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PRACTICAL APPLICATION OF A COMPUTERIZED FLIGHT BY FLIGHT FATIGUE TEST SYSTEM

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ABSTRACT

The evolution process on fatigue testing methodology achieved by Agusta, led to the use of servo-hydraulic systems; the need of a larger utilization of this technology associated with cost containement criteria determined the decision to develop their own product.
Hydraulic actuators and electronic equipment have been designed in the Mechanical Laboratory and they constitute today a powerful, cheap and fast means to set up any kind of test bench.
The new testing technologies allow more sophisticated methods such as flight by flight fatigue test to be used.
A detailed description is given of hardware (hydraulic, mechanic, electronic etc.) and software of the system, set up in Agusta.

1. GENERAL VIEW OF THE DEVELOPMENT ACHIEVED ON THE FATIGUE TESTING FIELD BY AGUSTA LABORATORIES

1.1 Fatigue testing laboratory

The needs conditioning the certification of a helicopter, and the general development of the state of the art, also led Agusta to modernise and up-date the Mechanical Laboratories; in particular in the fatigue testing field the following requirements had to be met :

a) test time reduction; in terms of both test bench manufacturing and run-out time

b) minimum need of operator's assistance, during test run out

c) improvement accuracy and reliability of test

d) containment of investment and exercise costs

To meet the requirements at points a., b. and c., the best solution seemed to be the utilization of more sophisticated electronic instruments and servo-hydraulic cylinders; but this was working against point d. because of the significant investment required.
The compromise of a partial utilization of these technologies, only for the most important cases, had been considered unsatisfactory because it was contrary to points a. and b. which were to lead to the introduction of standard methods and possibility of automation.
The final choice, has been to develop, their own product designing the servocylinders and control electronic equipment. The result of this enterprise is that at present 50 units are already working and by the middle of 1982 a further 70 units will be ready and completed with electronic controls, load measurement and alarms.
Due to the large number of manufactured units, the design costs were divided in a way which was more than satisfactory with regard to point d.
Compared with old mechanical systems, the cost of investment is slightly less, while the exercise costs are much lower, and furthermore the reduction time is more than satisfactory. A further contribution has been obtained by designing standard modules for the mechanical Set-up of the benches. This allows a reduction in the number of "relative components" and speeds up the assembly operation.
A further very important advantage of choosing to design one's own experimental equipment is the achievement of knowledge and a utilization capable of allowing study in fields other than fatigue testing, and which would also be useful for future development.
A concise description of the standard units follows in appendix A.

1.2 Flight test data survey

Following a similar philosophy that bestows as much as possible to the internal development of our standard data collection systems we have tried to obtain the maximum integration and automation degree in the data transition from the flight test activity to the fatigue test bench. Data availability in discrete format obtained from the telemetry system (PCM or FDM) underlines the advantage of extending the process in terms of computer compatibility. The logic flow obtained is shown in fig. 1.

Such a diagram shows how in a strictly operative phase, a major integration should be easily obtained by means of a network that does away with the off-line activities due to the magnetic support interchange.

