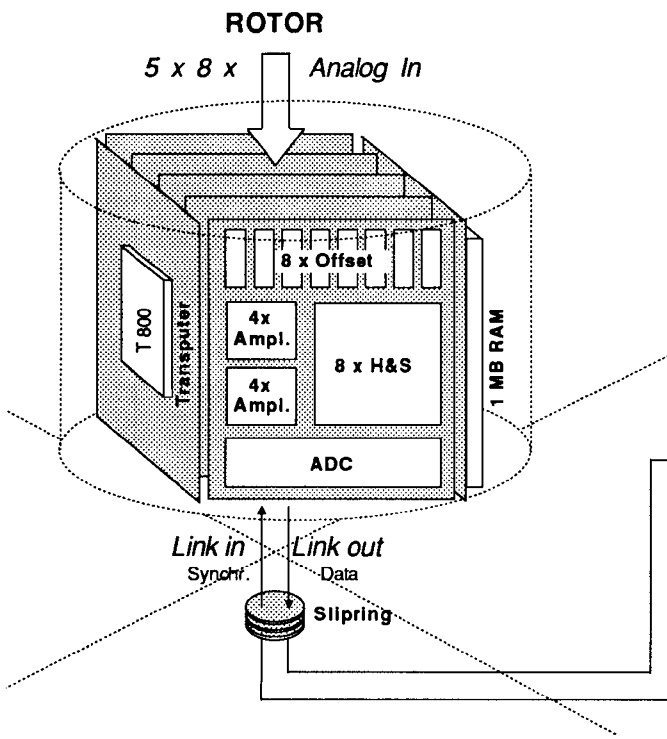


Figure 4. Data Acquisition of Rotor Module.

installed that transforms 28VDC to +5V and +-12V. (In a modified case some more Amp.- boards shall be available.)

The processor is a transputer that has the advantage of integrated serial "Links." The data are sent down via slipring to the Central computer where another transputer board is inserted which again is equipped with 1MB RAM and can communicate via DMA with the Central processors RAM. This configuration generates best flexibility. There is the chance to store fast generated data in the rotor module's RAM or in the base transputers RAM or directly in the central RAM. Each way has advantages and depends how data are needed. Since there are more modules that send data via transputer link (each transputer has four links), the base transputer should be kept free from on-line calculating tasks. These should be done in the module's processor.

A flight mechanics' module transmits data from the basis of the helicopter. In preparation is a nose-boom module. The same processor board and only one Ampl./ADC board as used on the rotor will be installed in the nose-boom with very short pressure tubes from the five-hole-probe to the pressure transducers that are located at the Amp.- board. Then transputer calculated TAS, Alpha and Beta (true airspeed, angle of attack) are directly sent to the Central computer.

Remark: DLR's BO 105 are equipped with sliprings. For other types of helicopters another data transport system shall be used. It is not decided if this will be telemetry or an optical system. Power for the rotating system is obtained from rechargeable batteries in the rotor systems case. These can be recharged to a certain degree by solar

cells on top of the case. Additionally a simple Power Management (Transducer power only if needed) will help to save energy.
The Central computer controls the frame built from these rotor signals and the others coming from the basis helicopter. Additionally an RS232 telemetry frame is generated. All data are stored on removable hard disks or tape or floppies.

PC - TYPE CENTRAL COMPUTER

General aspects

MFI 90 was designed and applied for Flight tests since 1990. Then no one thought the Central FT computer would be a PC. They were a pdp11/93 or a MicroVAX. Since then the performance of PCs increased very fast and will increase. For the PC's main field (Video, business, games etc.) fast CISC/RISC processors with excellent communication facilities and enormous storage capacity in RAMs or ROM recording devices are necessary. These advantages should be used for FT instrumentation where the same requirements are needed. As a matter of worldwide use the PC components are low cost articles.
There are some differences. The FT components have to work under quite different conditions and airborne restrictions. On the other hand there are many similarities. Analog signals (a much higher number) have to be converted to digital data streams that have to be stored or transported. The PC's domain, large information in fast changing pictures produces high data rates just like the FT signals data streams. It should not be decided if the processing and calculating programs are more complex. Because specialists are working in the field of flight testing there is no need for the comfortable MB-consuming WINDOWS presentations. FT can work with some instructions as are found in DOS, UNIX, . . . operating systems and does not need the enormous storage capacity for those programs. The only exception is pictures or displays for the pilots' instructions. But these must be very simple and need no high resolution.
So, if it is intended to use this technology in its original offer on the market there is only one question "How can we teach the PCs to fly." This is mainly a hardware problem.
Besides, nobody can predict what the future developments will be except higher performances. Therefore a solution should be planned which doesn't worry if X86 or Power PC or . . . will win.

