NINTH EUROPEAN ROTORCRAFT FORUM

Paper No.69

A129 HELICOPTER
FLIGHT CONTROL SYSTEM
CONFIGURATION AND DESIGN CRITERIA

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September 13 - 15, 1983
STRESA, ITALY

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Associazione Italiana di Aeronautica ed Astronautica

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ABSTRACT

From time immemorial the configuration of military equipment is influenced by the operating environment (both natural and artificial) in which such equipments will act.

It follows that the design of the subsystems of an integrated weapon system is imposed as well by the artificial environment that the enemy is able to create in order to interfere with the mission of the opposing party's machines.

Being based on these considerations, and obviously without forgetting the other usual constraints imposed on an aeronautical project, this paper intends to explain the impacts of vulnerability and survivability considerations on the preliminary and detail design phases of the flight control system of the A129, twin engined antitank helicopter.

After a short introduction of the A129 and of its leading particulars, the most important requirements of the flight control system will be described in detail.

Fundamentally, this requirements are:

- Survivability in the event of a double failure
- Survivability in the event of a ballistic damage

During the description of the flight control system final configuration, the system preculiarities about vulnerability and survivability will be emphasized.

A careful description of the system's major components will be given particularly to the hydraulic pumps and to the flight servoactuators.

The main and tail rotor servos, their functions and their integration with the IMS will be subject of a deep analysis.

The paper conclusion will be based on the description of the technical solution adopted to answer to the project requirements.

Mainly, these solutions are:

- Tail rotor servo fully FBW
- Copilot FBW Flight Capability
- Emergency pure mechanical mode for both Main and Tail servos
- SCAS function integrated into the servos
- Integrated armour dual body servos
- Three separated hydraulic systems
- Integrated Hydraulic Power Supplies

ABBREVIATIONS

BIT	=	Built-In-Test
CPG	=	Copilot/Gunner
EHSV	=	Electro-Hydraulic Servo Valve
FBW	=	Fly-By-Wire
FCS	=	Flight Control System
HPS	=	Hydraulic Power Supply
HW	=	Hardware
IMS	=	Integrated Multiplex System
IR	=	Infra-Red
LVDT	=	Linear Variable Differential Transformer
MR	=	Main Rotor
NOE	=	Nap-Of-the Earth
RVDT	=	Rotary Variable Differential Transformer
SCAS	=	Stability and Control Augmentation System
SV	=	Solenoid Valve
SW	=	Software
TR	=	Tail Rotor

INTRODUCTION

The Agusta A129 is the answer to the Esercito Italiano (Italian Army) general requirement for a light helicopter with antitank capabilities.

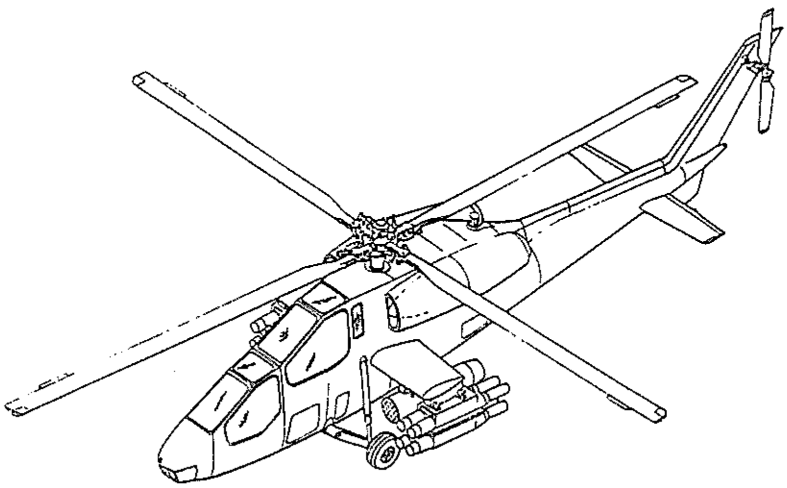
One of the principal targets to reach is to attain the survivability requirements through the manoeuvrability, the ballistic tolerance features and the optimization of the equipment for the mission.

The A129 (see fig.1) is a twin-engine helicopter, with a four blades main rotor and a two tail rotor; both rotors are composite-made to resist ballistic damage.

The MR is fully articulated by means of four single elastomeric bearings.

