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# CERTIFICATION APPROACH AND TEST OF THE EH-101 COMPOSITE TAIL UNIT

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# CERTIFICATION APPROACH AND TEST OF THE EH-101 COMPOSITE TAIL UNIT

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**ABSTRACT**

*The EH-101 composite Tail Unit is one of the bigger primary composite structures entering production for both civil and military helicopter market. The civil certification process of this component adopted a building block approach typical of the composite structures substantiation, in accordance with the key issues of Advisory circular 20-107A; this approach resulted in an extensive program of tests at coupon, element and component level to establish the basic material properties and the specific design features.*

*In particular the full scale static test carried out in adverse environmental condition (high temperature and moisture conditioning), showed the capability of the structure to carry the ultimate load, taking into account the effects of impact damage and manufacturing discrepancies .*

*The element fatigue tests established the fatigue properties of the structural components and the full scale test is giving confirmation of the safe life of the Tail Unit and is evaluating potential stiffness degradation, to be taken into account for flutter evaluation. Finally, the flaw tolerant activity is providing additional information on the damage tolerance features of the Tail Unit.*

## 1. INTRODUCTION

The use of fibre reinforced laminated composites for primary helicopter structures has presently achieved a wide number of applications, ranging from primary and secondary structures to dynamic components, mainly rotor blades and hub, to flight control rods and aerodynamic lifting surfaces.

Helicopter industries moved in this direction attracted by the advantages that could be obtained through the use of these materials in terms of weight reduction, increase in margin of safety, reduction of the number of parts and assembling costs.

On the other hand, the civil certification and military qualification processes of composite structures is more elaborate and costly than those of metallic ones, because they must address in the proper way the peculiarities of composites, in terms of structural characteristics (mechanical behaviour, failure modes ...) and of manufacturing quality (Ref. 1).

In particular the effect of adverse environment, in terms of high temperature and moisture absorption, on the reduction of their static and fatigue strength and on possible change of failure mode, must be carefully evaluated (Ref. 2).

*Fig. 1: EH-101 prototype*

These additional activities and associated costs for the certification of composites are however justified by the need of maintaining the same level of safety of conventional metal structures.

In this context, the EH-101, the large helicopter (14,290 Kg Max Take-Off Weight) jointly designed by Agusta and Westland, represents a confirmation of the mentioned growth in helicopter composite structural applications. The EH-101 design, resulting by the effort of making the helicopter a state of art conception not only in the structural field, includes in fact, apart from cowlings, doors and sponsons, a number of composite primary structures such as the Main and Tail Rotor Blades and Hubs, the Forward Fuselage section, part of the Flight Control Rods and the Tail Unit, one of the larger primary composite structures entering production for both civil and military helicopter market.

This paper presents the certification basis agreed and the approach adopted for the Tail Unit substantiation and the results of the activities and tests carried out for civil certification and military qualification; moreover the special considerations and the test techniques used for the tests carried out in adverse environment are described.

## 2. COMPONENT DESCRIPTION

The EH-101 Tail Unit is an Agusta designed composite assembly common to all variants (naval, civil and utility) of EH-101 helicopter; the only difference between the naval and the civil variants is that the first one is foldable while the others are fixed.

This 3.2 m high, 4.3 m long component supports the anti-torque rotor and its gearbox, the intermediate gearbox and allows the installation of a low set asymmetric stabilizer. The Tail Unit could be divided into two main parts: the tail cone and the vertical fin that is inclined at an angle of approximately 12° to port to make easy the helicopter stowage into the ship's hangar.

From a structural point of view, the Tail Unit (Fig. 2) is mainly constituted by a central skeleton which supports two external skins and the upper and lower closure panels and is connected to the Rear Fuselage by means of four Titanium attachments.

In turn the skeleton is constituted of two vertical spars and six ribs; each skin incorporates, in the cone area, two longerons, originating from the Rear Fuselage

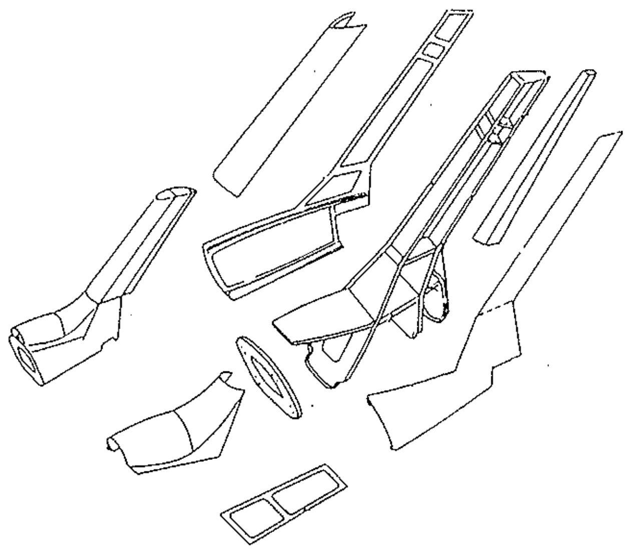

*Fig.2: Tail Unit structure*

attachments and running to the stabilizer attachment area.

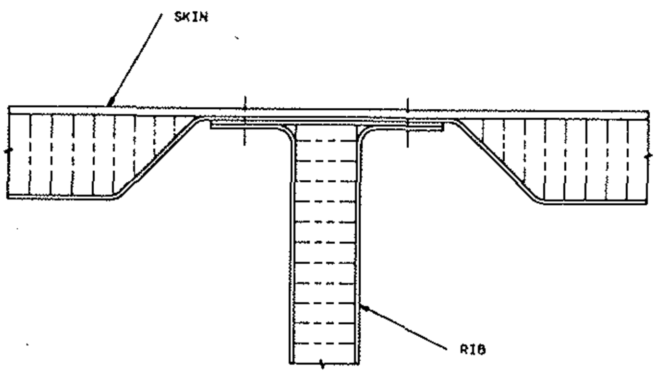


*Fig.3: Typical skin-rib intersection*

All these components are autoclave cured sandwich panels (Graphite-epoxy/Nomex/Graphite-epoxy) ramped down at the intersections (Fig. 3); the cone longerons instead have a foam core. The Tail Rotor, the intermediate gearbox and the stabilizer are fitted to the Tail Unit by means of metallic attachments. To protect the outside surfaces and for material compatibility reasons, an external ply of glass epoxy is used on composite-metal interface areas and along the rivetting lines.

