

**SIMULATION CONCEPTS AND TESTING OF THE TAIL ROTOR FLY-BY-WIRE
SYSTEM OF THE A 129 HELICOPTER**

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SIMULATION CONCEPTS AND TESTING OF THE TAIL ROTOR FLY-BY-WIRE
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ABSTRACT

The paper will mainly deal with the simulation concepts established and adopted to test the Tail Rotor FBW System of the Agusta A129.

A brief introduction of the Helicopter will help to better understand the leading characteristics of the tail rotor actuation system, its deep interconnection with the Integrated Multiplex System, and its redundancy management capabilities.

After the introduction, as a consequence of the peculiar performances of the tail rotor system, the simulation concepts adopted will be explained.

It is a point to note that the simulation has the main purpose to check the behaviour of the system in presence of failures, both hydraulics and electronics, in such a way to substantiate the redundancy management of the FBW System.

A description of testing equipments, both hardware and software, will follow, emphasizing those characteristics strictly related with the failure simulation.

The conclusion will be based on the critical review of the first tests results, basing the judgement on the capabilities of the system under test to manage its redundancies in case of failures, plus enabling a continuous safe flight of the helicopter.

INTRODUCTION

The Agusta A129 is one of the most modern lightweight antitank helicopter in the world (see fig.1).

Due to its peculiar type of mission great importance to the ballistic requirements was given during the design phase.

These requirements lead to the decision to adopt a Fly-By-Wire (FBW) control for the tail rotor.(1)

This paper intends to shortly illustrate this system, the method of testing it, and the first results.

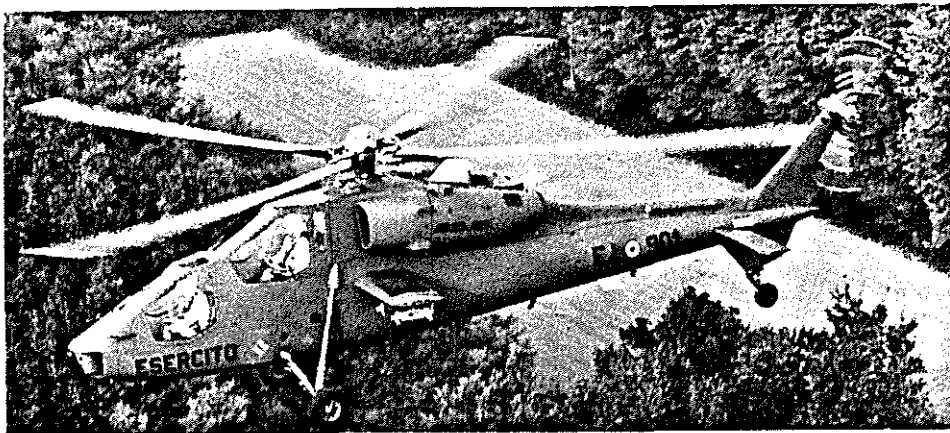


Fig.1 - AGUSTA A129

TAIL ROTOR CONTROL SYSTEM

General

The tail rotor servoactuator is intended to be normally operative in FBW mode using the normal body, with the capability to fly in an emergency case in FBW (backup body): it has also the possibility of the pure mechanical mode (no FBW, or both hydraulics off).

Pilot's inputs (see fig.2) are given to the pedals assembly and read by three Rotary Variable Differential Transformer (RVDT), the output electrical of which is the input in the FBW loop.

At the same time, the pedals displacements are transmitted to the tail servo by means of a typical "pulley and cables" assembly.

The tail rotor servo is installed inside the right angle gearbox, coaxial with the tail pitch link.

The servo (see fig.3) is a fixed type, two separate

Fig.2

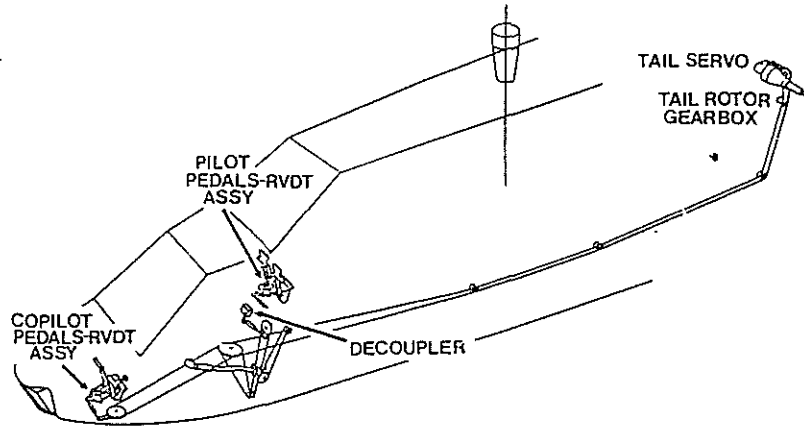
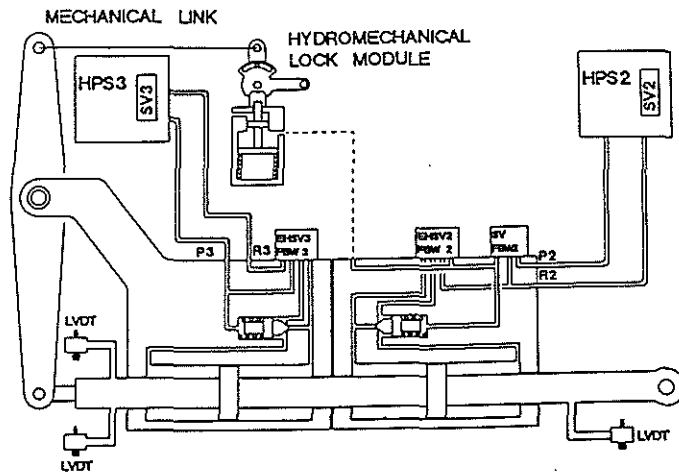


Fig.3



bodies tandem configuration.