FIG.1

A129



The crew is formed by the pilot/mission commander and by the CPG.

The A129 has been designed to be operative in all-weather conditions in typical sophisticated battlefield environment, that is nearly all the mission time in presence of natural obstacles (hills, trees, etc.).

In order to perform NOE mission in such an environment, the agility and controllability characteristics of the helicopter have been pushed to the top.

Great importance has been given to vulnerability and survivability, keeping in mind the class of machine requested.

Good vulnerability performance have been achieved making an extensive use of composite materials (around the forty-five percent in airframe weight, plus important dynamic components like the rotors blades) and to a careful internal installation of the critical components.

The ballistic tolerance has been obtained through the application of the redundancy techniques on the critical systems, and by means of a crashworthy airframe design.

A low radar signature, IR suppressors and a low tip blades noise greatly contribute to the low detectability against any type of ballistic threat.

Survivability is increased by means of a set of electronic devices (i.e. radar warning, IR warning, radar jammer, IR jammer and chaff dispenser).

In Tab.1 are summarized the main characteristics of the A129.

Tab.1

A129

MAIN DATA

Gross Weight	3700 Kg (8160 lb)
Horsepower	2 engines, 1000 SHP each
MR Diameter	11.9 m (39.1 ft)
TR Diameter	2.1 m (7 ft)
Wing length (with pods)	3.6 m (11.8 ft)
Horizontal Stab length	12.3 m (40.3 ft)
Height (overall)	3.4 m (11 ft)

DESIGN PHILOSOPHY

The A129 operative requirements have led to a configuration of a FCS capable to guarantee the helicopter controllability (that is, survivability of the FCS itself) in case of double failure, even if one of these if of ballistic type.

This requirement is the informing principle on which has been founded all the design of the FCS, starting from the preliminary phase up to the detail one.

Hence it follows the choice to use MR servoactuators capable to operate, during an emergency phase, in FBW mode with possibility for the manual one.

The TR servoactuator is intended normally operative in FBW mode, but it has the possibility of manual mode as well.

In Tab.2 is shown the complete set of actuation modes of the flight servoactuators.

Tab.2

FLIGHT SERVOS ACTUATION MODES

	NORMAL	EMERGENCY	
		FBW	MANUAL
MAIN ROTOR SERVOS	Manual input and hydraulically powered output.	FBW actuation (on one of the two bodies)	Without hydraulic power.
TAIL ROTOR SERVO	FBW actuation (on "normal" body)	FBW actuation (on "emergency" body)	Without hydraulic power.

FLIGHT CONTROL SYSTEM

The FCS of the A129 can be thought as formed by four main parts:
- Mechanical
- Hydraulic
- Servoactuators
- FBW Management

MECHANICAL FLIGHT CONTROLS

Both the pilot/mission commander and the CPG have the capability to fly the helicopter through traditional means, such as pedals, longitudinal and lateral sticks, and collective levers.

This to give the CPG the means to fly in safe way even if the mechanical control chain that ends up at the pilot is out of use.

The CPG's controls are mechanically linked to those ones of the pilot, in such way to enable the "pursuit", and so avoid that in case of transition from pilot's control towards CPG ones, the latter has his commands in a position not corresponding to the attitude of the helicopter at that moment.

An automatic decoupler device has anyhow installed on the linkage between the two crewstations (see fig.2), in such way that if one of the commands becomes locked, this event shall not inhibit the freedom of movement of the other one linked to the former.