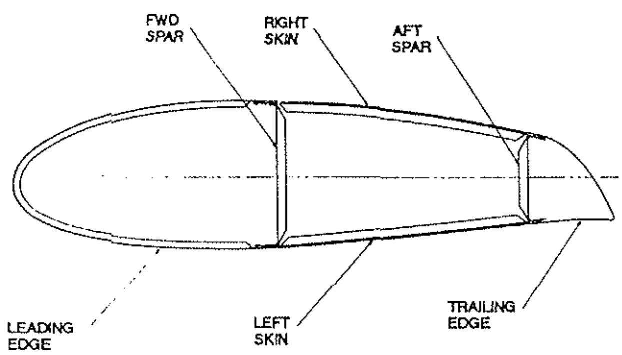


*Fig.4: Vertical Fin cross section*

The primary structure that weights about 110 Kg, is assembled with bonding and riveting and is completed by the forward fairing and leading edge fabricated from Kevlar-epoxy/Nomex/Kevlar-epoxy sandwich panels and by an Al-Alloy trailing edge (fig. 4).

All the composite materials used, i.e. graphite (both unidirectional and fabric) and kevlar fabric are high temperature (177°C) curing materials.

## 3. CERTIFICATION BASIS

Since the very early stage of the EH-101 certification process, it appeared evident to everyone involved, from both the Authorities' and Constructors' side, the enormous effort that they had to face with, due to the size and complexity of the project to be developped for military and civil variants, the number of involved parties and the relatively novelty of the design.

This effort concerned the High Management Level of the project and the nine Working Groups established for each specialist discipline (fig. 5), because of the mentioned size of the program, its peculiarities and the need for a technical assessment of the design with respect to the different instances, not always converging of sheduling, compatibility between conflicting design specification requirements and cost effectiveness.

The helicopter is being certified in Italy by Registro Aeronautico Italiano, in U.K. by C.A.A and in the United States by F.A.A.; for the structural aspects, the certification basis is constituted by:

- FAR 29 to amendment 29-26;
- BCAR Section G to issue 9.

In particular the Tail Unit, from a strutural point of view, was designed to cover both military (AR 56, MIL and AVP 970) and civil requirements.

Dealing with the composite primary struture, the Structure Group, in charge of the demonstration of compliance with the Civil Airworthiness Regulations, was first concerned to be sure that the current set of requirements would have been sufficient to cope with the specific issues applicable to composite materials, due to their unconventional structural behaviour.

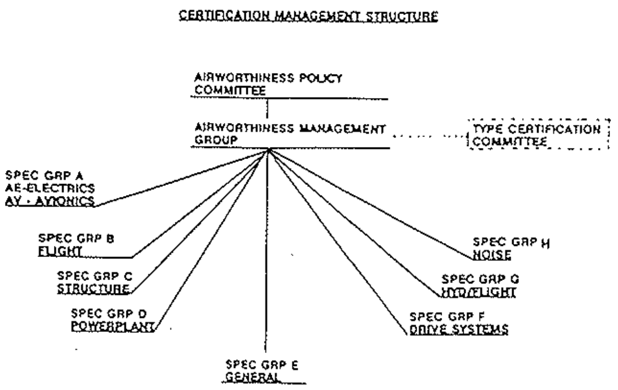


*Fig.5: EH-101 Certification Management Structure*

Since a damage tolerance requirement was still at the rulemaking stage at the date of application for the EH-101 civil certification, it was not considered appropriate by the Airworthiness Authorities to impose a complete damage tolerance substantiation on all critical structures of the EH-101; however, mainly during the maturity phase of the program, to satisfy also the military requirements, a demonstration of the reached degree of damage tolerance on selected components will be carried out by analysis and tests.

## 4. SUBSTANTIATION APPROACH

### 4.1. The regulatory requirements and the AC 20-107A issues

For the composite structures the use of AC 20-107A (Ref. 3) was judged to provide an acceptable and achievable damage tolerance level; so, for the composite substantiation, the guidelines of that Advisory Circular were addressed at appropriate application level.

In particular the following items were identified:

- Effects of composite variability on structural strength;
- Effects of acceptable manufacturing discrepancies on structural strength;
- Effects of Barely Visible Impact Damage (BVID) up to a cut-off energy of 50 J, on static and fatigue strength;
- Strength substantiation of Clearly Visible Impact Damage (CVID);
- Effects of environment on long term structural performances;
- Effects of repeated loading and environmental exposure on stiffness properties to be taken into account for flutter phenomena;
- Effects of lightning strike on structural performances.

### 4.2. The pyramid of tests

To address the previously indicated issues, a *building block* approach (Ref. 4, 5) was considered the best way and a pyramid of tests was established and agreed having identified the main areas to focus on relevant regulatory requirements and guidelines. The pyramid of tests was divided in the following four main phases:

<u>Coupon level testing for:</u>

- Producing consistent data base and material allowables for the most adverse environmental conditions; A & B basis allowables were determined according to MIL-HDBK-17B (Ref. 6) procedures;
- Determining the moisture absorption characteristics of the selected materials.

<u>Element level testing for:</u>

- Strength methodology verification of different structural elements;
- Composite material variability definition;
- Generation of additional data about environmental effects;

- Evaluation and quantification of the effects of impact damages and manufacturing discrepancies on static and fatigue strength.