In the normal mode, only the body pressurized by the tail rotor integrated hydraulic group (HPS3) is operative by means of its FBW3.

This body is equipped with a three-coils electro-hydraulic servovalve (EHSV) adjusting the fluid flow according to the signal from the command loop: the electrical feedback is given by three separate Linear Variable Differential Transformer (LVDT), the mobile equipment of which is jointed to the servo piston rod.

In case of failure at FBW3 loop, or at its hydraulics, the backup body is switched on by the opening of its own solenoid valve, and by the closure at the same time of the depressurizing solenoid valve installed on the HPS3, in such way to avoid an hydraulic lock.

In case of a second failures, the pure mechanical mode is possible depressurizing both the bodies at the same time, and this is done closing both the solenoid valves related to the hydraulic feedings of the servo.

This avoids a double hydraulic lock and enables the mechanical lock device to stiffly link the input lever of the servo to the mechanical chain from the pédalès.

Tail Rotor Fly-By-Wire System

Since the FBW is the primary control mode for the tail rotor, its function is "flight critical"; consequently, this system is implemented in hardware isolating it from the Integrated Multiplex System (IMS) of the helicopter, even if the IMS can act as an arbitrator in case of a second failure.

The tail FBW is a triple redundant analog system, with the three channels located in three separated and different units (see fig.4).

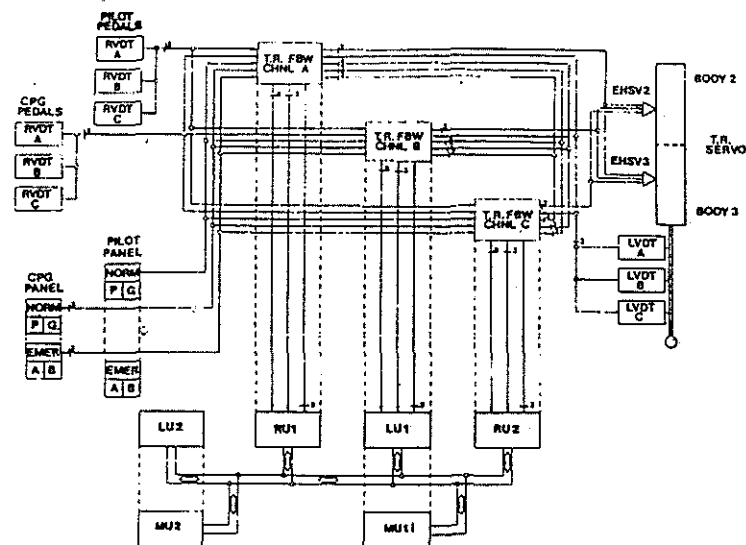


Fig.4

Each channel receives signals from a set of sensors.

There are three LVDTs providing the feedback of the actuator position, three RVDTs providing the input from the pilot's pedals, other three RVDTs doing the same from the copilot's pedals.

Furthermore, each of the two EHSVs of the tail servo has three coils: the magnetic flux developed by the coils is flux-summed in the servo to have a triple redundant drive of it, so providing a passive fault tolerance in case of a single failure.

Infact, each channel can supply the full range of drive current to its own EHSVs'coil; so, in case of a channel failure, the other two channels will supply enough drive current

to overcome the failed channel and to continue to provide the correct drive.

A channel failure is discovered by a hardware monitor in each channel that is continuously comparing its own drive current with that produced by the other two; if there is a significant deviation, the drive current of the failed channel is switched to a dummy load.

In this last case, the IMS will use a mathematical model to select between the two remaining channels, if a significant deviation between them should occur.

The IMS monitors also the servo's hydraulics operations to check if it is necessary to switch to the other body; however, it has not the ability to switch off both the hydraulics feedings: besides, the IMS provides the Stability and Control Augmentation System (SCAS) input to the tail rotor servo's EHSVs.

Built-In-Test/Redundancy Management

The Built-In-Test (BIT) and the Redundancy Management (RM) of the FBW system includes both hardware and software components.

The activities they carry out are related to the electronics and hydraulics subsystems of the tail rotor.

The primary function about the electronics subsystem is a comparison test via the hardware.

Each channel has its own BIT circuitry to compare its drive current with those supplied by the other two channels.

Also the LVDTs' demodulators are tested via an hardware implemented BIT.

The BIT about the tail rotor hydraulics has three main tasks:

- Check of the status of the hydraulics systems.

The fig.5 illustrate the interface between the hydraulic equipment and the IMS.