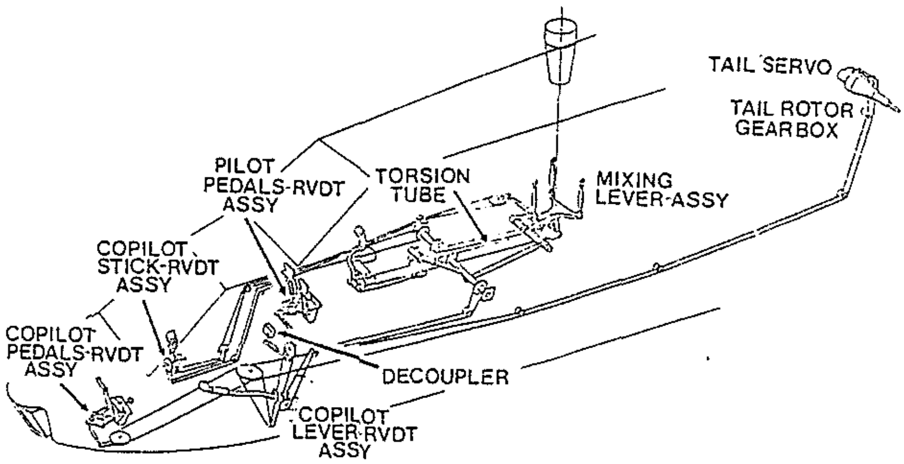


FIG.2 - MECHANICAL CONTROL LINKAGE

The pilot/mission commander has at his disposal the classical helicopter flight commands:

- Pedals
- Lateral and longitudinal cyclic stick
- Collective lever

The movements of the pedals are taken by three RVDT, the output electrical signal of which, proportional to the angular displacement, represents the input in the TR servo FBW loop.

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

The cyclic stick movements are instead taken by two couples of RVDT (one couples for lateral cyclic and the other one for the longitudinal cyclic) to be utilized in MR servos FBW loops.

The normal mechanical inputs reach the MR servo input levers by means of the mixing lever assembly.

Since the torsion tube (linking the pilot cyclic stick to the mixing lever) has a critical importance from a vulnerabilistic point of view, it is manufactured in composite-material; so, it shall not collapse if hit by a projectile.

Still for ballistical reasons, the MR mast architecture has been completely upset; in fact, it is internally hollow in such way to accomodate, at its interior, the push-pull rods, and avoiding so direct ballistic damage to such flight critical components.(see fig.3)

As for the cyclic, the collective lever movements are "read " by a couple of RVDT.

As far as the CPG is concerned, his station is equipped with pedals, collective lever and stick, too; but, since its emergency peculiarity, the cyclic stick is arranged right sideways to the CPG seat.

As in the pilot station, also here the command displacements to the cyclic stick and collective lever are electrically read by a pair of RVDT each.

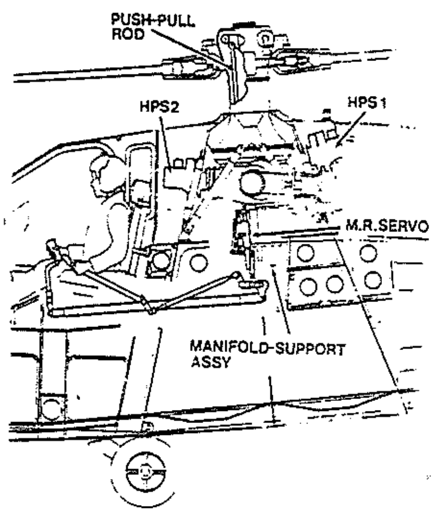


FIG.3 - MAIN TRX AREA

The input signal from the pedals is instead given by three RVDT, as in the pilot station.

HYDRAULIC

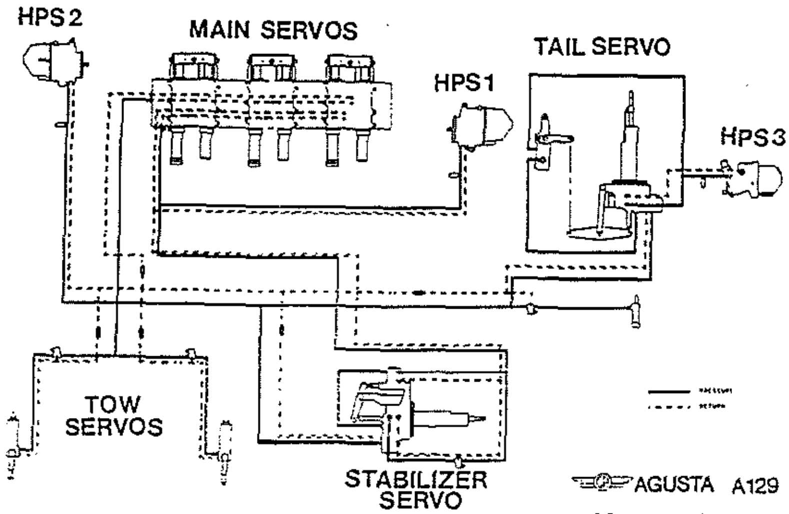
The A129 hydraulic system (concerning the FCS) is pressurized by three hydraulic power integrated package, called HPS.