Point design testing for:

- Checking the strength of structural details;
- Generating empirical structural design allowables.

Subcomponent/Component (full scale) testing for:

- Verification of load path and analytical methodologies;
- Establishing load truncation level to be applied during spectrum fatigue tests;
- Verifying static and fatigue strength and stiffness;
- Determining the BVID energy levels, to produce them in the most critical areas of the components to be tested;
- Interrogating the structure response in both Room Temprature Dry (RTD) and Elevated Temperature Wet (ETW) conditions, to cope with possible unpredictable competing failure modes typically observed at full scale level;
- Substantiating the acceptability of maximum allowed manufacturing discrepancies in critical areas;
- Strength substantiation of CVID.

## 5. MANUFACTURING DISCREPANCIES

The effect of damages that could be induced during the production phase, was accounted for in the subcomponent and component tests by introducing a set of manufacturing discrepancies in the test articles. These discrepancies were selected based on the manufacturing technique used and the experience gained in production of development Tail Units and other composite parts gathered by Agusta.

The following discrepancies, in dimensions representative of the maximum levels that could be accepted in production, were deliberately introduced into the test articles:

- Disbonding of sandwich panel sheets from core;
- Delamination of sandwich panel sheets;
- Debonding/delamination of laminates;
- Disbonding of sheets from foam core;
- Honeycomb core crushing;
- Waviness;
- Rivet area damage;
- High/Low resin content;
- Bridge.

These defects were simulated in the test articles by teflon diskettes, ring and or strips deliberately introduced during their manufacturing or were the result of dedicated techniques.

## 6. IMPACT DAMAGE

To properly take into account the effect of impact damage on static and fatigue strength, it was first necessary to identify the probable hazards to which the Tail Unit was expected to be exposed to during its production route and operational life and to quantify the frequency and severity of these hazards ; to this purpose an impact hazard analysis was carried out.

In this analysis six different types of hazards were evaluated:

- Dropped tool;
- Dropped part;
- Foot traffic;
- Ground equipment;
- Runway debris;
- Hail.

Then damage susceptibility tests were carried out on spare Tail Unit components; these tests showed that BVID levels typical of the different areas were higher than or very close to the maximum levels that could be expected during the life of the helicopter, as determined by the hazard analysis, up to a maximum energy of 50 Joules, as agreed with the Authorities. Therefore it was no necessary to take into account the effect of in-service low energy damages greater than BVID, caused by impacts up to the cut-off energy of 50 Joules.

## 7. LIGHTNING STRIKE

Regarding the effects of lightning strike, the Tail Unit primary structure, except for the lower panel which was considered as a 2A Zone, was considered to be in Zone 3 (zoning according to ref. 7) and so it was not expected to receive a direct lightning attachment, but it was only required to conduct the full threat lightning current.

The large amount of carbon fibre present in the component and the protection measures adopted for the underside (metallic mesh and dedicated bonding straps from the stabilizer attachments to the rear fuselage attachments) were considered an adequate protection (fig. 6).

Lightning tests carried out satisfactory on the Tail unit section supporting the Tail Rotor Gearbox confirmed this assumption.

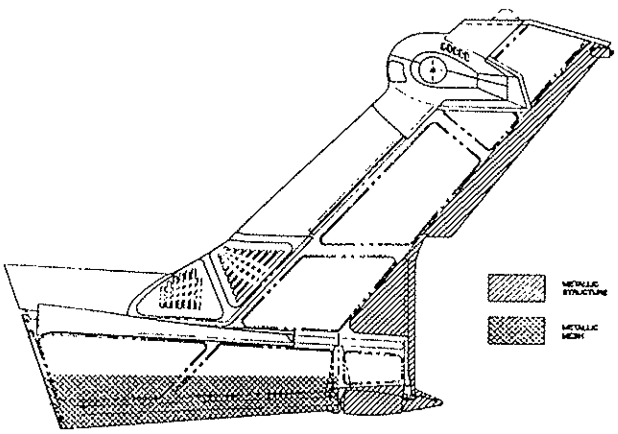

*Fig.6: Lightning Protection Features*

Dedicated bonding strap was also used to protect the anticollision light, located on the top of the Fin.

## 8. ENVIRONMENTAL CONSIDERATION

Long term exposure of composite to high humidity ambient results in moisture absorption into the component; the presence of moisture, combined with high temperature, has an effect in lowering the glass transition temperature of the matrix and therefore degrades the matrix dominated and the interface dependent properties and reduces the allowable operating temperature of the composite component.

The way in which moisture is absorbed depends upon many factors, the most significant being the climatic exposure of the helicopter, that is the severity of its exposure to humidity and temperature; this in turn is related to the intended operational location of the helicopter.

In the EH 101 design, the approach of using a constant Relative Humidity that will produce a representative moisture condition, to assess the effect of various climates on the total and on the distribution of moisture within a laminate was followed and it was agreed that the worst world wet environment could be simulated by a constant relative humidity of 84% +2%, -0%, the mean annual temperature being 26°C (ref. 8, 9).

The moisture absorption parameters (i.e. the diffusion coefficient D and the equilibrium level $M_\infty$) of typical materials and stratifications used on the Tail Unit, were determined at different temperature levels by measurements on coupons and were used to estimate the time needed for complete saturation of the test item and to compare the moisture distribution obtained from accelerated conditioning of the test article with that resulting from the natural moisture absorption at the end of life.

To take into account the environmental effects on static strength, different approaches could be followed (Ref. 2, 10). Basically, the most direct one is to derive knockdown factors (ratio between ETW and RTD properties) from tests on elements or subcomponents and to implement these factors in the form of load amplification factor in the full scale test carried out in RTD environment; the second one is to conduct a test on a fully environmental conditioned item.