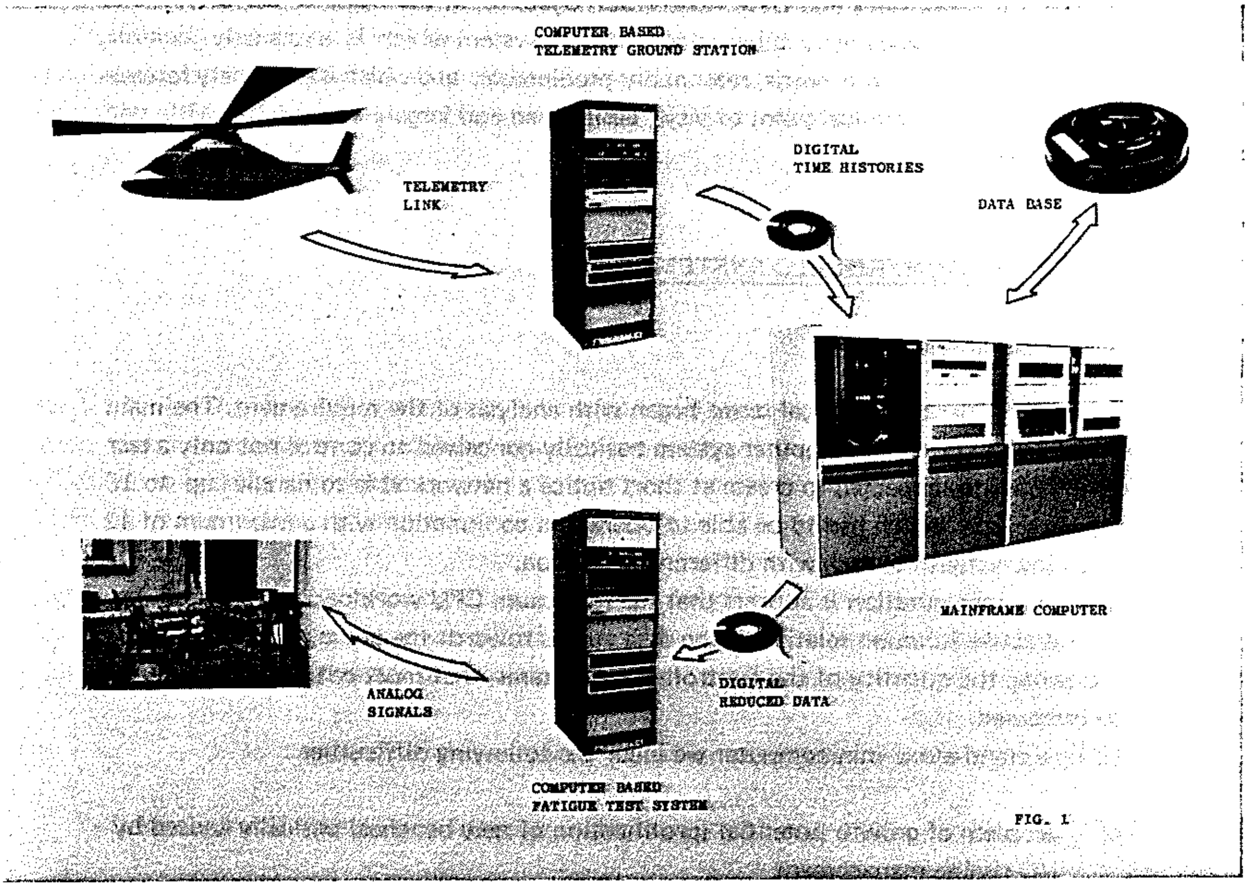


FIG. 1

2. FLIGHT BY FLIGHT FATIGUE TESTS

The progress of electronics and hydraulics and the continuous development of capabilities and diffusion of computers besides providing a notable technological improvement in the field of traditional mechanical testing has also extended the field of investigation, in particular fatigue tests with actual complex load sequences.
These experimental techniques which have already had practical industrial applications, in particular in fixed wing field, are also now interesting the helicopter industry.
Obviously the interest has more than a pure experimental aspect, since the subject concerns analysis methodologies and design philosophy and involves wide and profound research.
Agusta, started to deal with this subject in cooperation with PISA university, and the first experiment has been performed utilizing PISA facilities (Ref. 1) the aim of this first step of research is to achieve some elements of evaluation to allow a reduction in the excess of conservativism due to the uncertainty of interpretation of actual load spectra.

From the experimental point of view the need was to set-up test equipment to be able to complete that research, mainly performed on simple components, speedily tested, not too expensive, and then to be able to execute flight by flight fatigue tests on more complex components. The integration of the experiences acheived by the two groups, Mechanical Laboratory and Data Acquisition Systems, in the fields of servohydraulics and computers respectively, allowed setting up a system which is extremely flexible, adaptable to the various needs, reasonably predictable, and which is extremely foreseeable from the economical point of view, easily used and largely expandable with contained costs.

3. COMPUTER CONTROLLED SYSTEM

3.1 System definition

The achievement in practical terms began with analysis of the requirement. The main target was to obtain a computer system basically conceived to control not only a test bench but also expected to create at short notice a network able to handle up to 10 benches. Each bench had to be able to operate in conjunction with a maximum of 12 hydarulic actuators, each with different excitation.
In such a configuration it appears that the maximum CPU workload is generated by the iteractive function relative to the data strobe towards the actuators; therefore by increasing the quantity of the controlled subsystems, that most critical function will be increased.
Using a stand-alone minicomputer we incur the following difficulties :

a) problem of growth potential (prolification of new benches) basically caused by I/O timing management

b) system saturation easily achieved due to the CPU lack of (speed)

c) users'area, or programs development capability concurrent to the benches management, rapidly diminishes as function of the slave systems increases

However, to dedicate a stand-alone computer to each bench even in a minor configuration is apparently not realistic because even considering the uniquely developed S/W (programs duplication capability), we should be heavily penalized in terms of cost by the need to arrange mass storage (discs, tapes) in each system for the data base management.
The only advantage of such a configuration is shown by the total freedom of the systems that would not be affected by single CPU failures.
The problem could be overcomed by means of a "local intelligence" available in the output phase dedicated to the actuators management, in particular :

