

TWENTYFIFTH EUROPEAN ROTORCRAFT FORUM

Paper n° L3

**EH101 HELICOPTER
DESIGNED FOR SERVICE**

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1. DESIGNED WITH RELIABILITY AND MAINTAINABILITY AS ONE OF PRIMARY REQUIREMENTS

The design of EH 101 model dates back to the middle of the eighties. Following an agreement between Italian and British Ministry of Defence for a common naval helicopter to replace the fleet of SH-3D/Sea King in service with the two Navies, Agusta and Westland started the preliminary definition of a helicopter capable of meeting the specification requirements. At the same time EHI was founded, a joint company shared 50% by Agusta & Westland. After the feasibility study, EHI and the two Ministries of Defence signed a contract to develop the EH 101.

Since the beginning the Specification was comprehensive of very specific and precise reliability and maintainability requirements fully integrated with all other design requirements. The design philosophy, the choice of materials and the system technology were also driven by those requirements. The values of reliability and maintainability stated in the specification were requested to be demonstrated during the development and in service. For that purpose a specific Maturity Programme was defined to take place at the entry in production of the helicopter.

2. FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS STARTED SINCE THE PRELIMINARY DESIGN COMMENCED

The design specifications of the subsystems internally to the companies and the procurement specifications externally to the suppliers were prepared including specific requirements to guarantee that the design of the component/subsystem would conform to the need for reliability and maintainability. The Reliability and Maintainability departments of the companies were involved from the beginning of drawing issue to verify the satisfaction of the expressed requirements. The Failure Mode Effects and Criticality Analysis was introduced from the outset of the preliminary drawings of systems, subsystems, components began and contributed to the optimization of the design. The drawings were issued only if the Reliability and Maintainability departments confirmed their acceptability. During the tendering for the vendor components, the compliance with reliability and maintainability requirements was classified with a high percentage of the total score.

3. THE FRACAS PROCESS WAS APPLIED FROM THE BEGINNING OF FLIGHT ACTIVITY

Since the beginning of the whole flying activity of prototypes and the running of major rigs considered representative of the flight, the Failure Reporting, Analysis and Corrective Action System (FRACAS) was put in place with two purposes: to validate the reporting procedure involving two different sites of activity and two work shares, to constitute a data bank for the validation of design and the implementation of product. Event Reports are made by more than 30 specialists in both companies covering all design disciplines and coordinating the design departments on the specific subject. In addition to these reports, the vendor specialists are also working on their respective components but reporting against the company processes.

4. RELIABILITY DESIGN CONCEPTS

The contractual reliability of the helicopter was not only limited to the mechanical one relevant to the single components and subsystems. The mission reliability was also a very precise commitment to be respected and demonstrated. The design philosophy of the helicopter was deeply impacted because of that. The primary systems were designed duplicated to guarantee the mission completion in case of first failure, the structural components were designed with redundant load paths and damage tolerance.

4.1 Hydraulic System

The hydraulic system comprises three independent circuits. The no.1 and no.2 circuits each supply one half of the quadruplex main and duplex tail flying controls servoactuators. The no.3 circuit supplies the ancillary systems during the normal operations and is provided with an emergency circuit supplied from a hydraulic accumulator. A six-way two-position solenoid operated changeover valve is incorporated in each of the no. 1 and no. 2 circuits. This enables the no. 3 circuit to be selected to supply either no. 1 or no. 2 circuits in the event of hydraulic power supply failure. The changeover valve also isolates the failed hydraulic power supply at the same time. An electrically driven hydraulic pump also forms part of the no.3 circuit and provides power for flight controls checking and maintenance via the solenoid operated changeover valves without having the engines running. It may be also used in flight as a standby supply for ancillaries, being available whenever the Auxiliary Power Unit is running.

4.2 Electrical System

The basic electrical power system consists of two channels powered by two oil cooled alternators. In addition, there is an emergency system consisting of an Auxiliary Power Unit driven oil cooled alternator. It provides power to essential loads in the event of main alternator failure. It also allows the avionics suite to be run in standby during periods of alert or during maintenance operations without the requirement for ground

power. Under normal flight conditions, both main alternators are operational. They feed their respective main busbars under control of their dedicated General Control Unit which monitors and maintains correct alternator outputs. In the event of a main alternator failure, the associate General Control Unit isolates the alternator and closes the tie contactor, thus connecting the two main busbars together for supply from the surviving alternator and the Auxiliary Power Unit may be started to provide an additional and alternative supply.