The first approach is less expensive and time consuming than the second one, but could result in unnecessary overdesign of any metal component or of some specific parts, because the knockdown factor could be not the same for all lay up; on the other hand it could neglect specific ETW failure modes. The second approach instead is of course more complicated and costly, but it's probably the only way to cope with possible unpredictable competing failure modes that could happen at full scale level.

So the approach of conducting a static test in Elevated Temperature Wet condition on a full scale Tail Unit was chosen as the best technical one.

The maximum operating temperature of the component was evaluated by taking into account the effects of external air temperature, solar radiation and reflection from stabilizer and ground; moreover the dynamic effects of engine exhausts and rotor/helicopter velocity were considered. As a result, the testing temperature of 70° C was selected and a restriction on the use of high absorptivity - low emissivity paint colours was imposed.

## 9. STATIC SUBSTANTIATION

### 9.1. Composite material variability

To address the inherent variability of the utilized composite material, due to the "batch-to-batch" variability of its constituents and to the manufacturing process used, a testing activity at element level was carried out.

A total of about fifty compression and shear tests were carried out in RTD environmental conditions, on laminate and sandwich elements manufactured with the same materials, but coming from several different production batches, and fabrication process used for the Tail Unit. Fig. 7 shows the different specimens used in the tests.

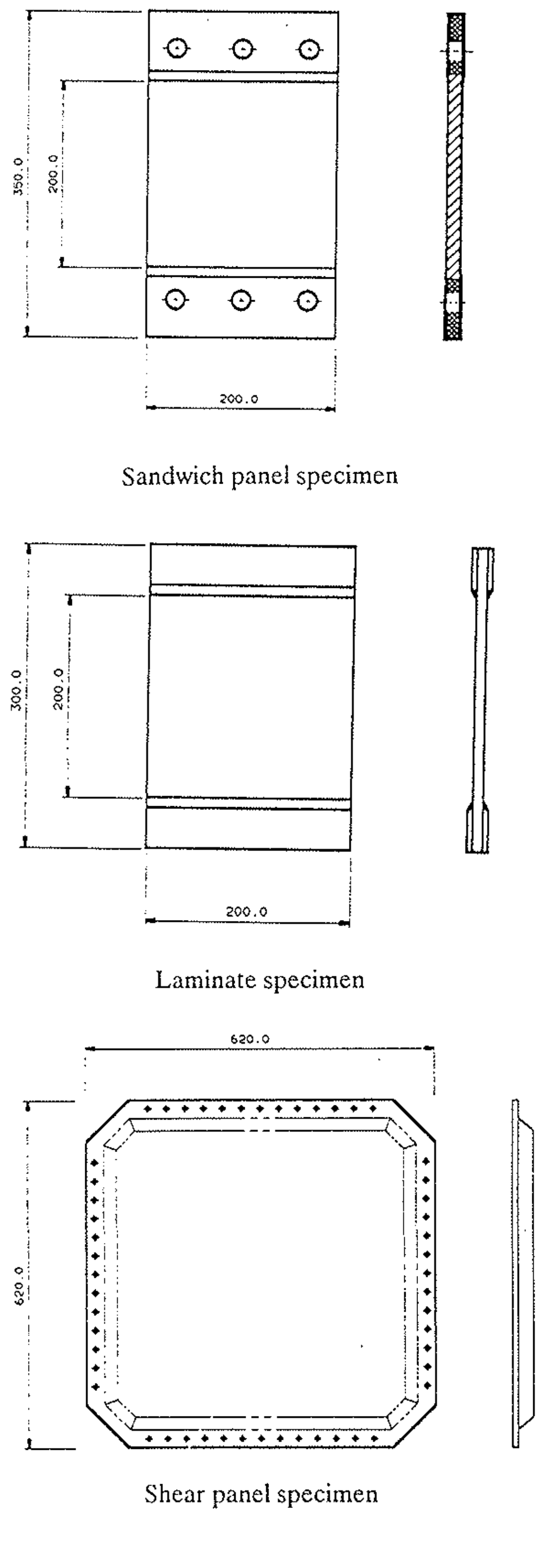


*Fig.7: Specimens for material variability determination*

The coefficient of variation for each type of involved failure mode were then established, according to ANOVA method (Ref. 6) and are summarized in table 1.

Based on these results, a test load amplification factor of 1.15, reflecting the worst coefficient of variation, was used in the subcomponent and full scale static tests.

| Element | Test type | C.V. (%) |
|---|---|---|
| Laminate | Compression | 10.5 |
| Sandwich | Shear | 3.2 |
| Sandwich | Compression | 10.5 |

*Tab.1: Composite material variability (C.V.)*

### 9.2. Full scale static test

9.2.1. Test objectives

Due to the size and the criticality of the component and the number and type of expected answers in respect to the regulatory requirements, the ETW full scale static test of the Tail Unit was considered as one of the key events of the certification/qualification program.

Primary scope of the test was in fact to show the ultimate strength capability of the structure and this was done by a test at ultimate load level, carried out at high temperature (70°C) on an aged component, impacted in 12 different locations, with BVID levels ranging from 10 to 50 Joules, and including 29 discrepancies deliberately introduced in different locations.

9.2.2. Environmental conditioning

To reach the required moisture content in an accelerated time, the test article was placed for about 7 months in a temperature and moisture controlled climatic chamber; 84% Relative Humidity and 70°C temperature conditions were maintained in the chamber during this time period.

The moisture gain of the component was monitored by measuring the weight gain of three different witness specimens (100 mm x 100 mm), fully representative of the moisture absorption characteristics of the critical areas of the parent structure.

The witness specimens were small enough to be easily weighed and were sealed on the edges against moisture ingress; they always accompanied the test article, even when it was moved from the climatic chamber to the test rig and so they experienced an identical environmental exposure history.