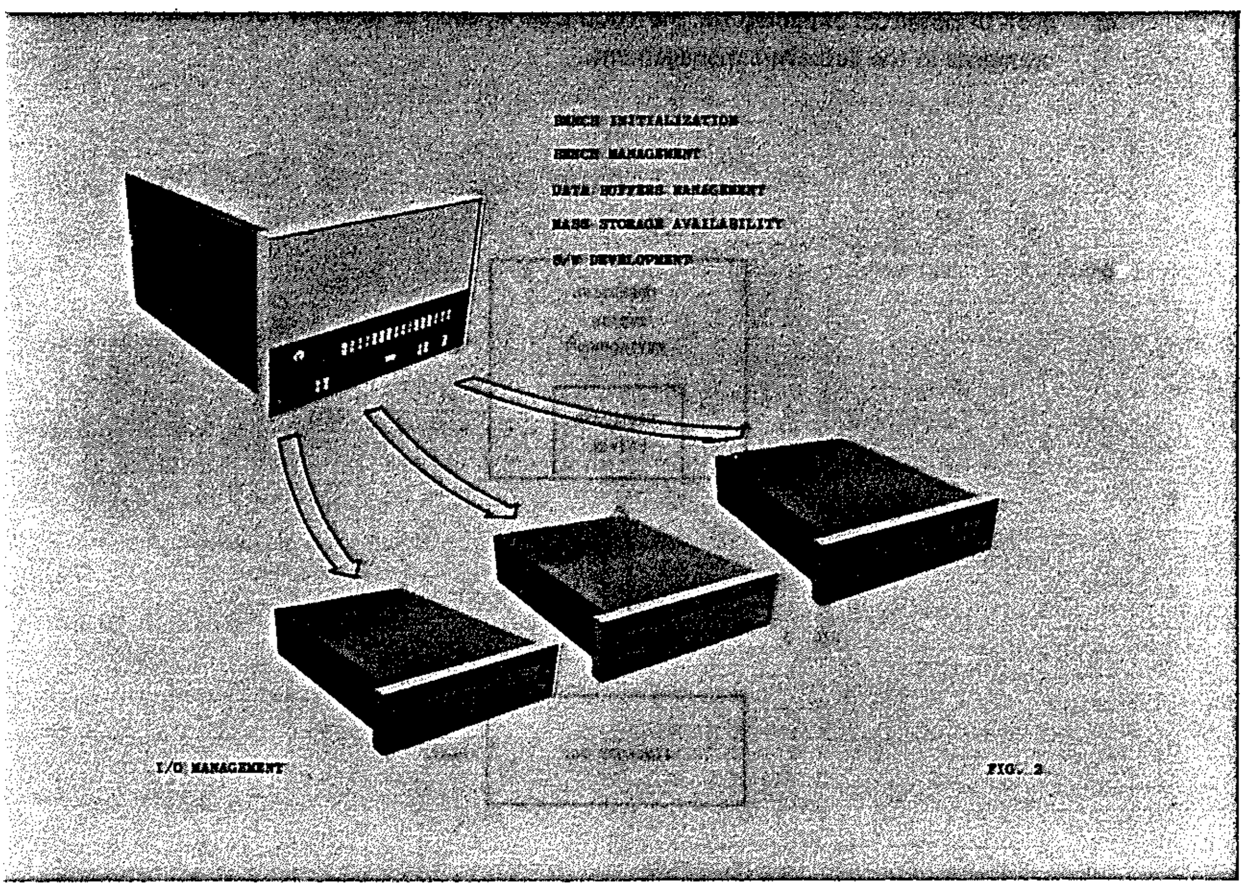
a) I/O buffering

b) independent timing

c) point interpolation capability

Such an "intelligence" taking the iteractive task orientated to the data strobe, leaves the CPU with the only assignement of initializing and transfering the buffers towards the I/O bus besides monitoring the functions; fundamental tasks but relatively lightly onerous and therefore prolific without penalizing the efficiency of the system.
Taking this into consideration we were therefore obliged to apply a master-slave type solution. Such a solution allowed us to optimize the above mentioned aspects, being able :

- to have common mass storage (master)
- to delegate to the skilled pheriherals (slaves) the bench management in terms of output handling, dis-engaging the master CPU from the timing problems concerning the data strobe
- to allow a centralized monitoring on the existing situation
- to diversify the slaves H/W configuration without significant modification in the network architecture
- to allow increase in the number of benches controlled by minimum computer H/W investment and without additional S/W development costs



I/O MANAGEMENT FIG. 2

To define the hardware required we turned the survey towards a "middle mini" usable as a supervisor and towards a CPU in minimal configuration usable as a satellite. The possibility of considering as an alternative "one board computers" or "naked mini" available on the OEM market was not considered in this phase in order to minimize the development costs even if this meant loading the initial investment. Should the number of subsystems required demonstrate the advantage of a different approach we could implement a solution taking into account that, as mentioned above, it will not significantly change the H/W and S/W networks aspects.
It is therefore obvious that, assuming the development of the interfacing and the communication procedures of the two units, to choose a single supplier should reduce the compatibility problems.
An evaluation of substantial equality of the computers available on the market emphasized the value of choosing the manufacturer for which the maximum "know - how" for the expected application was available in Agusta; we chose therefore an HP1000F serie computer as master and HP1000 L serie CPU as slave.
Significant advantages of these choices for Agusta were :

a) the personnel assigned to development of the system already have a wide background of knowledge available in terms of operation, interfacing and drivers' writing
b) similarity of the two machines in terms of characteristics instruction and I/O
c) growth potential expected for the 1000 L serie, such as to allow for further increments in the actuators management.

