TWENTY FIRST EUROPEAN ROTORCRAFT FORUM

Paper No XII-7

THE TEST AND VERIFICATION APPROACH FOR THE NH90 COMPOSITE STRUCTURE

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August 30 - September 1, 1995
SAINT-PETERSBURG, RUSSIA

ECD-0044-95-PUB

Paper nr.: XII.7

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1. Abstract

For the NH90 (NATO Helicopter of the 90's), a quatro-lateral military development program, the composite technology has been selected for the fuselage to fulfill the demanding requirements of a modern weapon system. Within the workshare between France, Italy, the Netherlands and Germany the latter has the leadfunction for the structure, being responsible for the centre and rear modules. France and the Netherlands are responsible for cockpit, engine cowlings (ECF), tail module, landing gear sponsons and sliding doors (FOKKER).

Based on experience and on development results from research programs and current helicopter programs, such as the BK117 Composite Fuselage Program, the EC135, the TIGER and several other programs, the verification of the NH90 fuselage structure is following the principle of an analytical substantiation in combination with a proof concept, resulting in structural tests on different levels.
This concept had to be thoroughly assessed under time, risk and cost criteria and had to be harmonised with all related NH90 partner companies.

After tests for material and process validation, tests related to verification/qualification on components, assemblies for load introductions and - as the final structural test - a full scale static test with the complete primary structure will be performed. In addition, tests focusing on other functional aspects as crashworthiness accompany that sequence.

The qualification of the NH90 is governed by the requirements from the 'Weapon System Development Specifications of the NH90', resulting in the application of especially the FAR Part29 incl. amdt.31 and AR56 for the definition of the test loading conditions.

The substantiation work, including tests, is presently progressing towards the first flight date of the first prototype at the end of 1995. Several tests out of the verification program have been already carried out, while others are in preparation or planned.

2. Introduction

For the NH 90, the new European 9-ton-class helicopter, the four nations Italy, the Netherlands, France and Germany on customer and on industry side share the development with the following ratio:

AGUSTA with 26,9 %
FOKKER with 6,7 %
EUROCOPTER FRANCE with 42,4 % and
EUROCOPTER DEUTSCHLAND with 24,0 %.

The customers are represented by the NATO Helicopter Management Agency (NAHEMA), while industry's management organisation is NATO

Helicopter Industry (NHI) - both based in Aix-en-Provence (France). Prototypes are now in the assembly phase and first flight is planned to take place in Marignane (France) at the end of 1995.

The helicopter will be produced in two military versions:
- the naval NFH (NATO Frigate Helicopter) and
- the TTH (Tactical Transport Helicopter)
for four Navies, three Armies (Italy, France, Germany) and one Air Force (Germany).

Figure 2.1: Artists impression NH90 TTH-version

This two engine powered multi role helicopter will have the option of being fitted either with the RTM 322 or the T700 engine.
Significant features of the TTH will be the rear ramp, which is chosen by all Armies, and the manual tail folding, whereas the NFH shows the typical ship interfaces e.g. automatic folding of tail pylon and main rotor blades and the provisions for landing and traversing on a ship deck. Despite these obviously different attributes, communality between the two helicopter versions is one of the important design targets from the beginning.

3. EC-experience gained on serial-, technology- and development programs

Within EC the first application of composite material for a H/C primary structure were the rotor blades of the Bo105 (first flight 1967). This material was selected for the design of the highly dynamically loaded blades due to its superior fatigue characteristics.
On the fuselage side first secondary parts like cowlings, doors etc. were made out of composites mainly due to weight reasons.
Later on first parts of the primary fuselage structure were developed in composite material in order to take advantage of the superior characteristics of this material.
Such parts were for example

- the horizontal stabiliser of the BK117- and
- the tail unit and horizontal stabiliser of the DAUPHIN-serial helicopters.

The first application of composite material to an essential part of a fuselage primary structure was realised within the BK117 composite fuselage technology program. This program was performed to demonstrate the applicability of composite materials for primary fuselage structures.
The strength substantiation of this helicopter was done by analysis based on test evidence. Testing was performed at coupon level at RT and under hot/wet-conditions, at component level at RT and hot condition and a complete fuselage structure was tested at RT. Mainly static tests were performed.
One demonstrator helicopter was built and is still in service.
However within this program also preliminary investigations and tests concerning an energy absorbing composite subfloor structure were performed.