To maintain the conditioned state and to obtain the required high temperature during testing, the test article was completely enclosed into a special box fabricated from thermal insulating material (Polypan).

The required environmental conditions inside the box were achieved by circulating heated (80°C) and moisturized (84% R.H.) air in the box by means of one external climatic chamber and were monitored using three thermocouples located on the Tail Unit surface and one hygrometer.

The insulating box (5m x 4m x 2m dimensions), was of self supporting type, to allow the deflection of the test article during load without interference with the structu-

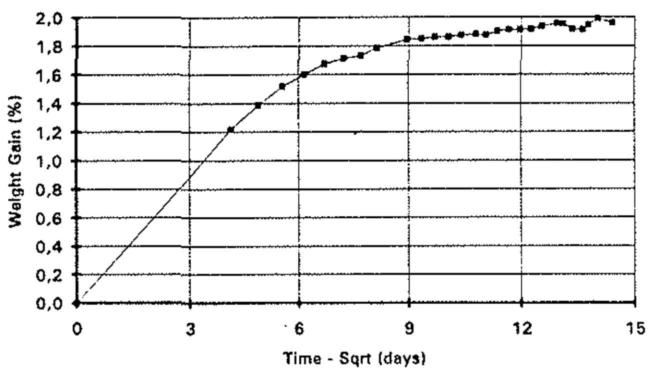


*Fig.8: Sandwich panels moisture absorption curve*

re; small openings were provided in it to permit the exit of the instrumentation cables and wires.

Analysis of the witness specimen data showed that all graphite thicknesses less than 5.1 mm were completely saturated (in fig. 8 is shown the moiture absorption curve of a witness specimen representative of the sandwich panels); only the highest laminate thicknesses of about 9 mm, typical of only few specific locations of the Tail Unit, didn't reach the equilibrium level.

To determine the real moisture distribution in this high thickness, the specimen was analyzed at RAE-Farnborough using the *slicing method* (Ref. 11); the through-the-thickness moisture distribution so obtained was correlated with the simulated natural ageing distribution, with the methodology contained in Ref. 12 and a natural ageing of about 7 years was determined to be equivalent to the artificially obtained moisture content in this particular section.

9.2.3. Load selection

As previously said, the Tail Unit was designed to cover both the critical in-fligth and landing conditions contained in civil and military regulations.

All the conditions coming from these regulations were analyzed to select the critical ones; a preliminary evaluation of all the maneuver's set was carried out and the following group of maneuver families was selected as the critical for the Tail Unit:

- Yaw maneuver in forward flight;
- Yaw maneuver in hovering;
- Rolling pullout;
- Two wheel landing.

A critical selection of these maneuver families was then carried out by comparing the maximum internal forces in different sections of the Tail Unit, so allowing the reduction of the cases to be analyzed and the selection of eight single specific maneuver conditions.

Finally a detailed stress analysis was executed using NASTRAN code (Fig. 9); particular emphasis was put on this activity in order to be able to derive only one loading condition to be tested, to reduce the test number and complexity and to minimize the associated costs. This analysis identified the minimum strength margins and the corresponding loading condition for each area of the Tail Unit and it was of paramount importance for substantiating the proposed testing condition as the most critical one.

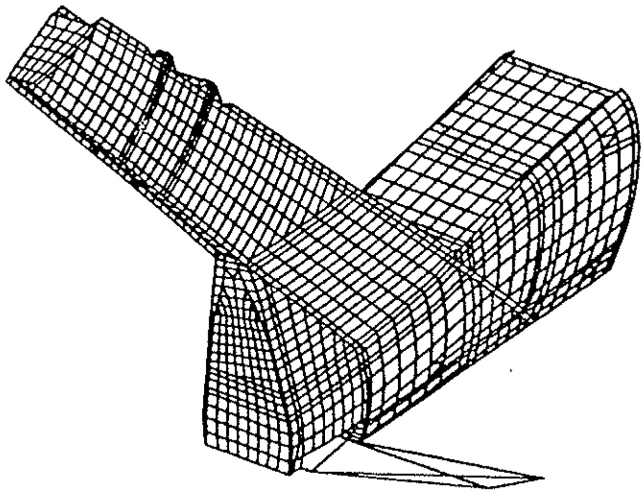

*Fig.9: Tail Unit NASTRAN model*

As a result of this activity, a *hybrid load condition* was selected as the one to be tested; table 2 shows the loads applied and the related maneuver.

| **Flight condition** | **Applied load** |
|---|---|
| Yaw maneuver at $V_{NE}$ | Max Tail Rotor Thrust |
| Yaw maneuver in hovering | Max Tail Rotor Torque |
| Rolling Pull-Out at $V_D$ | Max Stabilizer lift |
| Rolling Pull-Out at $V_D$ | Max 43° Gearbox loads |

*Tab.2: "Hybrid" test loading condition*

9.2.4. Test description

The validation of the static strength was accomplished through a limit and ultimate test to the critical loading condition identified above.

To that purpose, a special loading rig (fig. 10) was set up at Agusta Structural Test Laboratory.

The test article was fastened to a flat plate at the interface to the Rear Fuselage and cantilevered off one end of the rig. Loads were applied to the specimen in the following three locations:

- Tail Rotor Mast
- Intermediate gearbox
- Stabilizer

utilizing eleven hydraulic jacks. Stabilizer loads were applied through a properly designed frame; in order to facilitate the test execution, the fin lift was applied at the Tail Rotor Mast location. Load values, application points and directions were established as required to develop the proper shear, moments and torsion.