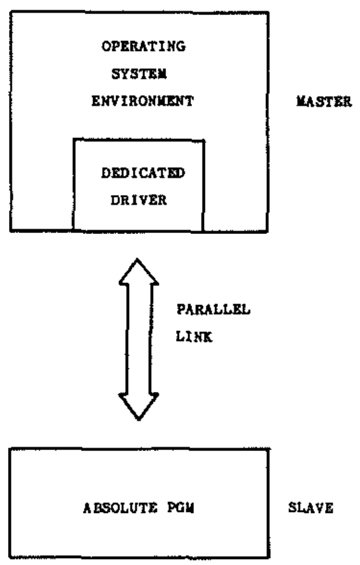


FIG. 3

3.2 SOFTWARE PHILOSOPHY

The conventional approach of utilizing a network's resources was the possibility of using the distributed system (DS/1000) supplied by the manufacturer that allows dialogue between CPUs working independently. This kind of solution, though offering an undoubted advantage of an off-the-shelf product, entails the following disadvantages :

a) necessity of an operating system (RTE–L) on the slave; this operating system would take the major part of memory resources available.

b) serial type connections (RS 232), considering the wide range of data for transmission and the low rate allowed with that standard, would penalize the transfer time

c) the polling method, typical in a distributed system, did not allow immediate aknowledge of bidirectional attention flags.

As stated, the availability of an operating system was not essential because the programs' development capability is not required; to exploit therefore the local resources of the satellite it was preferible to use an absolute program, small in dimension, that would allow the maximum exploitation of the data area. Such a program allowed moreover a parallel type connection between CPUs (over 1 Mbytes/sec) and the immediate interrupts recognition capability. On the master, a driver organized as require by the standard procedures, allows communications without any interference with the RTE environment. Therefore our choice was the following :

a) master with operating system – Maximum flexibility of files management, programs development, standard I/O handling

b) slave with absolute program – Maximum execution speed and optimized memory sharing

c) dedicated communication monitor – Maximum efficiency due to the use of only the required functions.