Fig. 5 shows the MFI 90 Central computer installed at the same place where the DEC instrumentation was located. The needed volume is only one fourth of the old device (computer plus data recording.) The weight is nearly one third.

Hardware

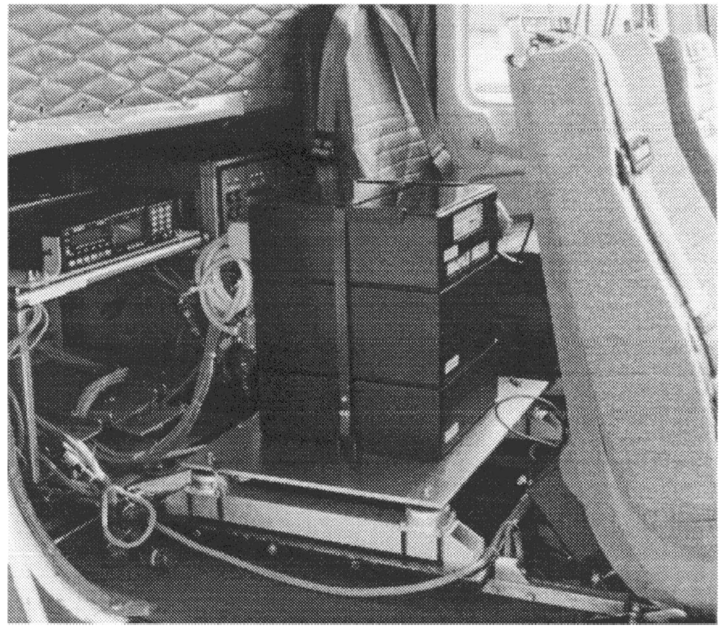


Figure 5. MFI 90 in Helicopter BO 105.

The main problem in designing a FT-computer from office-PC components is to find a solution that withstands the rough environmental conditions on board helicopters and similar applications. The first point to be considered is the very high vibration level of sometimes more than 2g with frequencies from some Hz to 100 Hz and more. Another point is the movement and the acceleration in all axis and angles that especially act on rotating devices (Disk Drives) and cause coriolis and precessions forces. A good electromagnetic shield should be foreseen against active and passive interference with the electric and electronic devices of the base vehicle. Temperature is not so important because there are no large differences especially on board helicopters. It should be considered that sometimes dust or oil is present which especially for the recording devices can be a problem.

According to philosophy this computer is also built from modules. In use are now modules for the computer itself with the necessary controllers, power unit modules, drives modules and interface units. The advantage of this is obvious. If in another test or with another vehicle another configuration is needed, it easily can be designed. E.g. since our helicopters have on board 115 VAC the very inexpensive power module with the original PC power supply can be used. In other aircraft a module with DC/DC transformers is necessary. The same is valid for the record units or interface modules. The assembly of one module is very simple. Three walls, front and the two sides are folded from 2mm aluminum. Only the backside wall carries all the FT connectors. The backside wall is only inserted in slots of the sidewalls without any screws. So it can be taken easily aside for measuring purposes or if a connector must be exchanged. The advantage of such a design is the good flexibility and last not least its manufacturing is very simple and cost saving.
The ground plate carries the computer's mother board. It is fixed with some rubber shock absorbers and screws through the original holes of the chosen board. Thus, in case if another main board (of another PC-type or a faster X86-type) should be chosen it only had to be exchanged on the ground plate. Maybe, some new holes have to be drilled or a new plate shall be used - all other parts stay the same.
A special design is necessary to fix the controller boards. The original assembly with one screw cannot protect the board against vibrations. So, the technique shown in

Fig. 6 was chosen. Each controller (of variable size) is mounted on a standardized 1mm-aluminum plate. These are hold by two bars with fitting slots.