Each HPS is formed by the functional union of pump, pressurized reservoir, filters group, and sensors to check the working parameters (temperature, pressure, oil level,etc.).

Each HPS feeds the various functions of the flight servoactuators, in such a way to guarantee the working of these latter after the first hydraulic failure (see fig.4 and Tab.3).

FIG.4

A129
HYDRAULIC
SYSTEM



Tab.3

SERVOACTUATORS HYDRAULIC FEEDINGS

	3 M.R. SERVOS		T.R. SERVO		HORIZ.STAB. SERVO		LAUNCHING RAMP SERVOS
	Bodies 1	Bodies 2	Body 3 (Normal)	Body 2 (Emergency)	Normal Body	Stow Body	
HPS1	X					X	
HPS2		X		X	X		X
HPS3			X				

NOTE: The horizontal stab. servo needs both HPS1 and HPS2 to normally work, otherwise it shall be automatically stowed.
On the other hand, each body has incorporated the function "STOW". See later on

The HPS main data are given in Tab.4.

Tab.4

HPS MAIN DATA

SYSTEM DESIGN SPECIFICATION	MIL-H-5440,TYPE II,CLASS 3000 PSI AND MIL-H-8775,TYPE II.		
SYSTEM PRESSURE	207 BAR (3000 PSI)		
HYDRAULIC FLUIDS	MIL-H-5606 AND MIL-H-83282		
	HPS1	HPS2	HPS3
TYPE	VARIABLE DISPLACEMENT AXIAL PISTONS, BOOST IMPELLER	VARIABLE DISPLACEMENT AXIAL PISTONS, BOOST IMPELLER	VARIABLE DISPLACEMENT AXIAL PISTONS
PRESSURE-FULL FLOW	196.5 BAR (2850 PSIG)	196.5 BAR (2850 PSIG)	196.5BAR (2850PSIG)
RATED FLOW	19.0 LPM (5.0 GPM)	23.6 LPM (6.2 GPM)	4.5 LPM (1.2 GPM)
DISPLACEMENT	2.5 CCPR (0.15 CIPR)	2.5 CCPR (0.15 CIPR)	1.28 CCPR (0.072 CIPR)
RATED SPEED	8020 RPM	9950 RPM	4046 RPM

A point to emphasize is that the packages HPS1 and HPS2 which pressurize the concerning circuits are fully and completely interchangeable between them.

SERVOACTUATORS

The servoactuators devoted to the aerodynamic surfaces control are:

- three MR servoactuators
- one TR servoactuators
- one horizontal stabilizer servoactuator

Moreover, there are two servos, installed into the two short wings, to allow the vertical pointing of missile launching ramps.

- Main Rotor Servoactuator -

The three MR servos are installed on the three lateral faces of a special manifold-support unit.

This unit, apart from hydraulically feeding the three servos, also provides to fix all this assembly just underneath the main transmission box.

Each servo is a fixed type, two separate bodies, side-by-side configuration.(Hydraulic Scheme,see fig.5).

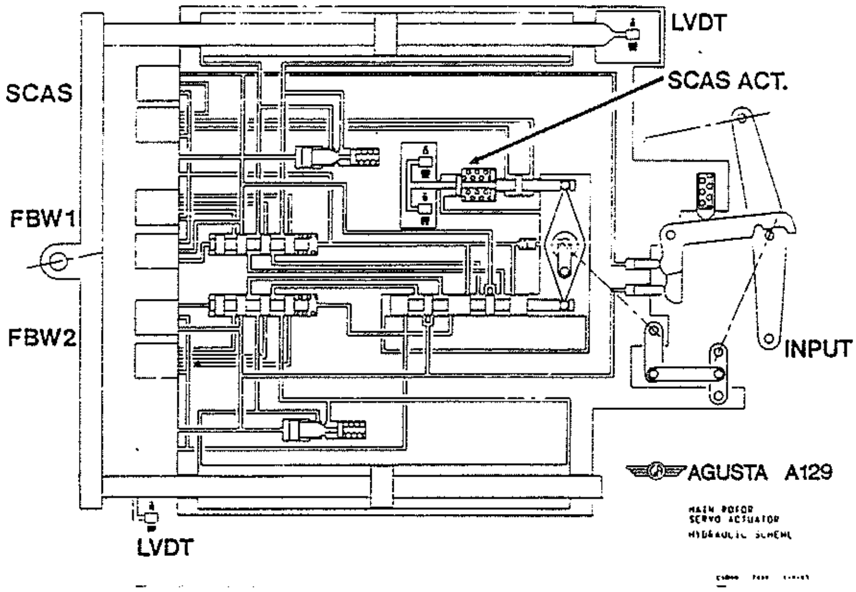


FIG.5 - MAIN ROTOR HYDRAULIC SCHEME

The only common parts are the main control valve, the yoke connecting the two piston rods, and the input lever.