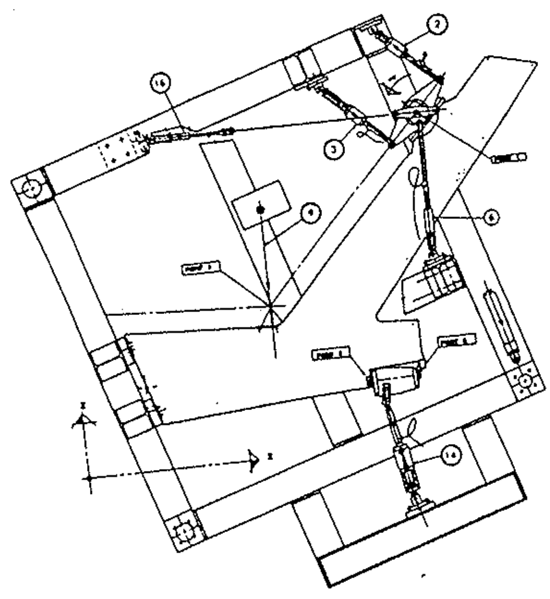

*Fig. 10: Test Rig Arrangement*

The test article was instrumented with 17 LVDT to monitor the structure deflection, with 14 strain gauges and 20 rosettas to measure the local deformation.

Special procedures, developed by Agusta, were followed for the specimen instrumentation in order to avoid any possible damage due to adverse environment both during conditioning in the climatic chamber and during testing.

9.2.5. Test results

With a surface temperature of 70 °C, the Tail Unit was initially loaded incrementally with 20% of limit load steps, up to 115% of design load; the load was then removed. Examination of data after the test showed no permanent or detrimental deformation .

So the specimen, at a temperature of 70.1°C, was loaded up to ultimate load which was sustained for more than 3 sec.; then loading continued up to failure that occurred at 220% of test load, therefore leaving a margin for a potential growth in helicopter performances.

The structure showed linear behaviour (fig. 11) up to failure. The failure mode was of compression type and originated on the right side of the Tail, at the interface between the skin and the bottom cone longeron and propagated diagonally upward and downward achieving an impact damage induced on the bottom panel and progressing up to a drain hole on it.

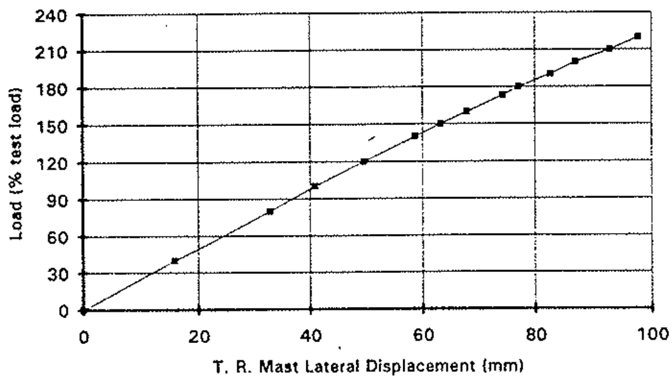


*Fig. 11: Full scale static test load-displacement curve*

This type of failure was similar to that experimented in a development test carried out in RTD conditions; so it appears that the adverse environmental conditions didn't change the type of failure mode.

The effect of adverse environment on the stiffness was evaluated by comparing the global displacements of the Tail Unit obtained during the ETW static test with those obtained from a RTD static test up to limit load that was carried out on the full scale specimen used for fatigue testing. The data showed a reduction of global stiffness, measured at the Tail Rotor Mast station, of 9.8%.

This is the result of combined effect of humidity and high temperature; tests carried out on elements showed instead that the stiffness degradation due only to moisture absorption is of 3%.

## 10. FATIGUE SUBSTANTIATION

### 10.1. Fatigue scatter factor

To carefully investigate the fatigue variability of composite materials for the most significant failure modes, in order to derive appropriate scatter factors to establish safe life limits, an extensive program of constant amplitude fatigue tests on elements was carried out.

The variability was investigated on 3 configuration of impacted sandwich elements (fig. 7) and 2 configurations of bonded/rivetted joints (fig. 12) and S-N curve shapes were obtained based on the four parameter Weibull relationship.

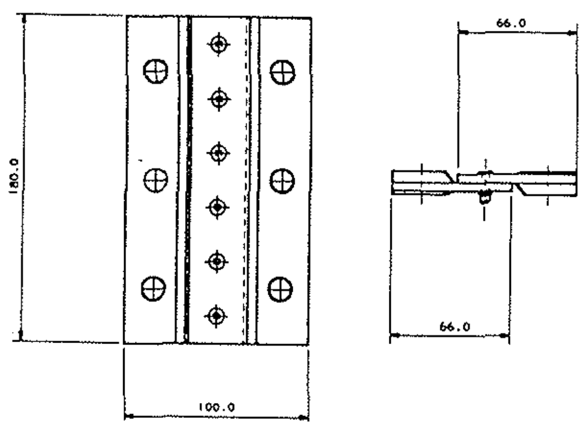


*Fig. 12: Joint Specimen*

For each specimen type, 20 tests were carried out in RTD condition to derive the S-N curve shape and 10 tests in RTWet condition to confirm the curve shape and to derive the knockdown factor due to humidity only. Typical results are shown in fig. 13 for sandwich panel specimens and in fig. 14 for a bonded/rivetted joint. Fig. 15 and 16 show instead the effects of moisture absorption on fatigue behaviour of sandwich panels and joints in the worst case.