4.3 Standard Avionic System

The Avionic architecture consists of two main processing areas which perform the functions of aircraft management and mission management, Aircraft Avionic System and Mission Avionic System. Each of the two systems uses a dual redundant MIL-STD-1553B data bus as the main data transmission medium. The aircraft Avionic system consists of an Aircraft Management System completely duplicated, an Automatic Flight Control System made of two identical digital computers arranged internally in a dual-coupled configuration for each of the four axes which allows automatic failure isolation in the event of the first failure. An Electronic Instrument System incorporating six identical colour display units driven by three symbol generator units. Each symbol generator is identical and interchangeable with the others and in the event of failure the remaining could be reconfigured to operate all display units. The Navigation System comprises Inertial Reference Unit, Global Positioning System, Attitude Heading Reference System, Doppler Velocity Sensor, Display Mode Selector, Air Data System and Radio Altimeter.

4.4 In Built Check Out System

The In Built Check Out System is the integration and centralization of the Built In Test Equipment (BITE) information as provided by subsystems and Line Replaceable Units. The primary Repair and Maintenance requirement is able to diagnose avionic failures of a single Line Replaceable Unit in the aircraft. The principal equipment involved with In Built Check Out System is the Aircraft Management Computer and the Mission Computer Unit. The Aircraft Management Computer and Mission Computer Unit Avionic Monitoring Software Functions will collect BITE data via the data bus and monitor the data received to individuate any fault. When a fault is detected, several different functions are activated. The actions consist in the storage of the fault in the Maintenance Fault Log and the generation of alerts to the crew. The Fault Log is recorded in a non-volatile store of the Aircraft Management Computer. The Mission Computer Unit passes its Fault Log data to Aircraft Management Computer for storage. The Fault Log also contains information of faults of all aircraft systems (i.e. Hydraulic System, Transmission System, Fuel System, Engines, etc.) which are detected by Aircraft Management System sensors. The Fault Log is displayed in the Common Control Unit when selected by the operator under the Maintenance function. Options exist to access selectively the occurred failure, the time of occurrence, the number of occurrences checking system by system.

4.5 Fuel System

The basic tank layout consists of three main tanks and a transfer tank, the latter being used to top up the three main tanks as fuel is consumed by the engines. The three main tanks act as collector tanks, each of which feeds one engine. The three fuel feed systems designated forward, centre and aft are situated in the collector tanks. Under normal operating conditions, the forward system supplies fuel to the no. 3 engine, the centre to no. 2 engine and the aft to no. 1. A duplex Alternating Current driven fuel booster pump, assembly mounted within the canister of each main fuel tank, supplies fuel to its designated engine via a manifold valve assembly of four separate multi-way valves, one for each engine and one for Auxiliary Power Unit, providing low pressure and firewall shut off and crossfeed facilities. The manifold valve assembly provides direct feed to each power plant from its respective collector tank, crossfeed management enabling any engine or engines to be crossfeed from any alternative main tank. In the event of double booster pump failure, the engine driven pumps will draw air free fuel from the tank, down to the minimum useable fuel condition. For this purpose the tank mounted fuel booster pump assembly is provided with a suction bypass. Fuel is transferred by a duplex AC driven fuel pump assembly in the no. 4 transfer tank to the main tanks via the common refuel, defuel, jettison, transfer gallery. Transfer normally takes place automatically. When the fuel level in a main tank falls to 80%, a separate motorised transfer valve opens to allow fuel to enter the tank and closes when the level reaches 100%.

4.6 Automatic Flight Control System

The Automatic Flight Control System (AFCS) consists of two Flight Control Computers, Sensors, Pilot Control Unit and Hover Trim Controller. The AFCS provides stability, attitude hold and autopilot functions appropriate to requirements. Two identical digital computers are used. They are arranged internally in a dual-coupled configuration for each of the four axes and allows automatic failure isolation in the event of the first failure. The computers interface with the AFCS sensors and some navigation sensors which provide data on aircraft attitude, heading and accelerations. The AFCS supplies computed electrical outputs to Aircraft Management Computers 1 and 2. It outputs attitude, caution and warning data and Built-in-Test commands. The Electronic Instrument System displays the steering mode, heading, course and vertical speed selection on the Display Mode Selector. The AFCS outputs mode engagements state data and autopilot mode data to the Electronic Instrument System. Sensors supplying the AFCS are Dynamic Sensor Unit, Yaw rate, vertical and lateral acceleration, Vertical Gyros, Pitch and Roll attitude, Doppler, Attitude and Heading Reference System, two Air Data Units, two Radar Altimeters, Inertial Reference Unit, Global Positioning System, Secondary Air Data Sensors, Instrument Landing System. The Pilot Control Unit allows the pilot to manage the AFCS. Facilities are provided to allow the engagement/disengagement of the various lanes and axes of the Automatic Flight Control System, displaying their status. It also allows the pilot to engage and disengage the various autopilot modes and to display the selected modes.