Composite material was selected for the intermediate rear structure of the SUPER PUMA Mk.II and the complete TIGER fuselage too.
The SUPER PUMA Mk.II intermediate rear fuselage was substantiated based on analysis supported by test

evidence. Static as well as fatigue testing was performed from coupon up to full-scale level taking into account extreme environmental conditions.

The TIGER will be the first serial helicopter with a primary structure mainly made out of composite material. The strength substantiation will be also done by analysis supported by test evidence with a variety of tests at levels ranging from coupon level up to complete fuselage tests.

The coupon tests are performed at RT and hot/wet, static component tests at RT and under hot condition (taking into account the effect of moisture by applying overtemperature or an overload based on coupon test results). The static and fatigue testing with the complete fuselage will be performed with a hot/wet-conditioned structure.

The TIGER will become also a crashworthy helicopter. Therefore the fuselage structure has to fulfill the related requirements concerning strength and energy absorption. The development of crashworthiness is done in a similar way as for static and fatigue strength, it is based on analysis supported by tests on different levels ranging from subfloor element tests up to a full scale drop test.

The intention of the French 'Large Helicopter Fuselage Main Section - Research Program' was to consider and to validate technological solutions for a helicopter in the class of the NH90. Reference for cost, weight, military missions and airworthiness respectively crashworthiness was the SUPER PUMA. This development was one step to the configuration of the NH 90 composite centre fuselage.

It was similar e.g. for:

- principle geometry (overall dimensions, doors)
- three central frames to react to the heavy upper deck masses and the loads from the landing gear
- subfloor fuel tanks.

In the scope of this program tests were carried out related to:

- material properties with coupon tests
- tests for the effects of lightning protection and ballistic impact
- structural static and drop tests with elements of the subfloor structure and complete frames
- a drop test with a complete centre fuselage structure.

Due to the above presented experience with composite structures this material was selected for the NH90 and the substantiation approach is based on the knowledge gathered in the previous programs.

4. NH90-fuselage design description

To satisfy the demanding requirements, especially for low weight and protection against corrosion, it was decided to use composite material for the primary and secondary structure. Following the industrial workshare agreement, EUROCOPTER is responsible for most of the structure, which is made of carbon- and aramid- fibre reinforced composites (CFC and AFC) to a very high degree.

The overall dimensions of the fuselage are around 16.m in length, 3.8 m in height and 4.4 m in width. Its characteristic diamond-shape cross section was selected for detectability reasons.

One of the important targets of the structural concept was, to achieve a modular architecture.

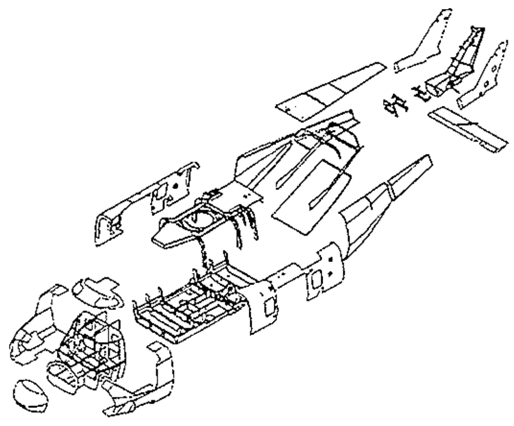

Figure 4.1 : Exploded view

The functional intersection at the folding area links the FOKKER tail module to the EUROCOPTER parts with a hinged connection. The forward- (ECF), rear- (ECD) and centre-fuselage modules (ECD) are joined together by means of riveted and bolted connections.

The primary structure is mainly made of carbon fibre composite (CFC) in monolithic and NOMEX-sandwich design. Aramid is only used in hybrid application for crashworthiness reasons in the subfloor section.
The selected resin system is a 180° C curing system.
Metal elements are used especially in load introduction areas and in areas with requirements for fire protection.