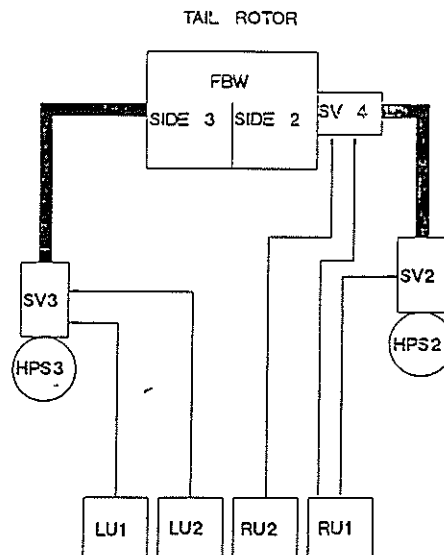


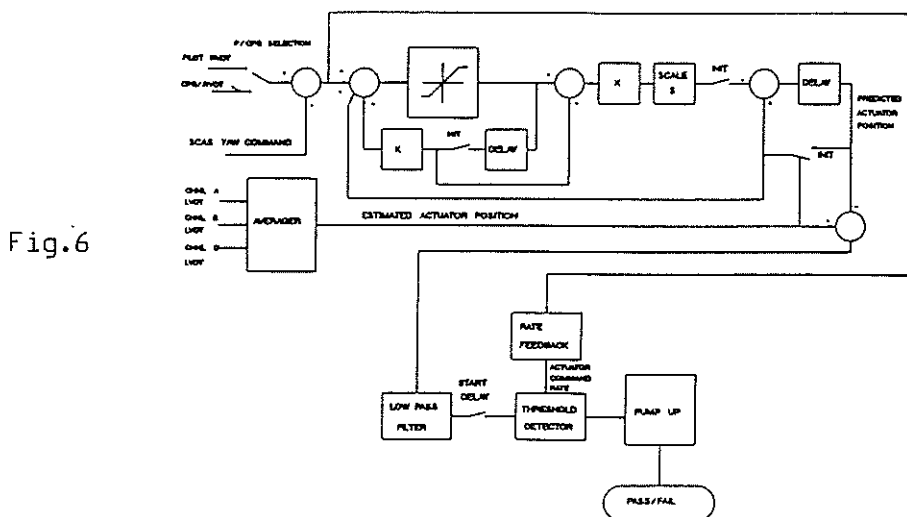
Fig.5

A dedicated software ("Hydr") is responsible to command the state of all the solenoid valves, while the BIT/RM is responsible to vote for a particular state, which the "Hydr" will act if in accordance with its own control algorithms.

"Hydr" monitors also the status of the HPS3 and, in case of failures, switches to the backup side of the HPS2, supplying a pressure warning signal concerning the HPS3.

- Verification of the operational status of the tail servo. This is done by means of a model, that enables to check the behaviour of the servo itself in response to the pilot's commands.

The block diagram of this model is shown in fig.6.



The model simulates a closed-loop, second order system with one pole of the open loop system at the origin.

An airspeed dependent rate limit allows the model to simulate the aerodynamic loading.

In order to reduce false alarms due to transients, the threshold to compare the model with the servo is increased as the rate of servo's command increases.

- Arbitration in case of two hardware failures, using an overall model of the yaw channel of the helicopter, to determine if it is properly working in response to the pilot's commands.

The fig.7 shows the structure of the whole model.

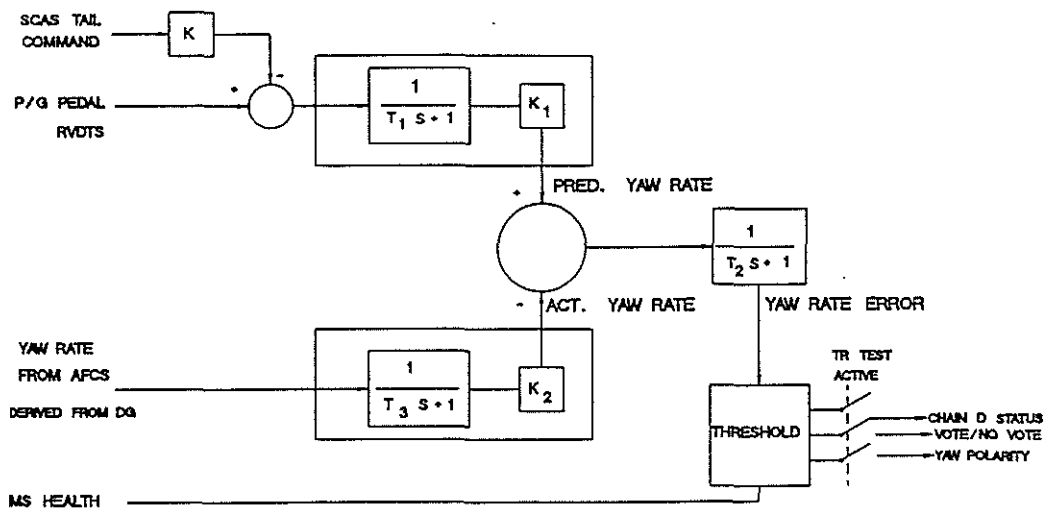


Fig.7

This "fourth channel" of the IMS informs each of the three tail rotor channels about its vote.

The voting may indicate the inability of the IMS to make a choice between the two remaining channels, allowing so to fly in pure mechanical mode.