4.7 Main Rotor Head Redundant Load Path

Each Main Rotor Blade is fully articulated with an elastomeric bearing carrying centrifugal load through the composite hub. A second elastomeric centering bearing focuses flap and lead/lag shear loads via metal support cones directly back to the metallic hub section. The centrifugal load from the blades is transmitted via tension links to the elastomeric spherical bearings and hence to the hub. The composite hub has load path redundancy by providing primary structural paths along both peripheral and loop windings. Thus the centrifugal load is shared and in the event of a single winding failure an alternative load path exists. The articulation system, comprising the centering and centrifugal force elastomeric bearing is arranged such that, in flight, the majority of the shear loads pass directly into the central core of the hub via the hub centre arm, and the only portion entering the composite structure is that derived from the stiffness of the centrifugal force elastomeric bearing. With this arrangement the composite hub is subject mainly to centrifugal static loads, whilst the hub centre arm is designed for fatigue. Nevertheless the accidental failure of the hub centre arm will not preclude safe continuous flight to a normal destination. Following such a failure the shear loads would be reacted within the composite hub itself.

4.8 Main Gearbox Attachments

The Main Gearbox Upper Casing is connected to the fuselage main lift frames by four struts. The lift moments and shears are reacted from top of the gearbox through these struts. The struts are sized and configured to enable them to react the loads in the event of a single strut failure. The torque reaction is taken directly into the aircraft structure at the cross members of the lift frames by four horizontal struts system which places the struts in compression. Again these are sized to react the redistributed loads following a single strut failure.

4.9 Main Lift Frames Redundant Load Path

The upper structure of the main cabin is designed with significant fore and aft members joining the main lift frames, but also continuing both forward and aft to the adjacent frames. This permits significant vertical loading to be beamed to the adjacent frame should the primary lift frame fail.

4.10 Main Gearbox Duplicated Lubrication System

The Main Gearbox has a duplicated integral lubrication system where oil is circulated by pressure pumps which, together with other lubrication system accessories, are mounted on bosses on the gearbox and connected to two separate oil distribution systems. Each one is providing adequate lubrication to each gear and bearing. In case of failure of one system, the gearbox could continue to operate without limitation. The gearbox has also completed the demonstration of the no oil test according to the Military and Civil rules.

4.11 Active Control of Structural Response

To increase the safety and mission reliability, a specific Active Control of Structure Response of the vibration induced by the rotor was designed and developed. The system consists of a computer that receives signals from 10 accelerometers positioned in different areas of the helicopter and drives 4 hydraulic actuators installed in the Main Gearbox suspension rods. The rods are made of composite material to provide the proper elastic deformation required by the actuators functionality. The system analyses the frequencies and associated amplitudes detected by the accelerometers and generates the appropriate counter phase to level the general vibratory environment of the helicopter. Because of that, the vibratory level remains flat across all the flight envelope with values well below the specification requirements. As a result, not only is the comfort of the crew and passengers improved, but all the components, usually subjected to severe vibratory levels that increase the dynamic loads that impact life and reliability, also the benefit.

4.12 Health and Usage Monitoring System

The Health and Usage Monitoring System has been designed inside each helicopter system as a part of it. Since the preliminary design started, the requirement to have a Health and Usage Monitoring system integrated in the helicopter was defined and introduced into the system design and procurement specifications. It consists of 114 dedicated sensors plus the standard ones already present to provide the information to the pilot. This information is controlled by the Aircraft Management Computers that provide the real time analysis and storage in a non volatile memory. The information relevant to the flight safety is displayed to the pilot. The transmission system itself is monitored by 5 wear sensors, 3 magnetic plugs, 15 accelerometers, 2 azimuth sensors, 4 bearing temperature probes, 4 torquemeters, 5 pressure transducers, 5 temperature transducers, 4 level transducers. A large amount of tests to define and validate the algorithms and thresholds have been carried out and completed. The Aircraft Management Computer software contains this information and provides the real time status of the transmission system. The use of Health and Usage Monitoring introduces the principle of variable Time Between Overhaul and parametric life of the major components of the helicopter. In fact the Health and Usage Monitoring System is able to determine the real usage of the helicopter and compare it with a conventional flight spectrum for the parametric evaluation of Time Between Overhaul and component lives. At the end of each flight, the Health and Usage Monitoring data are loaded in a Data Transfer Cassette via a Data Transfer Device installed on board the helicopter and driven by the Aircraft Management Computer. The Ground-based Data System is a software package installed in a conventional Personal Computer. This processes the data stored in the Data Transfer Cassette and provides all the relevant information to the ground crew for the scheduled maintenance, unscheduled inspections derived from anomalies detected by Health and Usage Monitoring and life expiring components.