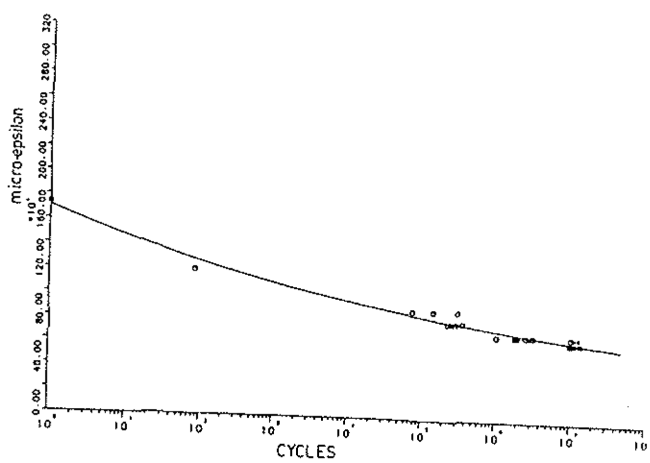


*Fig. 13: Typical S-N curve for sandwich panels (RTD)*

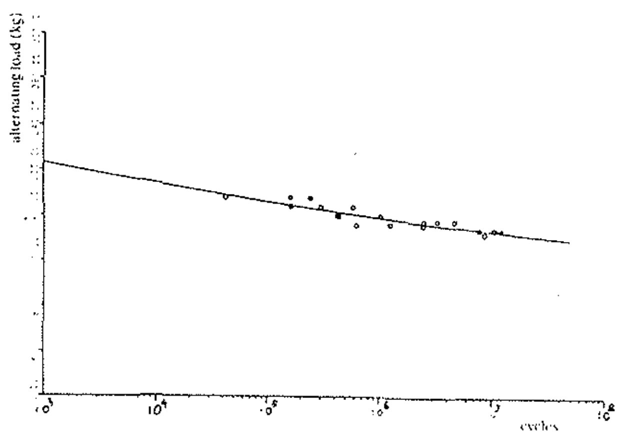


*Fig. 14: Typical S-N curve of joint (RTD)*

Coefficients of variation were calculated for each type of tested specimen and are summarized in tables 3 and 4; in the same tables the load amplification factor for humidity effects, the worst one derived from tests on moisture saturated elements and joints, are indicated.

| Element type | Fatigue load | C.V. (%) |
|---|---|---|
| Sandwich type 1 | Comp. - Comp. | 12.0 |
| Sandwich type 2 | Comp. - Comp. | 4.7 |
| Sandwich type 3 | Comp. - Comp. | 10.7 |
| Worst C.V. : | | 12 % |
| RTW factor: | | 1.12 |

*Tab.3: Sandwich Element Fatigue Tests - Summary Table*

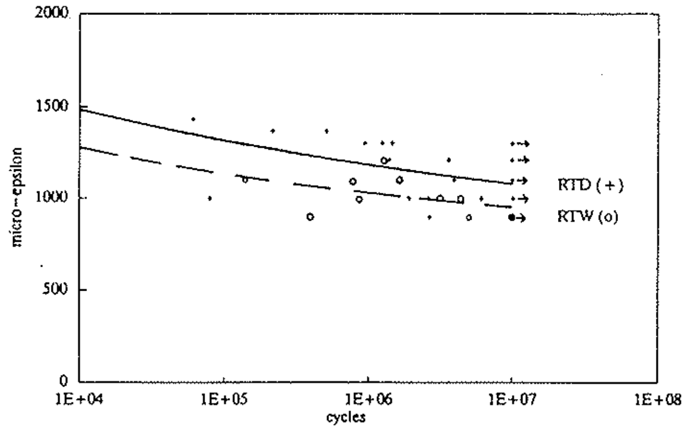


*Fig.15: Humidity effect on sandwich panel S-N curve*

| Element type | Fatigue load | C.V. (%) |
|---|---|---|
| High thick. Joint | Shear | 3.0 |
| Low thick. Joint | Shear | 3.5 |
| Worst C.V. : | | 3.5 % |
| RTW factor: | | 1.2 |

*Tab.4: Joints Fatigue Tests - Summary Table*

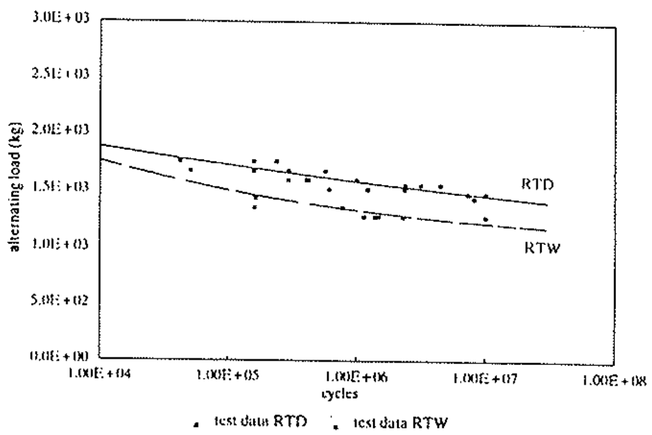


*Fig.16: Humidity effect on joint*

**10.2. Static strength after fatigue**

To demonstrate the ultimate load capability of the structure after cycling, the way indicated in AC 20-107A para 6.b was followed and tests on two subcomponents were carried out.

The two test articles contained manufacturing discrepancies and impact damages and were conditioned up to saturation with the modalities already described for the full scale Tail Unit.

The testing sequence on these subcomponents was the following:

- static test in ETW condition up to 80% of limit load;
- spectrum fatigue test in RTW condition to the full life (40,000 flight hours);

- static test in ETW condition up to ultimate load and then to failure.

The specimens were enclosed in thermal insulating boxes and the same technique used for the full scale test of the Tail Unit was utilized to maintain the humidity level (84% R.H.) during cycling and the humidity and high temperature (70°C) during ETW static tests.

During the test periodical measurements of the stiffness were carried out (fig. 17) and also the extension of impact and manufacturing damages included in the specimens was monitored. The results showed that the combination of adverse environmental condition and fatigue cycling had no effect on static strength and stiffness and that there was no significant propagation of the damages/discrepancies artificially introduced.