Where possible, the shape of the frames and flanges was chosen as simple as feasible and interface provisions were integrated into panels.
The joining principles are: hot bonding, cold bonding and riveting on the parts level. On the module assembly level the connections are performed mainly by riveting.

Forward Fuselage Module

The main functions of the forward fuselage are introduction of loads from nose landing gear and floatation, to fulfill specific requirements such as bird impact and wire strike, to contribute to crashworthiness and to allow adequate installation of all cockpit equipment.
The structure is constituted as follows:

- two main beams in form of an 'L' with brackets for NLG attachment
- frames
- cockpit floors
- shell segments in CFC NOMEX-sandwich design
- the canopy.

The 'L' beams support the forward fuselage and form the sidewalls for the nose landing gear compartment and for the avionic bays. In their lower part they have to be crushable for energy absorption in case of crash. The beams of the canopy use closed cross sections for weight reasons and allow good external view. The shells are characterised by their requirements for EMI and lightning protection and by sometimes big openings for access holes and the emergency floatation system.

Centre Fuselage Module

The most important functions of the centre fuselage are to carry the loads introduced from the dynamic system (e.g. main gear box, engines, tail rotor drive system), the forward and rear structure, the main landing gear, to support the fuel tanks and to provide energy absorption in the subfloor area. This module includes the passenger and cargo compartment.
The centre fuselage has a modular design. The sub-modules are:

- upper deck
- side shells
- subfloor group
- floor panels

The upper deck consists of the main and auxiliary frames, the longerons and sandwich panels made out of composite material. Metal parts are used for load introductions and for fire protection in the engine compartment. The main gear box is attached via the anti-vibration and isolation system with metal fittings. For the load introduction of the main landing gear and the shock absorber metal brackets are used .
The subfloor group is built with frames, longerons and a sandwich bottom shell. This module is mainly designed to achieve the required crashworthiness characteristics. Therefore the frames and longerons are designed to be energy absorbing. The design of this area has to meet the crashworthiness requirements as well as to fulfill the basic functions of the structure (strength, stiffness, stability and interfaces-provisions) commonly.

Rear Fuselage Module

The shape of the rear fuselage is dominated by the geometrical constraints for tail folding and by the structural and space provisions for the rear ramp integration.

This results in the following breakdown:

- complete and partial frames
- lower longerons
- folding beams
- side-, bottom- and upper shell panels.

Frames and longerons are mainly CFC monolithic design, whereas all the shells are built as CFC sandwich. The connection to the tail fuselage is performed by two metallic hinge beams.

5. NH90 fuselage structure requirements

The different versions of the NH90 helicopter shall be able to fulfill a variety of missions in various environments.

To fulfill this tasks and to provide an adequate level of safety for the crew and occupants this H/C will be designed according to basic airworthiness requirements as well as to meet program-specific requirements.

According to the development specifications, the structure of the TTH- and NFH-versions of the NH90 helicopter has to be developed to fulfill basic airworthiness requirements based on the civil FAR 29 as well as on the military MIL-S-8698 and AR-56.

Among the specific NH90-requirements crashworthiness is the most important one for the design of the fuselage primary structure. With respect to crashworthiness the NH90 has to fulfill requirements which are based on the MIL-STD-1290A.
Within the H/C-system the fuselage primary structure is one of the main subsystems.
It shall be designed for a lifetime of 10 000 flying hours over 30 years.
For the complete required mission spectrum the NH90 composite structure shall have sufficient strength and rigidity throughout its service life.
The dimensioning requirements for the fuselage are basically the static and fatigue strength including damage tolerance and crashworthiness.
Therefore the structure is designed for a variety of static load cases (e.g. according to FAR 29, AR-56, MIL-S-8698, NH90-specific requirements) covering all the different configurations and the complete weight- and c.g.-range.
With respect to fatigue strength the structure has to be designed to provide a sufficient fatigue life taking into account the mission spectrum as well as the related maintenance requirements.
The typical characteristics of composite material, as applied for the NH90 fuselage, will be taken into account based on the AC20-107A.

In particular these are the following aspects:

- effects of environmental conditions on material characteristics
- effects of variability of material characteristics
- effects of acceptable manufacturing defects
- effects of in-service defects.