5. MATURITY AND RELIABILITY ENHANCEMENT PROGRAMME.

At the completion of development activity and the certification of the helicopter, EHI was requested to demonstrate the evidence that all the features introduced in the design were giving to the helicopter the proper mission reliability. A specific and dedicated contract was signed between Italy and UK Ministry of Defence and EHI. The contract was called "Maturity and Reliability Enhancement Programme" and the relevant statement of work were specified in 3 documents: EHA 1340 "Production Investment Phase Plan", EHA 1424 "EH 101 Maturity and Reliability Enhancement Plan", EHA 1480 "Method of Assessment of the EH 101 Helicopter in the Production Investment Phase".

5.1 Scope of the Programme.

The scope of the programme is the acquisition and demonstration of maturity and reliability of EH 101 systems, subsystems and components to prove the project conformance with the requirements expressed in the design specifications in terms of Mean Time Between Failure of the entire helicopter in its different configurations. Another scope is the demonstration of the declared Time Between Overhaul for all dynamic components and the progressive extension of it. It also includes the demonstration and certification of Damage Tolerance for a number of primary sub-assemblies. The verification, extension of periodicity and optimization of the helicopter maintainability as established through Maintenance Steering Group 3 is also part of the contractual commitment. Finally, there is the development, verification and certification of Health and Usage Monitoring System involving the complete aircraft.

5.2 How the Objective are Demonstrated

5.2.1 Intensive flight activity using two pre-production helicopters, precisely S/N 50008 and S/N 50009. The helicopters are equipped with production components so that their configuration is as close as it can be to the final configurations which are supplied to the customers. The two helicopters are performing about 6000 flight hours having started in March 1996 with 50008 and in May 1996 with 50009. The flight activity is taking place on two sites which are representative of different environmental conditions, specifically the North Sea and Central Mediterranean Region. The flights are covering a mix of four different typical mission profiles, two of them are simulating civil operations and two are specific Royal Navy and Marina Militare missions. The duration of each profile is more than three hours.

5.2.2 Inspection and maintenance operations are carried out in compliance with the Maintenance Manual, using the appropriate tools and Aircraft Support and Servicing Equipments for the purpose of checking and validating both. The inspection periodicity is extended, where possible, and optimized according to the experience gained.

5.2.3 Intensive bench testing on all primary subsystem to support flight activity has been undertaken.

The testing campaign comprises 1200 hours on Ground Test Vehicle to anticipate Time Between Overhaul intervals on pre-production aircraft as a guarantee of achieving TBO targets and in order to increase safety levels. The transmission system is tested for 5900 hours on Banco Rigenerazione Elettrica in Agusta and Universal Transmission Test Rig in Westland to perform type tests and factor-linked tests for the early detection and investigation of discrepancies, if any, and to assess modifications as required. The hydraulic system and fuel system are tested for 1300 hours each on their respective rigs to support flight activity and to check the reliability of components which are not included in the helicopter S/Ns 50008 and 50009 configuration.

5.2.4 The systems and sub-systems not a part of the common configuration or not installed in the preproduction aircraft are subject of specific Reliability Growth Test. The tests are performed in a dedicated rigs simulating the real operational environment. They include the application of operational vibration levels, temperature range from -40 to +55 deg. C with soak test to -55 deg. C and the salt spray. The 46 tests planned are covering 70 part numbers. Some systems are subject to functional cycles, some are subject to endurance tests for a total of more than 50000 hours.