The "normal mode" of the MR servo is defined as the working mode given by a mechanical input and the output hydraulically powered.

The mechanical input, as given by the pilot station, can be summed with the SCAS signal, the components of which (one energizing SV, one EHSV, two feedback LVDTs) are fitted in only one of the two servo's bodies.

In emergency mode, only one body can be pressurized, since its thrust is however sufficient to withstand the design aerodynamic loads.

If the emergency is given by a mechanical control chain failure, the FBW mode is switched on.

Both servos's bodies may run in FBW, but this mode can be switched on in only one body at a time; this to avoid output force conflicts.

Thus, every body has fitted on all the components related at their own FBW (i.e. one energizing SV, one EHSV and one LVDT for the feedback signal).

Such servo offers even the possibility of pure manual mode (that is, manual input and output with both HPS off).

The manual mode is automatically switched on by depressurizing both HPS1 and HPS2; this enables the engagement of the main control valve input lock, to provide the pilot a fulcrum point to manually operate the servo.

The MR servo main data are given in Tab.5.

Tab.5

M.R.SERVO MAIN DATA

M.R. SERVO - MAIN DATA

Operating Pressure	:	165 to 207 bar
Input Stroke	:	115,5 mm.(4.54 in.)
Output Stroke	:	84 mm.(3.3 in.)
Rate	:	>170 mm/sec.(6.7 in/sec.)

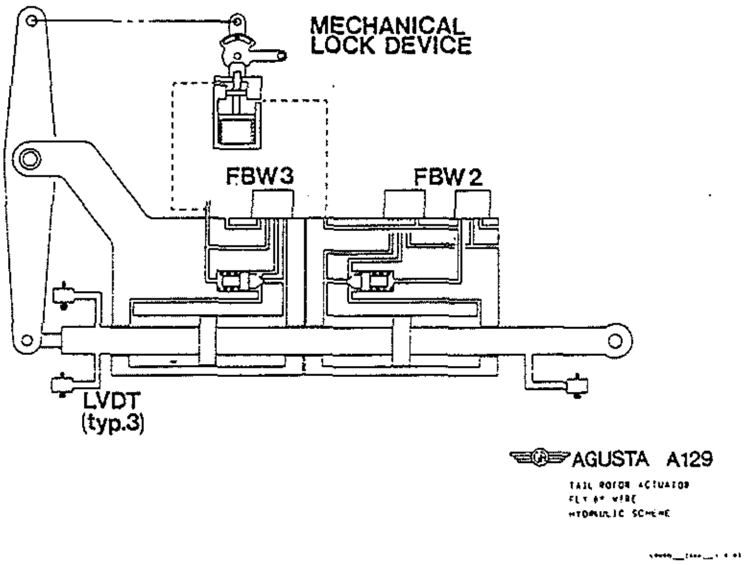
- Tail Rotor Servoactuator -

This servo is installed inside the ninety degrees tail rotor transmission box (see fig.2), coaxial with the tail pitch link.

The servoactuator is fixed type, two separate bodies, tandem configuration with FBW function on both bodies, and emergency manual mode possibility.(Hydraulic Scheme, see fig.6).

FIG.6

TAIL ROTOR HYDRAULIC SCHEME



Normally, only the body n°3 (so called because it is pressurized by HPS3) is operative by means of its FBW section.

On this body is installed a 3-coils EHSV, that adjust the oil flow according to the signal from command loop; the electrical feedback is given by three separate LVDTs, the mobile equipment of which is jointed to the piston rod.

The FBW n°2 (pressurized by HPS2) is switched on by the opening of the SV of the TR servo body n°2, and by the closure at the same time of the depressurizing SV installed on the HPS3; this to avoid the servo hydraulic lock.