Furthermore the NH90 has to be designed to a specified crash envelope. This crash envelope was defined to get a balanced and optimised H/C-system where crashworthiness is only one of several parameters to be taken into account.

The main crash requirements with respect to the H/C-system are

- horizontal velocity v_x = 0 to 15 m/s
- vertical velocity v_z = 0 to 11 m/s

From these system-requirements the energy share to be absorbed by the fuselage is derived.

6. NH90 substantiation philosophy

The substantiation of the composite fuselage structure will be based on analysis supported by test evidence.

6.1 Strength substantiation

The general procedure for the substantiation of the static and fatigue strength of the NH90 structure is shown below in figure 6.1.

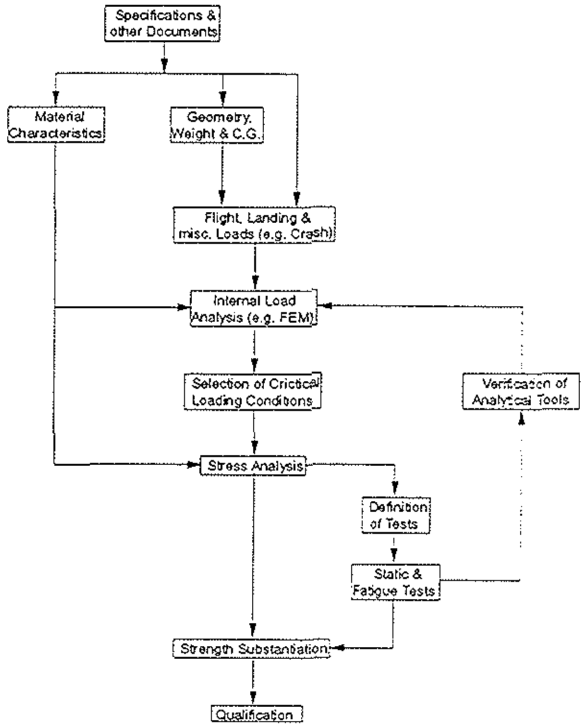

Figure 6.1: Strength substantiation procedure

At the beginning of the development phase based on the relevant specifications the general architecture of the H/C is established and the related fuselage structure basically defined. At this stage also the selection of the materials is performed and the determination of their characteristics started by means of coupon tests.

Then the fuselage structure is developed in an iterative process.

Based on the general architecture, the characteristics of the applied materials and the global loading conditions the structural internal loads are determined e.g. by means of FEM-models. Then the stress analysis is performed to dimension the structure as well as to select critical areas. Based on the stress analysis tests on structural elements, components and full scale test articles are defined for different purposes like the investigation of structural details, the verification of analytical results or for experimental substantiation.

6.2 Testing

To support respectively to verify step by step the analytical work the so-called 'building block approach' using different levels of tests (coupon-, element-, component- and full scale tests) is applied throughout the development phase.
The type of test level is always selected according to the required test results.
In the different test levels the following tasks are performed:

Coupon tests

- determination of basic material characteristics like stiffness, strength etc. taking into account extreme environmental conditions
- determination of damage tolerance characteristics (e.g. compression after impact, strain limits for no-growth approach)

Element tests

- determination of strength of joints, sandwich etc. taking into account extreme environmental conditions
- determination of empirical design allowables
- investigation of behaviour of structural details
- determination of effect of impacts and manufacturing defects
- substantiation of impacts and allowable manufacturing discrepancies
- investigation of structural behaviour at room temperature/ambient and hot/wet to check failure modes and to establish overload factors

Component tests

- investigation of critical areas
- verification of analytical methods (dimensioning, analytical models) on representative components
- establish BVID-level
- substantiation of impacts and allowable manufacturing discrepancies
- investigation of structural behaviour at room temperature/ambient and hot/wet to check failure modes and to establish overload factors

Full scale tests

- verification of analytical methods (dimensioning, analytical models like FEM)
- substantiation of impacts and allowable manufacturing discrepancies
- experimental substantiation at RT/ambient (necessary due to size of structure)

The testing according to the 'building block approach' allows to support the analytical work with the appropriate test results in each step of the development phase.
This approach uses a lot of tests at the lowest level (material coupons) taking into account extreme environmental conditions to establish a complete basis with respect to material characteristics for the following development work at the beginning. Later on these tests are used to establish a statistical basis according to MIL-HDBK-17B for the material properties..
With increasing size and complexity of the test articles and test set-ups the number of tests is decreasing and dedicated to defined tasks.
It can be summarised, that the 'building block approach' is with respect to technical risk, flexibility, time and costs an efficient way of structural testing.