5.2.5 The dynamic components and major structural components are subject of structural tests including adverse environmental conditions and pre-existing damage. The tests are carried out to prove the damage tolerance of the related assemblies and to prove the capability to withstand operational loads under a failure condition without jeopardy to safety. The tests are conducted on representative test specimens and on the actual assemblies applying loads according to the flight spectrum. The components involved in the damage tolerance demonstration are: Main Rotor Blade, Tail Rotor Blade, Main Rotor Hub, Tail Rotor Hub, Inboard Tension Link, Outboard Tension Link, Civil Tension Link, Tail Unit, Horizontal Stabilizer, Rear Fuselage and Main Lift Frame. The test are conducted to demonstrate the compliance to the JAR 29 Regulation.

5.2.6 The Health and Usage Monitoring System monitors the conditions of all helicopter components through a series of both dedicated and standard configuration sensors during the maturity flight profiles of S/Ns 50008 and 50009 helicopters. The data are collected after each flight and processed on a ground-based computer and then used to validate the system itself and provide information of component maintenance, inspection, time between overhaul and service life. This information is in addition to the standard preventive and corrective maintenance procedure providing the cross reference checks between the two systems.

5.3 The Maturity and Reliability Enhancement Programme has a starting point the completion of the majority of development activity. At that point the prototypes completed more than 4000 hours of development and certification work. The Ground Test Vehicle completed more than 2000 hours. The two transmission rigs totalled 2000 running hours including certification tests, fatigue test of gears and no oil running test.

The Hydraulic and Fuel System Rigs completed more than 2600 hours. In November 1994 the Civil Type Certification was achieved for two variants, utility and passenger transportation, and with RAI, CAA and FAA.

6. PRESENT STATUS OF THE PROGRAMME.

- 6.1 The two helicopters completed the Central Mediterranean Region phase of the programme in September last year. The area in which they operated was the south part of Italy flying over Adriatic and Ionian Seas and based in Brindisi. They have totalled more than 2500. flying hours and completed the demonstration of the first step of drive system Time Between Overhaul of 1000. hours. The activity was then moved to Aberdeen for the North Sea phase. They are based at Dyce International Airport and more precisely in the Bristow facilities. The hangarage, the maintenance team accomodations, the fuel, the support to the flight operations and the pilots are provided by Bristow. In fact at the beginning of the programme a contract between Bristow and EHI was signed to provide pilots for the complete programme and the support of the North Sea phase. The need to have pilots from a Civil Operator was decided at the beginning of the programme to operate the helicopters as any Customer could do, therefore more realistic from the Maturity point of view. The hours flown so far are more than 4000. and two more steps were achieved and demonstrated: 1500. hours of drive system Time Between Overhaul and contractual Mean Time Between Failure.
- 6.2 Inspection and maintenance procedures have been applied and verified. A complete feed back was provided enabling the Maintenance Steering Group 3 system to reiterate the information and update the Maintenance Manual. The optimization of the maintenance in terms of periodicity and procedure is still on going. The tools of the Aircraft Servicing and Support Equipments package have completed their validation.
- 6.3 The Ground Test Vehicle completed the 1200 running hours required supporting the flight activity of helicopters. The transmission rigs are continuing their activity testing the gearboxes with factorized power spectrum. The Banco di Rigenerazione Elettrica completed the 2350 hours required and the Universal Transmission Test Rig has completed 2000 hours of the 3550 required by the programme. The Hydraulic System Rig and Fuel System Rig have completed their respective testing providing the required evidences and validations.
- 6.4 The Reliability Growth Test programme is almost complete. Two systems are still under test while the remaining 44 have been completed. The tests highlighted some defects that have been fixed and the final reliability target proven.
- 6.5 The damage tolerance tests have been completed and the components were certified as damage tolerant. The maintenance procedure takes into account that capability in terms of type of inspection and intervals.

- 6.6 The Health and Usage Monitoring System is operative in both helicopters and is continuously providing data to the specialists to increase the data bank, to validate the algorithms, and to control the level of thresholds. The information from Health and Usage Monitoring are used as a feed back during the Time Between Overhaul extension of drive system and to support the maintenance of helicopters involved in the Maturity Programme.

7. CONCLUSION

The Maturity and Reliability Enhancement Programme is expected to be completed by June 2000. The scope of that four years programme was the validation and the demonstration of the reliability and maintainability principles introduced in the design of the helicopter. The only target still not demonstrated is the 2000 hours of Time Between Overhaul of the drive system that is expected to be achieved in May next year, while all the remaining targets have been achieved and the evidence of the reliability and maintainability objectives demonstrated. With more than 4000 hours flown by the Maturity helicopters in real operational environment and all the tests carried out on various rigs, together they have demonstrated the original objective: the EH 101 is designed for service.