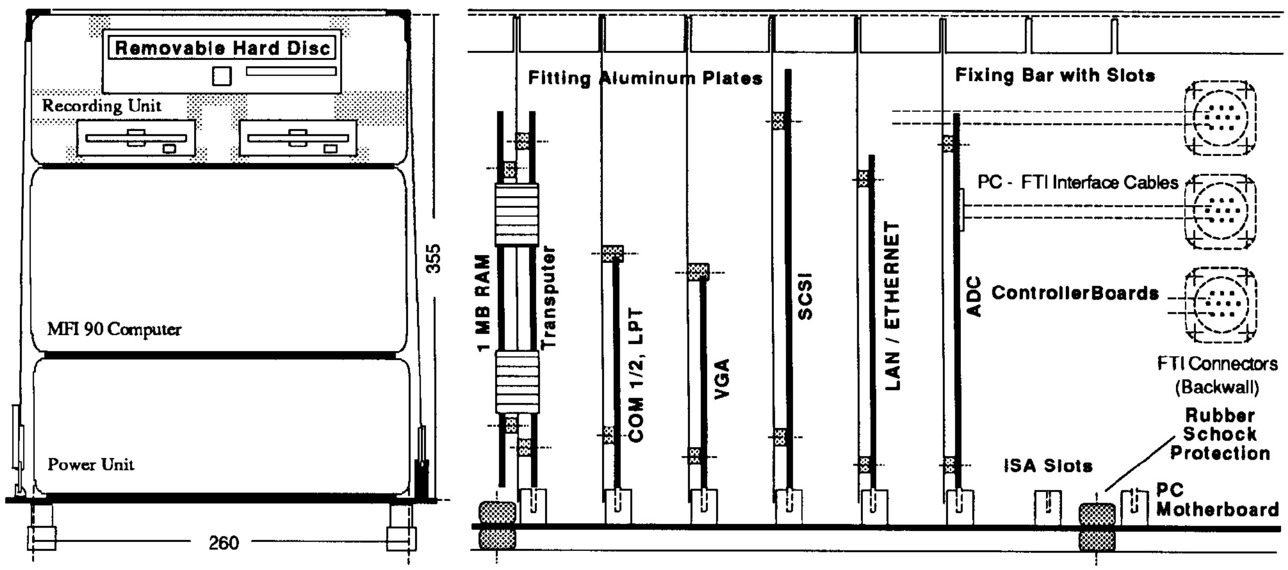


Figure 6. MFI 90 Hardware Design.

Because all parts of a module are mounted on the bottom plate this technology is very easy to handle in case of service or upgrading or trouble. Only the walls must be taken away and the whole interior can be handled from all sides. Other controller boards maybe inserted for testing. Each interface connector is then original PC type and a normal monitor or keyboard or printer etc. can be used.

Five screws attach the bottom plate to the sidewalls and the front wall. This type of screws with cylindric heads allow the heads to be used as fitting elements on the module below. This has the appropriate wholes in its upper edges. So each bottom of a module is the top plate of the one below.

By this kind of design whatever modules may be stacked in any arrangement. They are all fixed in x and y directions by the screw's heads. And the modules can easily be taken away or exchanged even if the whole device is already installed in the aircraft. The fixing for the z direction is done by an adjustable double metal tape and a snapping device with safety-pin. The assembly is tested and certified for the demanded 8g in x and z axis and 5g in the y direction.

Data Recording and Telemetry

"PC-world" needs for their applications (programs and data) more and more storage capacity. They offer 32 MB RAM's and more. For FT this means to have a Silicon Disc on board as long as power is on - from start to several minutes after landing. Then, data could be sent to ground station by cable (Ethernet.)

Now DLR is working with Removable hard discs with 88 MB. Devices with much higher capacity would run at the same interface, (an SCSI controller).

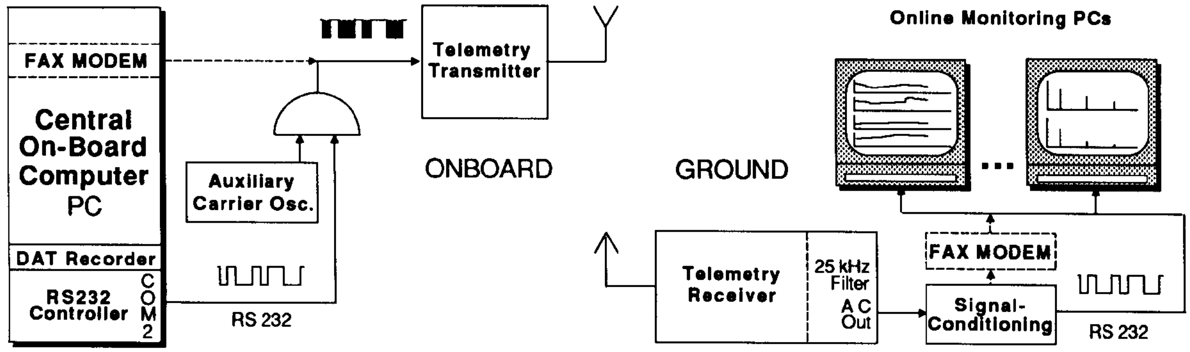


Figure 7. RS232 Telemetry.

With these two storage mediae a maximum of flexibility is available. Data can be written on-line on hard disc, as fast as this way allows (< 30 kB/sec). Or up to 32 MB maybe stored in RAM and after each or more RUNs be recorded on hard disc. A compressed or reduced data stream which is the same like the RS232 telemetry data stream maybe recorded in parallel during the whole flight on Floppy or DAT recorder. Because all data that shall be evaluated are recorded on board, the task of telemetry is on-line quicklook monitoring. For this purpose a reduced information data stream can be generated by selecting only the necessary signals with lower bandwidth and lower resolution. This can be transmitted with the RS232 protocol.