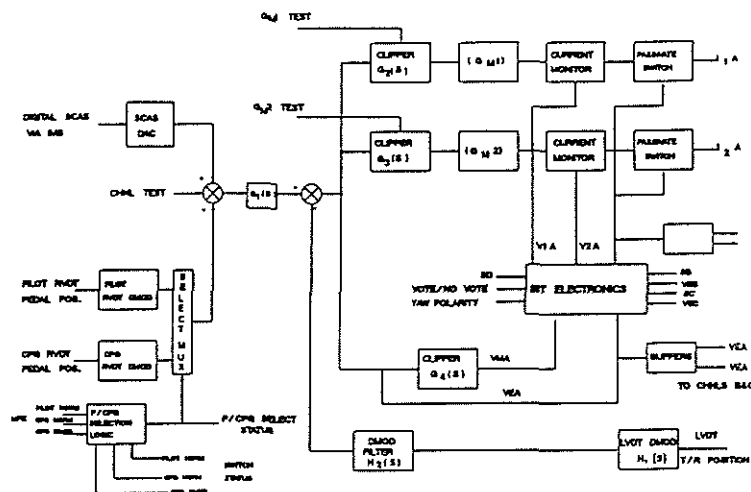
The IMS may also give an indication if it has no sufficient data to decide.

The last vote is for the polarity of the drive current.

The philosophy of the "fourth channel" model is based on the fact that the pilot (or the autopilot) tends to compensate for the erroneous channel by increasing his control in the opposite direction of the failure.

The block diagram of a typical channel is illustrated in fig.8.

Fig.8



The servo rotor position command, the sum of the SCAS and RVDT input are filtered by a 10 Hz. low pass filter.

The two output drive currents provide a control input to the EHSVs on the primary and the backup bodies of the tail servoactuator.

The drive currents are monitored for use by the BIT.

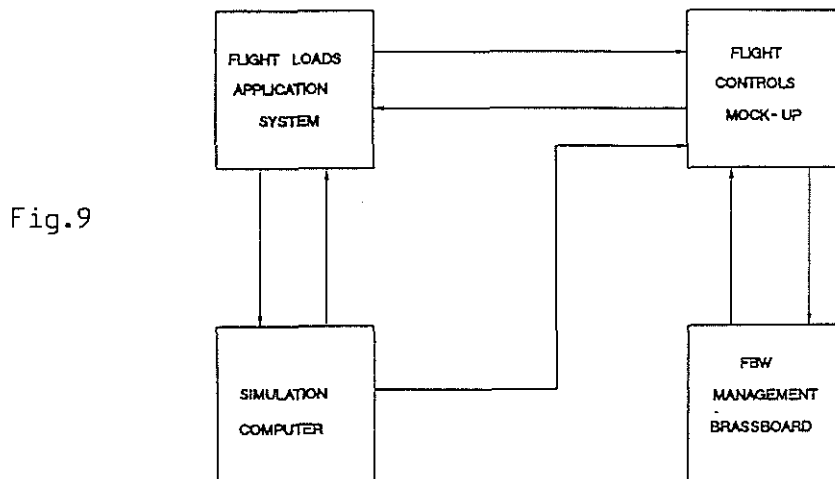
The passivation is made by opening switches in series with the outputs.

The outputs are then switched to a load simulating the servo valve DC-coil impedance.

In addition to self-test, each channel performs cross-channel checks with the other two.

SIMULATION SYSTEM

The whole Simulation System (see fig.9) is build up by the Flight Controls Mock Up, the Flight Loads Application System, the Simulation Computer and the FBW Management Brass board.



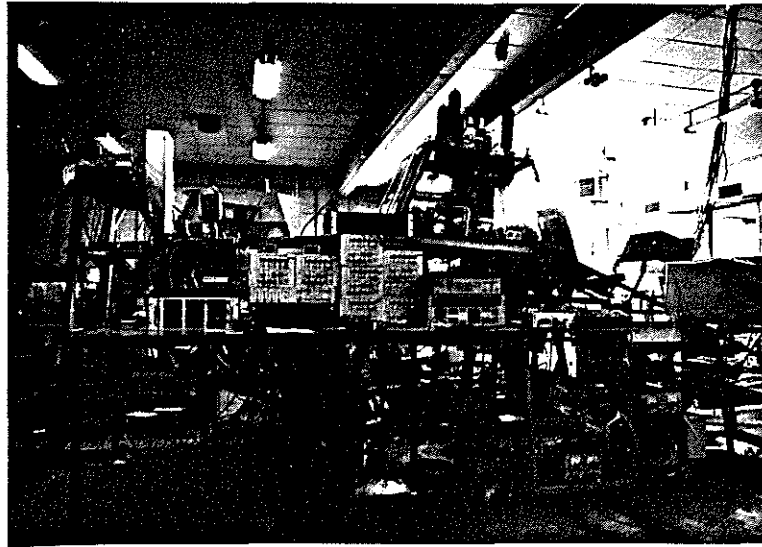
The Flight Controls Mock Up (see fig.10) is made by an iron structure, with the same interface dimensions of the helicopter, except for the tail boom area.

This installation is comprehensive of actual components, like all the pilot's commands, the whole mechanical linkage, the flight servoactuators, the integrated hydraulic groups, and all the tubes and hoses as per the actual installation on the helicopter.