A 3-coils EHSV installed on body n°2 provides to regulate the flow, while the feedback is always given by the three LVDTs.

The servo manual mode operation is possible by means of the depressurization of both bodies at the same time, and this is done by closing both the SVs related to the two hydraulic feeding of the servo; this permit to avoid a double hydraulic lock and, contemporaneously, to stiffly link the servo input lever to the mechanical command chain from the pedals.

TR servo main data are summarized in Tab.6.

Tab.6

TR SERVO - MAIN DATA

T.R SERVO - MAIN DATA

Stroke	: 80 mm. (3.15 in.)
Rate	: 150 mm/sec.(5.9 in/sec.)

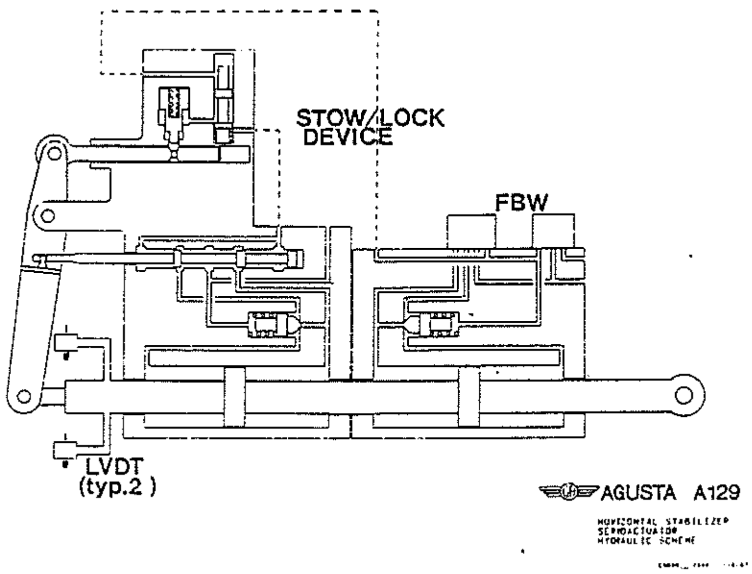
- Horizontal Stabilizer Servoactuator -

It is obtained starting from the TR servo from which is however different mainly about the working modes.

This servo (Hydraulic Scheme, see fig.7) is fixed type, two separate bodies, tandem configuration.

FIG.7

HORIZONTAL STABILIZER SERVO HYDRAULIC SCHEME



It normally works in FBW, which components are integrated on body n°2 (pressurized by HPS2).

On the other body, fed by HPS, is installed a hydromechanical device, capable to bring the piston rod in a prefixed position and lock it there.

This mechanism operates as soon as occurs a failure that cause the pressure loss of one of the two hydraulic circuits feeding the servoactuator.

If this failure is pertinent to HPS1, the displacement towards the lock position is driven by means of a proper electrical signal to the EHSV of FBW n°2.

FBW MANAGEMENT

Let us now see, more in detail, the FBW management logic.

First of all, we must underline the fact that both HW and SW pertinent to the FBW are part of the IMS.

From this point of view the IMS operates as a part of the FCS, to provide the FBW backup function for the MR servos, the FBW primary function for the TR servo and for the horizontal stabilizer servo; the IMS provides also a dual redundant SCAS function, to stabilize and improve the flight handling characteristics of the A129.

So, the FBW is designed as the primary means to control the TR servo and, at the same time, it provides the CPG a means to control the MR servos if the mechanical control chain is inoperative; consequently, as seen before, in emergency mode the CPG flies the helicopter totally in FBW.

- Redundancy -

The main rotor FBW and the SCAS are dual redundant.

Their architecture provides a fail-operational design using extensively HW and SW fault monitoring via BIT.

All the first failures of the SCAS that cannot be corrected reconfiguring the system, are passivated.

The system is capable to automatically detect a first failure and reconfigure the system in almost all the events.

In the few remaining cases, to reconfigure the system from the passivated states it is required the intervention of the pilot, who is helped by appropriate indications of the system itself.

The TR FBW has instead a two-failure-operational design, by use of redundancy and HW/SW fault monitoring.

The design has a three-channel (triredundant) configuration plus an extra fail-safe monitor channel to assure the capability to perform operations after the second failure.

- FBW Actuation -

The MR FBW is enabled by means of an emergency switch on the CPG control panel.