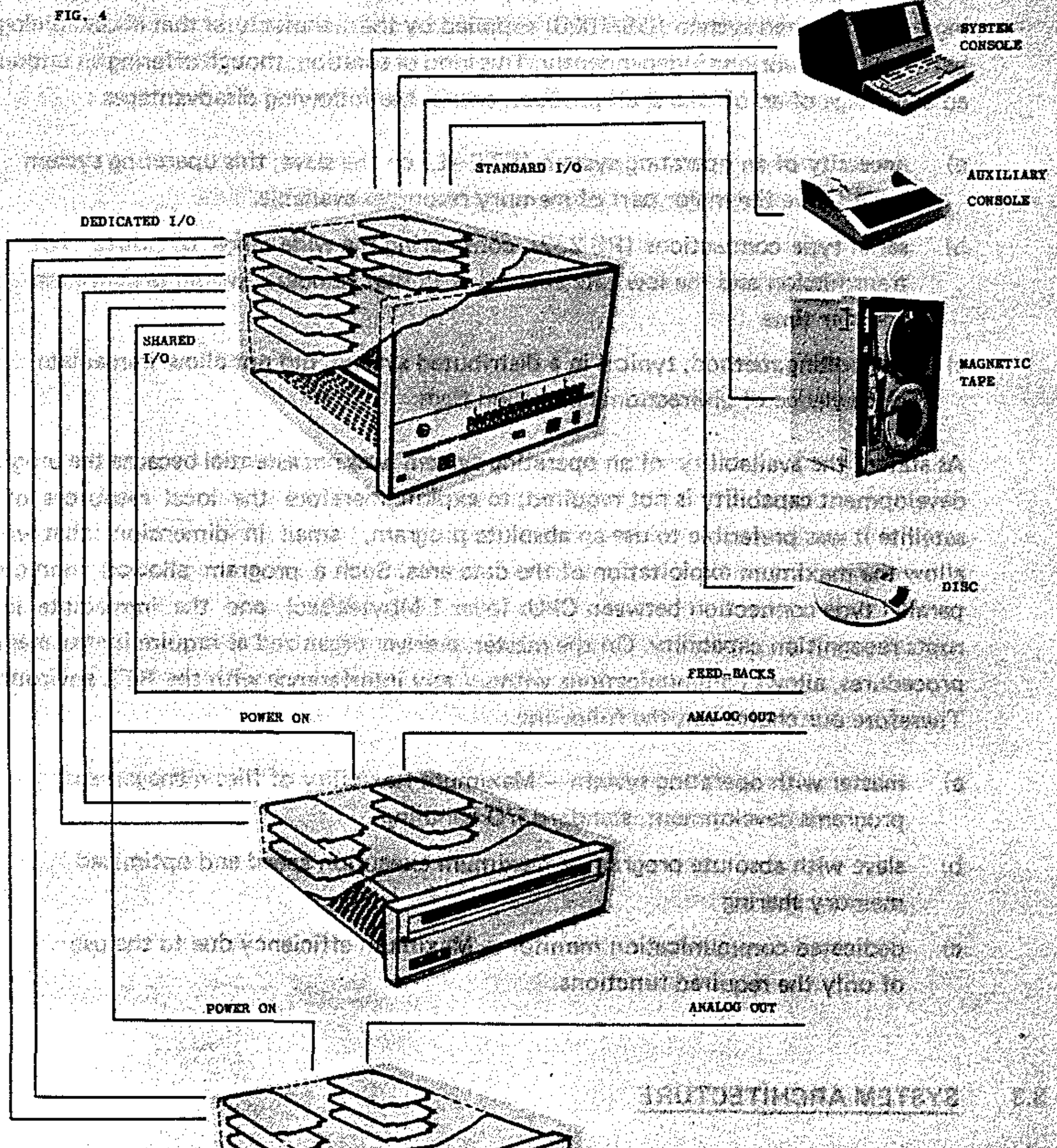
3.3 SYSTEM ARCHITECTURE

As a practical application the system was structured with the characteristics shown in fig. 4.

The master is based on a HP1000 F computer with 128 kwords "fault correction" type memory. This kind of memory slightly affects the memory performances but was chosen to minimize the faults caused by parity errors. The standard peripherals are :

- 20 Mbytes disc
- 1600 BPI magnetic tape
- CRT system console
- Printing auxiliary console

FIG. 4



SYSTEM CONSOLE
STANDARD I/O
AUXILIARY CONSOLE
DEDICATED I/O
SHARED I/O
MAGNETIC TAPE
DISC
FEED-BACKS
POWER ON
ANALOG OUT
POWER ON
ANALOG OUT

The slave is based on a HP1000 L minicomputer with 32 kwords memory. For the system bootstrap at power ON, a PROM module interface is available.
On the master, two I/O groups are dedicated to the benches management :

a) I/O shared between the subsystems composed by A/D for the feedback check and Relay output register for the power set-up of benches

b) I/O dedicated to each subsystem composed a parallel link to send-receive functions of data and commands, plus a breadboard interface to recognize attention flags generated by the slaves computers.

The slaves I/O, obviously dedicated, is done by the corresponding interfaces for send/receive data and commands and send attention flags, plus the D/A section necessary to drive the desired actuators.
Extending the system means adding a complete satellite besides inserting in the master I/O bus the corresponding communication interfaces.

3.4 SYSTEM FUNCTIONAL DESCRIPTION

System set-up commences the creation of disc files containing data of the waveforms needed. Such information, coming from the offline handling of the flight test data executed in the mainframe computer, are loaded by means of a digital tape.
Bench initialization occurs by use of a dedicated program that provide the characteristics needed for the operating phase;

- logic assignment
- actuator's number
- feed back channels required
- absolute program name for the slave unit
- data file desired

  etc.

Such information is stored into a system common area (or with access available to all programs) wherefrom the monitor finds and updates data relative to the single bench status and all the data buffer's pointers.
At the end of this phase the operator can activate the slave system which receives the power-on command through the master's relay output register. When the supply voltage is sensed, the slave system executes the booststrap resident on the PROM module; the bootsrap function consists of asking the master the absolute program linked to it.
The program, resident on the disc, is loaded into the HP1000 L computer RAM and executed. There are two tasks that effectively execute these functions :