To run the tests properly, other components are installed on the Mock Up, like the hydraulic motors to drive the pumps, the appropriate sensors to record pressures, tempera

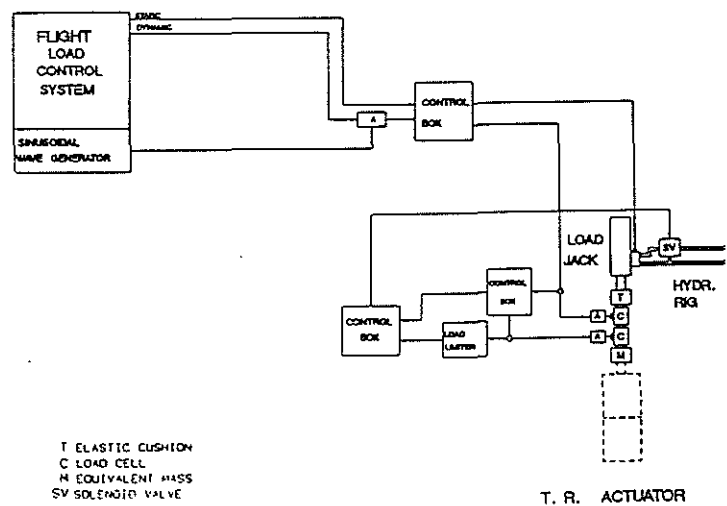
tures and strokes, and the hydraulic jacks to load the flight servos.

Fig.10



The Flight Loads Application System has the task to apply the aerodynamic loads to the flight servoactuators according to the inputs from the Simulation Computer.(see fig.11).

Fig.11



This is done by means of an EHSV controlling a load jack, with two load cells providing the feedback.

The Simulation Computer, as for its, receives the position of the pedals (or their speed change during a transient) and, managing the mathematical model of the helicopter, gives as its outputs the electrical signals to the Flight Loads Application System.

The whole mathematical model of the helicopter is given by the following set of equations' as given in Table 1.(2)

$$\begin{aligned}
\dot{w} &= Z_u^* u + Z_w^* w + Z_q^* q + Z_\theta^* \theta + Z_d^* d + g (\cos \theta - 1) + U^* q \\
\dot{u} &= X_u^* u + X_w^* w + X_q^* q + X_\theta^* \theta + X_d^* d - g \sin \theta \\
\dot{v} &= Y_v^* v + Y_p^* p + Y_r^* r + Y_A^* A - Y_b^* b + g \sin \theta - U^* r \\
\dot{q} &= M_u^* u + M_w^* w + M_q^* q + M_\theta^* \theta + M_d^* d + M_p^* p + M_r^* r + M_A^* A - M_b^* b \\
\dot{p} &= L_v^* v + L_p^* p + L_r^* r + L_A^* A + L_b^* b + L_q^* q + L_\theta^* \theta + L_d^* d \\
\dot{r} &= N_v^* v + N_p^* p + N_r^* r + N_A^* A + N_b^* b + N_q^* q + N_\theta^* \theta + N_d^* d \\
U &= U_0 + u \\
\dot{\theta} &= q \cos \theta - r \sin \theta \\
\dot{\psi} &= (r \cos \theta + q \sin \theta) / \cos \theta \\
\dot{\theta} &= p \dot{\psi} \sin \theta \\
\dot{h} &= U \sin \theta - (w \cos \theta + v \sin \theta) + w_w \\
\dot{\lambda} &= U \sin \psi \cos \theta + \cos \psi (v \cos \theta - w \sin \theta) + \sin \theta \sin \psi \\
&\quad (w \cos \theta + v \sin \theta) + V_w \\
\dot{\lambda} &= U \cos \psi \cos \theta + \int \sin \theta \cos \theta (w \cos \theta + v \sin \theta) - \sin \psi \\
&\quad (v \cos \theta - w \sin \theta) + U_w
\end{aligned}$$

where:

- θ = Longitudinal cyclic pitch
- A = Lateral cyclic pitch
- d = Collective pitch
- b = Tail rotor control
- U_0 = Trim speed in the helicopter frame of reference (f.o.r.)
- U = Helicopter instantaneous speed in its f.o.r.
- $\dot{\theta}, \dot{\psi}, \dot{\theta}$ = Angular speed components in the Eulerian absolute f.o.r.
- λ, ψ, \dot{z} = Helicopter absolute speeds in the ground f.o.r.
- u, v, w = Helicopter absolute speed components in its f.o.r.
- p, q, r = Helicopter absolute angular speed components in its f.o.r.
- U_w, V_w, W_w = Gust speed

Table 1

At the same time, the Computer controls also the instrument panel in front of the pilot seat, giving to the test engineer the information about what the response of the helicopter would be.

Summarizing, the Computer keeps into account the actual position of the pilot's controls, the previous flight conditions, and the stability derivatives of the helicopter to

compute its outputs in terms of flight load signals and instrument panel signals.

The instrument panel is simplified a lot, just to supply only the parameters about altitude, longitudinal speed, vertical speed, bearing and attitude (pitch, roll, yaw and hovering).(see fig.12).