Both crewmen can switch the helicopter to the normal mode pressing the NORMAL mode button on their control panels.

Furthemore, each crew member has a visual indicator signalling the helicopter flying mode and the operability lity status of the redundant channels of the FBW.

- Main Rotor FBW -

The MR FBW is intended as an emergency mode to provide the CPG with the capability to control the MR servos without the use of the mechanical control chain.

As seen before, the CPG controls are provided with dual, independent RVDTs for longitudinal, lateral and collective axes.

The FBW function is fully redundant and is provided on each of the three MR servoactuators.

The IMS performs the flight control function by means of a dual redundant processing of flight control equations.

The IMS monitors the redundant flight control input RVDTs and servos position feedback LVDTs and models the servos for the purpose of failure detection.

In case of a failure, the system isolates it and provides an automatic reconfiguration.

In the event that the BIT is unable to isolate the failure the IMS sends a message to the crew advising that is required an operator selection of a processor.

In the event of failure of a LVDT or EHSV the IMS automatically reconfigures the system and sends a message to the crew advising that a failure (loss of redundancy) has occured.

In the case that the IMS is not capable to reconfigure the system, is required the manual intervention of the crew.

In the emergency mode of flight the IMS provides four axes control paths for inputs by the CPG; in addition is provided a three axis (yaw, pitch, roll) stability augmentation.

All other modes are disengaged when MR FBW is engaged.

- Tail Rotor FBW -

The FBW is designed to be the primary control mode of the TR.

The primary control path from the pilot and CPG pedals is triple redundant (see fig.8).

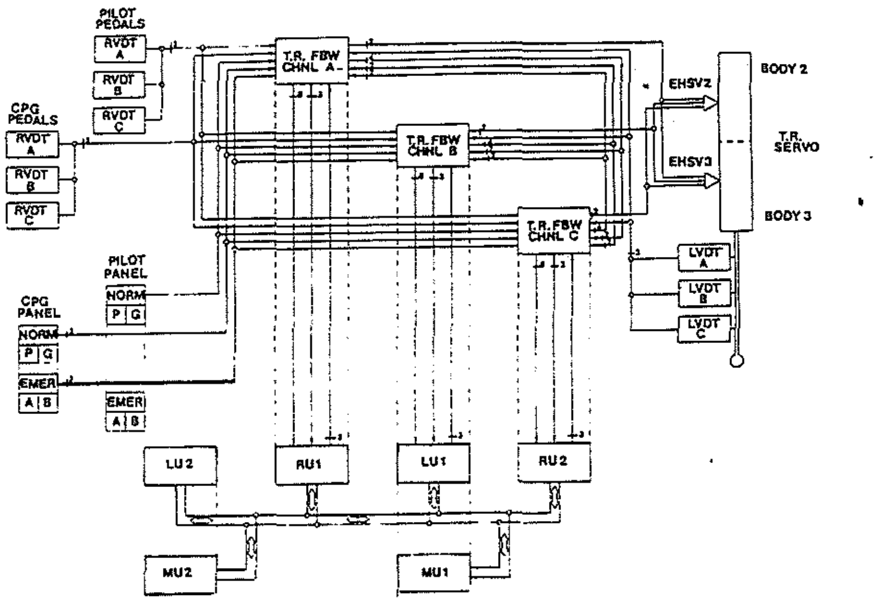


FIG.8 - TAIL ROTOR

Triple redundant RVDTs are installed on pilot and CPG pedals while the TR servoactuator is provided with three LVDTs; also, triple redundant servo amplifiers are provided.

The TR control is functionally independent of the IMS and is capable of operation independent of the IMS processors.

The IMS monitors the TR control and in case of a second failure (or the first failure in the hydraulic system) provides information to the TR control to allow its electronics to make the appropriate control channel selection or SV action to reconfigure the system.

The TR control is capable of detecting a first failure and reconfiguring the system independently of the IMS processor.

The TR FBW control is activated upon power up and may not be switched off from the IMS.

A separate switch enables the crew to remove current to the TR servo SV in the event of an uncontrollable system failure.

In this case, the mechanical lock module enables the manual control of the tail servo.

- Horizontal Stabilizer FBW -

The horizontal stabilizer servoactuator is control_ led by the IMS as a function of airspeed, collective lever and longitudinal stick positions.