- RUN
- RUN TEST

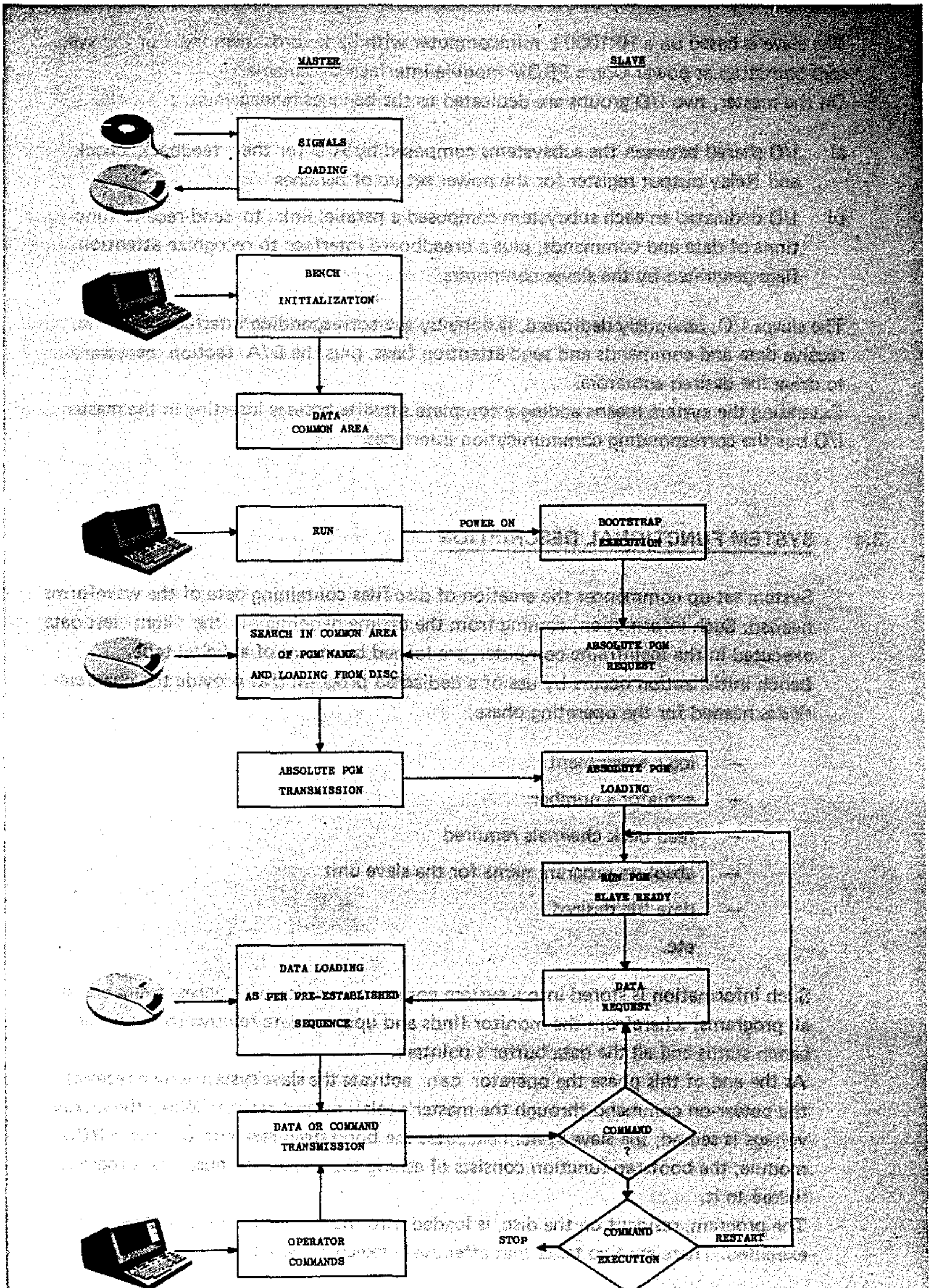

MASTER
SLAVE
SIGNALS LOADING
BENCH INITIALIZATION
DATA COMMON AREA
RUN
POWER ON
BOOTSTRAP EXECUTION
SEARCH IN COMMON AREA OF PGM NAME AND LOADING FROM DISC
ABSOLUTE PGM REQUEST
ABSOLUTE PGM TRANSMISSION
ABSOLUTE PGM LOADING
RUN PGM SLAVE READY
DATA LOADING AS PER PRE-ESTABLISHED SEQUENCE
DATA REQUEST
DATA OR COMMAND TRANSMISSION
COMMAND ?
COMMAND EXECUTION
STOP
RESTART
OPERATOR COMMANDS

FIG. 5

When the RUN TEST function is required the activated task executes the data strobe in form of sinusoidal or square waves; such signals will allow adjustment in gains and delays by means of the operator's interacting intervention on the system console or analog part associated to the D/A interface.
The RUN function permits the task to initiate the precise fatigue test bench excitation using the effective stress signals.
The process described above is explained in fig. 5.
Fig. 6 shows the memory allocation obtained in both master and slave systems.

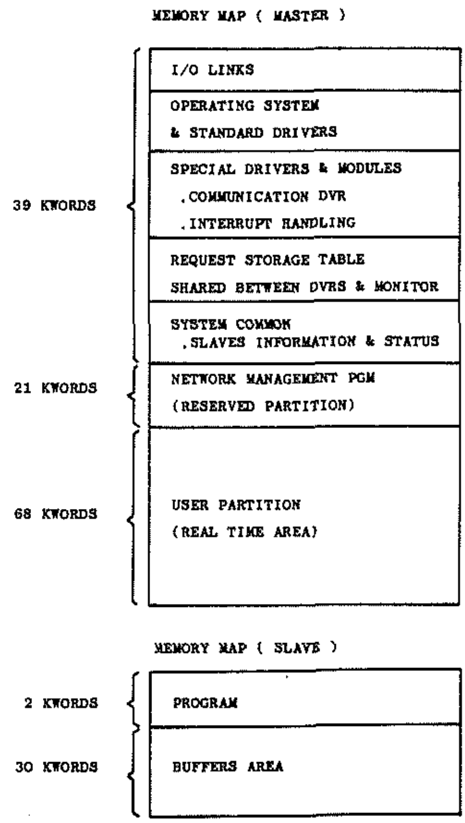


FIG. 6

The dynamic stress of the component on test continues until a failure is detected by the feedback system or until the suspension is defined by the operator.
The load blocks transmitted are chosen by means of fixed random sequences. The points transmitted represent the elementary form of the signal (relative maximum and minimum); to optimize the output analog form, intermediate cosinuosoidal interpolation is executed by the slave CPU, in a number function of the maximum clock rate allowable. To improve the computation performance, the intermediate cosinusodal values are obtained by means of a table.
A typical waveform transform is shown in fig. 7 (flight test data), fig. 8 (mainframe computer reduced data) and fig. 9 (computer generated analog data).