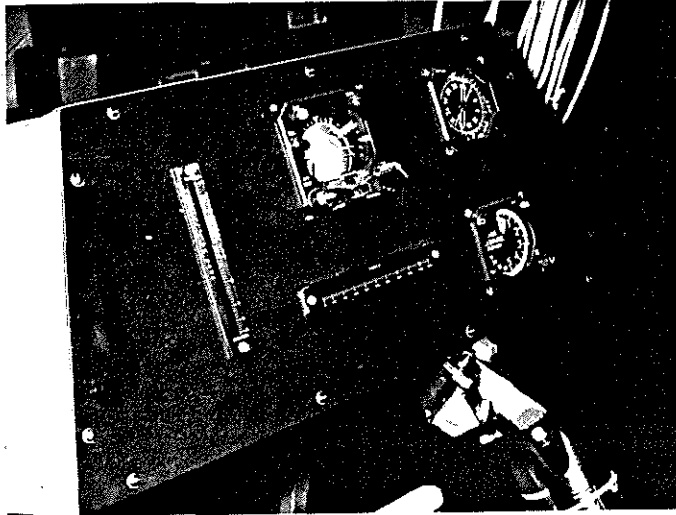


Fig.12

It is so possible to load the servoactuator with the expected flight loads or, better, reproducing the actual loads (static and dynamic, this last at its own frequency) recorded during the prototypes' flights.

The FBW Management Brassboard is all the hardware and software part representing the real FBW, but with a simplified math model and with the capability to simulate and to introduce failures into the system under testing.

In this way is possible to fully simulate in laboratory the behaviour of the whole Tail Rotor Control System, checking it in normal, emergency and pure mechanical modes.

It is also possible to reproduce almost all the failures (hydraulic, mechanical, electrical) that could affect the system, having so the possibility to check and to improve its capabilities to reconfigure itself .

It is almost obvious to underline the fact that using extensively the laboratory test rig gives a great improvement in terms of safety of prototypes' flights, costs savings, and possibility to study the effects of the most dangerous failures without incurring in catastrophic consequences.

TESTING CONCEPTS AND FIRST RESULTS

To better establish the various performances of the FBW system, it has been chosen to follow a "step by step" test procedure.

This procedure is based on the concept to start with the simplest functional configuration of the system under testing and subsequently, by adding one subassembly at a time, to reach its final configuration.

In this way is possible to distinguish and to understand the impact on the system's working mode of the many components constituting it.

First Configuration

So, the first step was mainly intended to check the interface between the servoactuator and the brassboard of the FBW management.

In this test configuration the two bodies of the tail servo were pressurized by a ground cart, not by the HPS3 and HPS2: the whole mechanical linkage was also omitted.

One of the main targets of this FBW testing phase was to substantiate the capability of the system's BIT/RM to auto reconfigure itself after one or two failures, whatever they should be.

It was important to check not only this capability, but also how and especially how much time was taken by the process to discover and to passivate a failure.

One of the first tests in this configuration was related to the substantiation of the self-test capability of each FBW channel.

A difference between the two output currents of a channel was generated and, as a consequence, the self-test logic passivated the channel (see fig.13), so enabling the servo to maintain its position.

Another test was run to demonstrate the cross-check capability of the BIT/RM.

A channel failure was simulated, saturating the drive current of a channel.

The behaviour of the servo during the reconfiguration was different if the first or the second failure was simulated.

In fact in the first-failure case (see fig.14) we had two EHSV coils operative during the reconfiguration phase, while only one EHSV coil was good during the reconfiguration consequent to the second failure (see fig.15).