Software

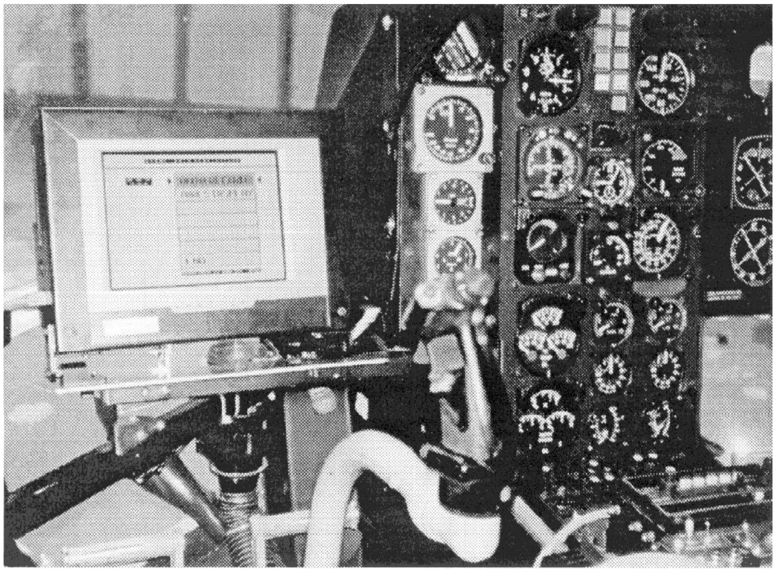
PC industry offers inexpensive compilers for every computer language. These allow people to write programs in a familiar language. Since digitizing and frame generating programs were written in Assembler language for the PDP/VAX, parts of those programs could be used on the PCs calling them from Pascal. Program parts are written in Fortran, C, QB45.

Our FT computers are controlled by programs stored on a System Floppy disc and are loaded from the AUTOEXEC.BAT file. So if the helicopter's power is switched on, the computer is booted and programs are loaded. Experience taught Floppy technique to be the best to withstand high vibrations.

Pilots Displays

<u>ILCD</u>

PC technology can also help to find a solution for inexpensive displays. Last year such a display was tested (Fig. 8.). It is a 486-Notebook. The TFT LCD screen was turned upsidedown and a case was built which can "fly." (Aluminum frame and Fiber glass front). Even if there are some problems with bright light, (a shade had to be used) the visibility from a wide angle was good. The advantages are obvious. There is a complete 486-computer available. Therefore, it is called ILCD = intelligent LC



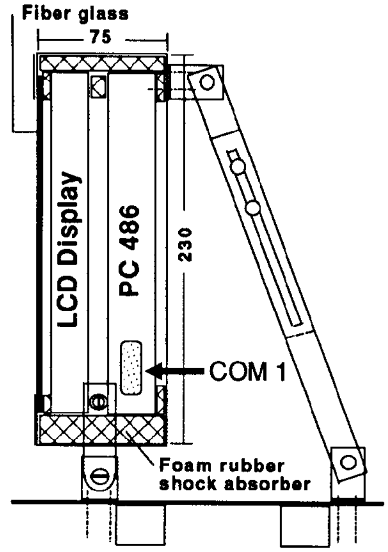


Figure 8. Intelligent LC Display.

display. Communication is simple via RS232 (COMx). Besides controlling the Central computer, necessary task information can be displayed (Attitude-, Velocities-, Controls- or Ratings diagrams.) The programs are stored on the Notebook's Floppy that can also record something, e.g. pilots ratings. Data are those that are sent to telemetry.
The keyboard is removed. Only the Cursor keys + Enter are connected to a special control device at the pilot's stick. This enables him to fly "hands on." Menu programs must be designed for simple controlling. He must only control with a familiar "Chinese hat" switch moving a good visible cursor up and down / right and left. Future tests will show if Double scan LCD screens have advantages in brightness. (Industry announced LCDs that display more than double as bright during this year.)

HuLCD

The last example how PC technology can help with flight testing is a simple and inexpensive "head up"-display. It origins from a "black and white projection panel." It was removed from its original case and assembled in a way that only two edges should have narrow black stripes. For safety reasons it was embedded in Fiber glass. If the screen is controlled maximum bright, the visibility through it is good. The information has to be programmed dark. The original's control-electronic was used and integrated in a special box that is located behind the ILCD. So only one cable is necessary and it displays what maybe programmed on the ILCD computer or the Central computer if the VGA controller output is used.

CONCLUSION

In spite this system had to be designed under low budget aspects it was not the first intention to save money.
It should be most flexible and easily be adaptable on future demands.
In the field of flight testing the main interest must be to get best information about aircraft's behavior. This is mainly a matter of the most difficult measuring of the true physical values. If all effort is concentrated on this - including the calibration - FT engineers should be happy if there are these easy to handle, flexible and inexpensive PC tools to bring those data home.