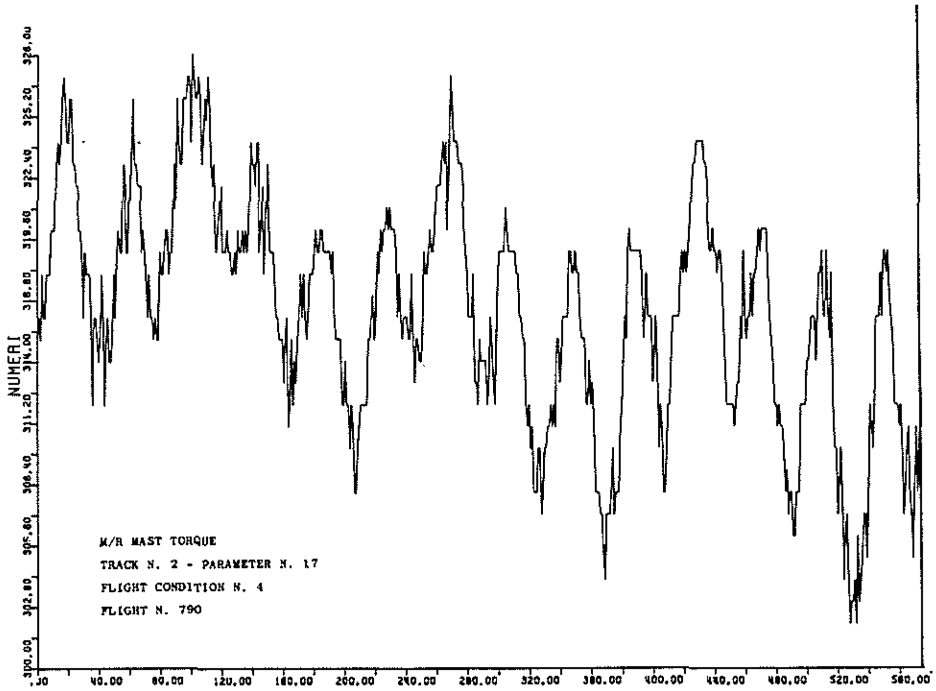
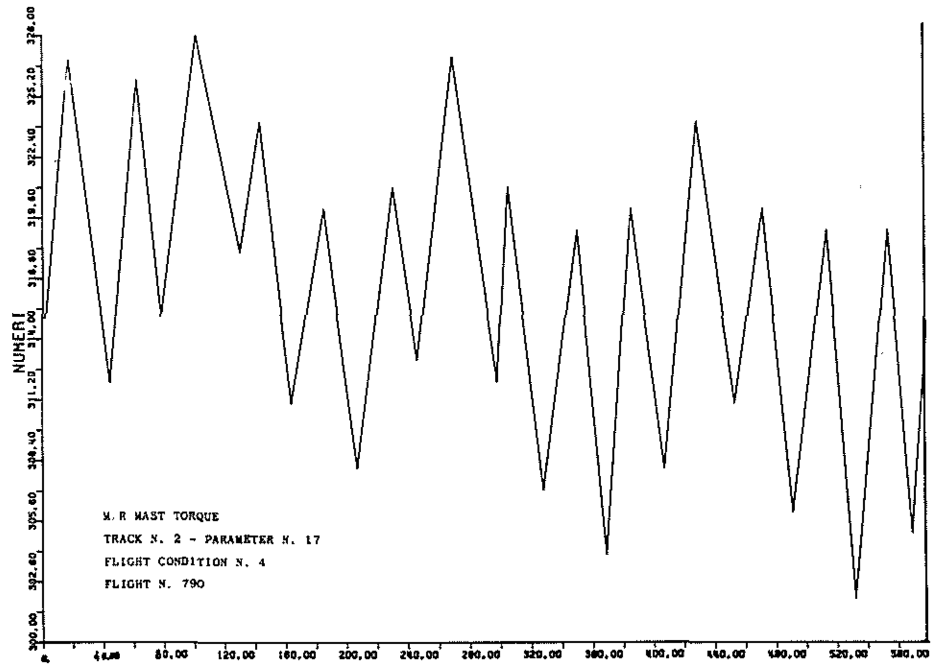

M/R MAST TORQUE
TRACK N. 2 - PARAMETER N. 17
FLIGHT CONDITION N. 4
FLIGHT N. 790
NUMERI

Fig. 7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FLIGHT CONDITION N. 4
FLIGHT N. 790
NUMERI