SELF-TEST

CHNL A
INIT: 3 OP. CHNLS

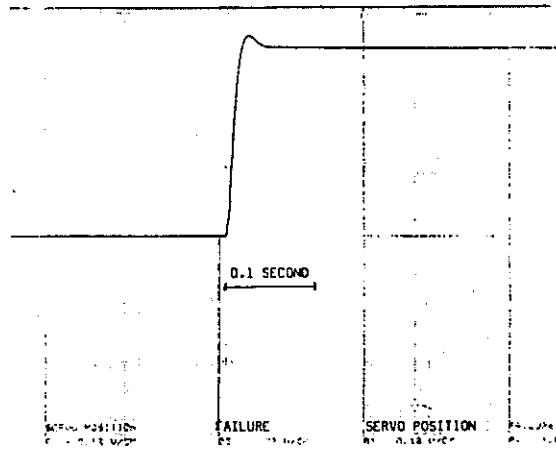


Fig.13

CROSS CHECK

CHNL B
INIT: 3 OP. CHNLS

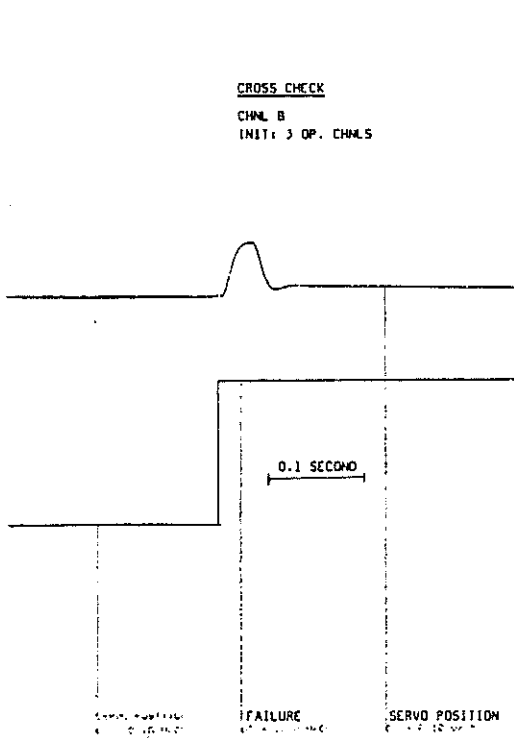


Fig.14

CROSS CHECK

CHNL B
INIT: 2 OP. CHNLS

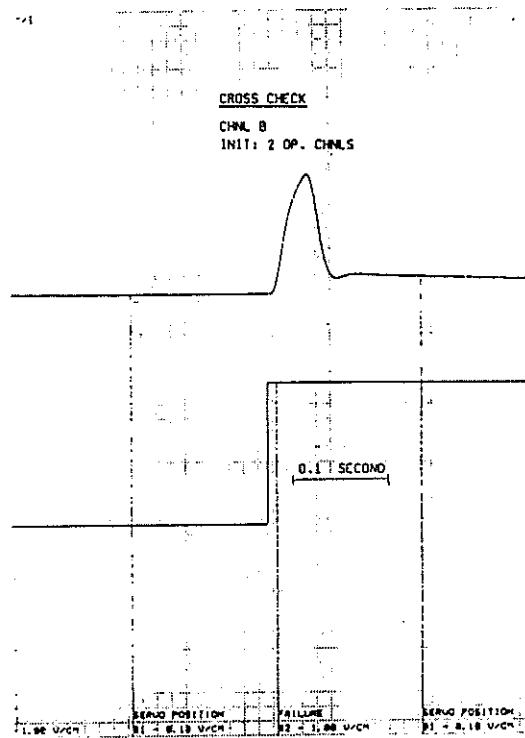


Fig.15

The same test was run in dynamic conditions, too (see figg.16 and 17).

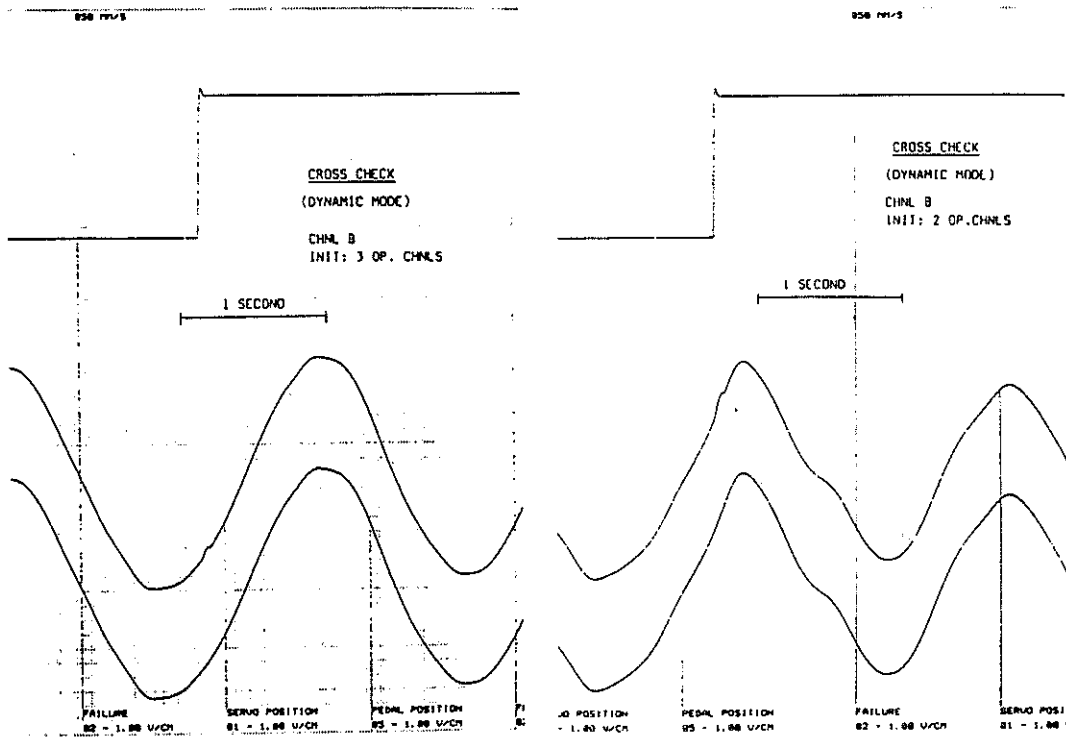


Fig.16

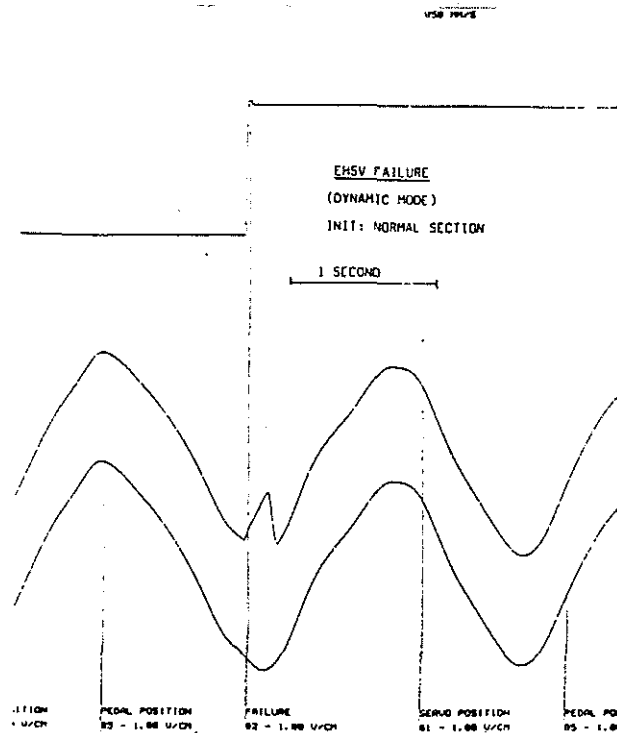
Fig.17

Also a EHSV failure was simulated; this was done by saturating (in current) two coils out of three, in such way to create an EHSV hardover.