First failure in the stabilizer controls results in passivation by switching off the servoactuator EHSV with an appropriate warning to the pilot.

This results in the automatic intervention of the hydraulic stowing and locking device.

The crew is provided with a pushbutton to command the stabilizer to its stowed position; pilot and CPG are also provided with a protected switch to force the stabilizer to stowed position independently of the IMS.

During stowing and unstowing operations, the rate of command to the stabilizer servo is limited according to the airspeed; for airspeeds greater than 75 knots the maximum stowing rate is of 1 degree per second, while for airspeed lower than 75 knots the stowing rate is of 5 degrees per second.

FINAL CONSIDERATIONS

In many areas of the FCS of A129 the concepts of survivability and redundancy have been applied; it is interesting to comment same of these applications.

All the hydraulic circuits are double redundant for all the servoactuators; in this way, every first failure of every kind -even ballistical- that affects an hydraulic circuit can be by-passed, keeping intact all the flight capabilities.

This is true even because the flight servoactuators are a separated double body-type, and then designed in such way that the useful thrust section of a single body is sufficient to generate the design loads, while the other body is hydraulically by-passed.

The body separation, at last, permits to stop a fracture propagation, saving the functionality of the not affected body.

About the servoactuators ballistical protection care was been taken to "hide" them.

The three MR servos are installed inside the helicopter, in protected area, and connected to the structure by means of a special manifold-support unit, with the double purpose to support them and share the HPS hydraulic fluid.

That means a substantial reduction of pipes (weight saving, reduced overall size, reduced complexity of the installation) and consequently less chance to be hit by a projectile.

Furthermore, the peculiar triangular-shaped cross-section of the support is so made to allow the three servo actuators (bolted on its three faces) to self-protect themselves from ballistic threats.

The redundant components (for instance the EHSVs related to FBW1 and FBW2 of each MR servo) have been fitted in such way to be not "visible" the one from the other; so, a single bullet cannot cut off a function and, at the same time, its redundancy.

The components that, whatever functions they carry out, pressurized by different circuits, have been fitted according to the same logic, as well.

So a single bullet cannot cause the loss of two hydraulic circuits.

Due to the shape of the support, this configuration is observed not only in each MR servoactuator, but even between contiguous servos.

Since the functions carried out by MR servos are very critical, to these components has been assured a high-degree functional redundancy.

Infact, we must remind that these servos have the capability to operate according to three different modes; two of these (normal and FBW) are redundant.

Active armour-plating concept has been used in the MR servo valve block; frangible glands have been applied to avoid rods ballistical lock.

The peculiar installation of the TR servo gives a good protection of servo itself; infact more than half length of the servo is inside the TR gearbox.

The components outside the gearbox (EHSV, SV, etc.) have been installed in such way to be mutually not visible; LVDTs housing are instead installed on the servo and inside the TR gearbox.

Another consequence of the effort to minimize dimensions and overall sizes are the HPSs; in this way, compacting in a single group all the components essential to the hydraulic feeding, it is possible to greatly reduce the number of pipes and hoses necessary to share the fluid, so reducing the exposed area to the ballistic threat.

Again, this saves weight and configuration complexity.

The decision to adopt the FBW mode to normally control the tail servo is mainly due to the fact that this control mode is less vulnerable than mechanical one, owing to the reduced number and reduced envelope of the necessary components, and to the facility to have redundant systems.

- In this particular helicopter, thinking to the distance between crewstations and TR, it has taken into consideration the high chance to have a ballistic damage in a so long control linkage.

Due to the same reasons, is the decision to install a third HPS (HPS3) very close to the TR servo, in such way to reduce the chance for a pipe to be hit by a projectile; the HPS3 feeds the normal body of TR servo, but not forgetting the always present ballistical threat, the emergency body is pressurized (when necessary) by the HPS2.

That is another good chance to avoid the loss of FBW capability of TR servo.

Anyway, to greatly improve the ballistic tolerance, a mechanical linkage is provided as backup control system, to guarantee the possibility to fly after two failures.

Besides, in a FBW system is very easy to sum the SCAS electrical signal, avoiding a new EHSV: the architecture of a FBW is very simple!

In this way, it has been possible to provide the CPG with fully (both MR and TR) FBW capability giving him, even in emergency events, good manoeuvrability, SCAS aids, redundancy on control modes.