Fig. 8

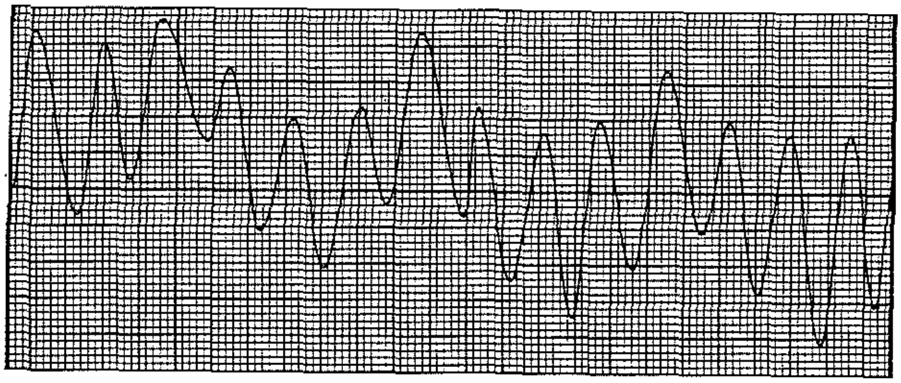

Fig. 9

4. CONCLUSION

As described above, is the result of integration of different technologies and experiences, achieved in different fields; the fact is common to many innovative processes. What it is important to point out is that, when the utilizer of technologies or experimental equipment has *also a high knowledge of these, then the best results* can be obtained from the technical and economical point of view, making precise choices whether "to buy or build"; and this probably with the best integration between the innovative technology and utilization needs.

These considerations are valid also in the experimental field, and must be considered, both in terms of economy and productiveness in addition to the quality aspects, in the same way as in every other industrial activity.

APPENDIX A
DESCRIPTION OF STANDARD SERVOSYSTEMS FOR FATIGUE TEST

The standard fatigue testing units consist of the following components :

a) hydraulic cylinder (fig. 10)
the construction is compact, strong enough and easily installed; seals and internal bushings are designed to provide the minimum external dimensions, in addition to low friction, and good sealing

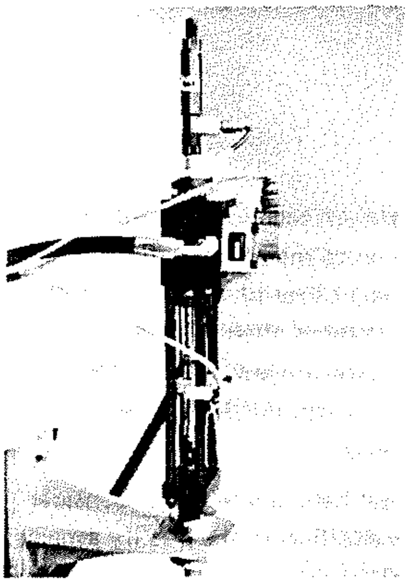

Fig. 10

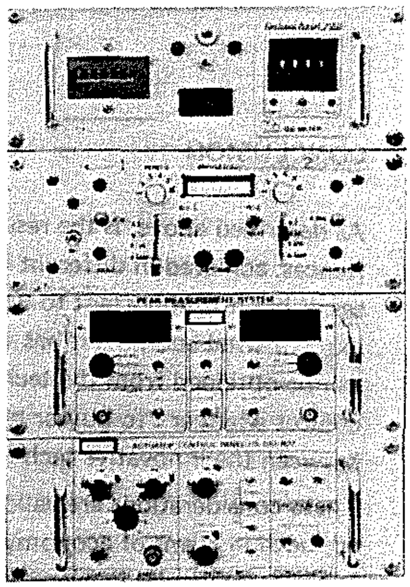

Fig. 11

b) feed back transducers can be installed independently, either a load coll or displacement transducer (LVDT)

c) controller (fig. 11 at the bottom)
The controller consisting of :
- one section for the above mentioned transducers conditioning; in addition a connector is provided for an externally conditioned transducer
- one section of function generation (steady & dynamic), with amplitude regulations, selection of wave forms (Synusoidal, Triangular, Square), and frequency adjustment. A connector for an external generator is provided.

(the described application above is connected with the computer output).
One section of feed-back control consists of : error amplifier, power output amplifier. and regulation of typical T.F. parameters

d) transducers measures (fig. 11 lower middle).
This unit gives to the operator, on two DVM, the contemporary readings of the steady and dynamic components of the F.B. signal

e) alarm unit (fig. 11 top middle).
This instrument reads the two components of the F.B. signal; if one of the inputs gets out of a preselected tolerance, the instrument is designed to stop the oil supply to the bench and cycle counter

f) cycle counter (fig. 11 top).

The above described system is autonomous and can work without any assistance; when more cylinders must work together, they are controlled by an external generator provided with 6 outputs adjustable in amplitude and phase. This instrument has been designed to allow connection in parallel with similar units when more than 6 cylinders are required.

REFERENCES

1.	G. CAVALLINI, A. LANCIOTTI G. ALDINIO, R. ROVELLOTTI	FATIGUE BEHAVIOUR OF HELICOPTER DYNAMIC COMPONENTS UNDER CONSTANT AMPLITUDE AND SPECTRUM LOADING AGARD – CP – 297 (sept 1980)