So, the servo moved itself towards an end of stroke but, doing that, the servo math model discovered a discrepancy between the servo's position and the pedal's position.

Therefore, the BIT/RM generated the passivation of the normal body and, at the same time, the activation of the backup section (see fig.18).

Fig.18



Second Configuration

The second step was to use the HPS3 to energize the servo (as in the helicopter) instead of a service cart.

In this configuration, the servo was so subjected to the actual flow and pressure pulsations.

Another consequence was that was possible to check the correct interface between all the electrical components of the HPS3 and the brassboard itself, having so the possibility to introduce further simulated failures, as a loss a pressure or a overtemperature warning.

The RVDTs output signals were yet simulated.

Final Configuration

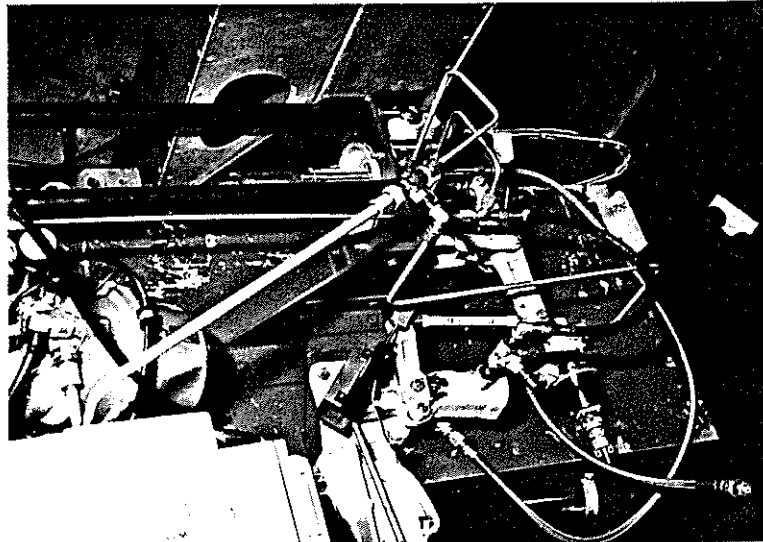
The last step was to link the brassboard with the whole Tail Rotor Control System, installed on the Flight Controls Mock Up.

Compared to the previous configuration, the major improvement was due to the presence of the pilot pedals with their three RVDTs assembly, and of the complete mechanical linkage between the pedals and the tail servo, passing through the mechanical lock device.

One of the first problems that had been investigated deeply in this configuration was given by the difference between the electrical and the mechanical inputs.

Better, the same input pedals displacement caused different outputs at the level of the mechanical lock device (see fig.19), since the command is transmitted, at the same time, via the mechanical linkage and via the FBW loop.

Fig.19



In a theoretical situation, a displacement of the pedals should cause a movement of the stop pin, internal at the window, equal to the movement of the window itself, being this last displacement caused by the FBW loop commands; so, the stop pin should appear still at the mid stroke of the window opening.

This problem was due to the non-perfectly simmetrical design of the tail rotor mechanical linkage, that is almost common in the most of the conventional mechanical control loops, where the pilot represent the sole element of the feedback.

In the A129 configuration the opening of the window corresponds to the +/- 35 per cent of the total stroke of the actuator, where the +/- 30 per cent is due to the SCAS authority.

So, only the +/- 5 per cent is devoted to keep into account for electrical and/or mechanical errors.

The mechanical error, revealed by the recording of some relative movements of the stop pin in respect of the window when the tail servo ran in FBW mode, was discovered to be greater than the maximum allowable one.

This fact could cause a "positive reaction" on the pedals if, in a sudden manoeuvre, the full SCAS authority sums itself to the mechanical error.

As a consequence, a redrawing of the tail control mechanical linkage had to be done, tailoring it on the base to do not give errors greater than +/- 5 per cent as measured at the input of the mechanical lock device.

CONCLUSIONS

The results obtained by the early FBW tests have demonstrate the conceptual validity of the A129 Tail Rotor FBW Control System, especially in the important field of the auto reconfiguration capability.

Further, more careful testing phases will better check and validate the whole hardware and software structures of the FBW System.

References

- 1) M.ZAVA, A129 Helicopter Flight Control System Configuration and Design Criteria, Paper presented at Ninth European Rotorcraft Forum, Stresa, Italy, 1983.
- 2) A.ABBA', A129 Helicopter Laboratory and Testing Method for: Flight Control System, Fuel System, Engine Compartments, Paper presented at Ninth European Rotorcraft Forum, Stresa, Italy, 1983.