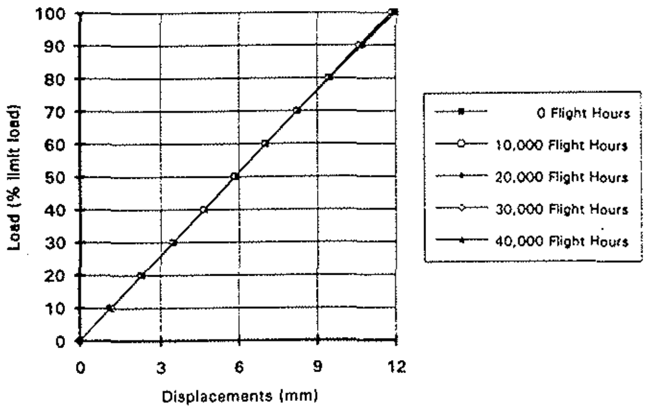


*Fig.17: Fwd Spar Subcomponent stiffness variation*

**10.3. Full scale spectrum fatigue test**

The effects of fatigue on stiffness finally was evaluated by means of a test on a full scale Tail Unit.

The test was carried out in RTD environmental condition on a test article identical to the one tested statically: the same number and type of manufacturing discrepancies and impact damages in the same locations were included; moreover it was costrained to the same rig and loaded in the same manner of the static one. Also the instrumentation was similar to that used during static testing.

In the test a fatigue spectrum representative of the flight loads was applied to the Tail Unit and the following combination of factors, based on the results obtained from element tests, was used :

- humidity factor = 1.12
- strength factor = 1.62
- life factor = 2

To reduce testing time, high frequency vibratory loads were not included in the spectrum; their non-damaging effect was demonstrated by tests on subcomponents.

To that purpose three subcomponents containing manufacturing discrepancies and impact damages, one of which is shown in fig. 18, were tested in RTD environmental condition with costant amplitude fatigue loads. Fatigue failures obtained in these tests were used to establish the endurance levels and to show that these endurance levels were higher than the vibratory loads.

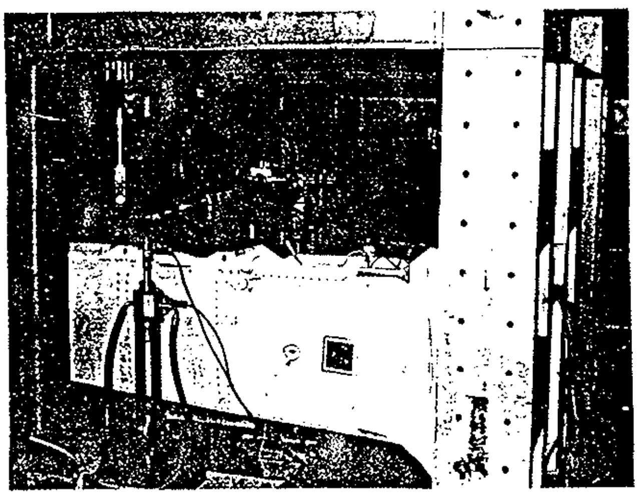

*Fig.18: Vertical fin subcomponent*

For certification, due to time limitations, an interim life has been demonstrated on the Tail Unit ; no failure has been experienced on the composite structure. The spectrum test is now continuing to demonstrate that at the end of life of the component there will be no reduction of the stiffness below a level compatible with flutter requirements, as a result of the combined effect of impact damages, discrepancies, humidity and cyclic loading.

## 11. DAMAGE TOLERANCE

As previously said, a complete Damage Tolerance substantiation of the helicopter was not requested. However, to cope also with some military requirements, it was agreed, in the certification activity, that a program of testing and analysis will be performed on selected components to investigate the extent of Damage Tolerance characteristics which have been imparted by the design. This activity should be completed in two years after Type Certification.

As far as the Tail unit is concerned, the activities have been already started and the following damages have been considered:

- Clearly Visible Impact Damage;
- Loss of fasteners;
- Skin cracks;
- Skin/core crushing;
- Manufacturing defects greater than allowed in production;
- Cracks in metal parts;
- Fatigue damages due to overloads.

Static and fatigue tests have already been performed on two subcomponents, after completion of the safe life tests, with positive results; no flaw growth have been recorded on the composite parts and the components sustained the limit load. In fig. 19 a typical CVID is shown.

The activity will continue during the *maturity program* which is also expected to give additional informations on the durability characteristics of the Tail Unit.

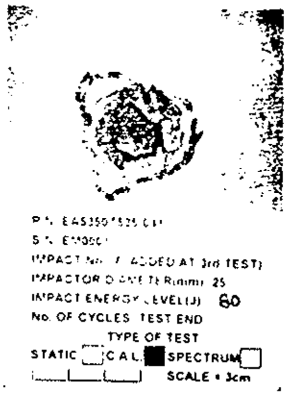


*Fig. 19: Clearly Visible Impact Damage*

## 12. CONCLUSIONS

**1.** The successfull application of composite materials to primary helicopter structures is today a reality. The substantiation of these structures is a high cost activity, justified by the need of maintaining the same safety level of the conventional metal structures, associated with the specific issues of composites to be addressed.

**2.** The criteria established in FAA Advisory Circular 20-107A, have been considered an affordable basis for the certification of the EH-101 composite Tail Unit and the building block approach the best way to satisfy its requirements.

**3.** In this context, the full scale static test carried out in adverse environmental conditions, gave a positive answer to the key issues of impact damage, manufacturing discrepancies, moisture absorption and composite variability effects on static strength. Moreover it showed that moisture and high temperature didn't change the failure mode of the structure.

4. The fatigue tests on elements allowed the derivation of scatter factors and RTW load amplification factor; moreover tests on subcomponents and full scale item carried out to date, showed no detrimental reduction of stiffness and static strength after cycling.

5. The EH-101 *maturity program* is proivding additional data on fatigue, flaw tolerance and durability characteristics of the Tail Unit.

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