6.3 Determination of defects

The strength characteristics of composite material are affected by defects occuring in the manufacturing process or lateron in service by accidental impacts. Therefore these kinds of defects have to be considered in the substantiation of the structure.
Typical types of such defects are manufacturing damages like:
- porosities, inclusions
- surface scratches

- poor bonding
- delaminations
- impact damages at assembly

and in-service damages like
- disbonds on sandwich areas
- disbonds of joints
- delamination of monolithic areas
- impact damages.

The maximum damage size to be considered will be determined by

- selection of the maximum impact damage size based on a probability assessment of impacts in assembly, maintenance and in-service. The maximum damage size will be determined according to the results of this assessment and the related visual inspection program.
- The maximum size of manufacturing defects will be determined according to the permissible defects specified in the related quality assurance documents.

Defects resulting from these two points will be considered in both static and fatigue dimensioning as well as in the testing by means of artificial manufacturing and impact damages.

6.4 Environmental effects

The strength and stiffness characteristics of composite material are dependent on the environmental conditions.

It is generally acknowledged that the hot/wet-conditioning effect for composite structure can be simulated correctly by absorption of humidity.

For the NH90 statistical processing of the atmospheric conditions encountered in the various operational regions shows that the maximum continuous degree of moisture is 85% relative humidity.

The temperatures to be considered are ambient air temperatures up to 50°C. Taking into account the effect of solar radiation with respect to the surface and the colour of the paints used, a general structural temperature of 75°C is applied. However local over-temperatures resulting from combinations of flight configuration, ambient temperature and exhaust gas are taken into account too.

7. NH90 test logic

The selection of the test articles for the structural parts takes into account the building-block approach and the generally different characteristics of different materials like composites and metal.

Related aspects are:

- the fatigue behaviour of composites is generally superior to metals
- composites are sensitive to out-of-plane loads
- composite properties degrade under temperature and humidity effects
- influence of stress concentrations is maximal for composites under static loading while it is maximal for metals under fatigue loading
- for composites impacts are critical because they can cause non-visible damages (NVIDs) reducing the strength
- if the strain level in composite material is limited, existing defects will not grow
- for metallic parts crack growth has to be taken into account.

Therefore most of the tests with composite parts are foreseen to be static tests whereas the majority of testing on metallic parts of the structure will be fatigue tests.

8. NH90 static and fatigue testing

Coupon tests are used to establish the basic material characteristics of the composite material. With these tests the material properties for different environmental conditions are determined. The effects of extreme environmental conditions are taken into account by

means of hot/wet-conditioning of the coupons. At this level also a sufficient number of tests is performed to allow a statistical treatment of the results to obtain material allowables as required by e.g. MIL-HDBK-17B.
This type of testing is also used for structural details like riveted or bonded joints and sandwich specimen.
This task today is already performed to a large extent.

For the following test levels only the tests required for first flight are performed/in progress whereas the other ones are only generally defined but not yet carried out.

Below an overview about the component tests related to the centre and rear fuselage structure is given.
Before first flight mainly static tests with

- main frame components
- main gearbox attachment
- main landing gear shock absorber attachment
- rear fuselage folding area load introduction

will be performed.
Later on static and/or fatigue tests with

- main gearbox attachment
- rear fuselage folding area load introduction
- engine mounts

are foreseen.

Component tests are carried out in the early design phase with small components like an upper corner main frame and a lower corner main frame to verify the design of these areas.
The upper corner area of the main frame was tested to verify the design and static strength of a curved area of an I-beam type frame. The loads applied correspond to a pull-up manoeuvre.

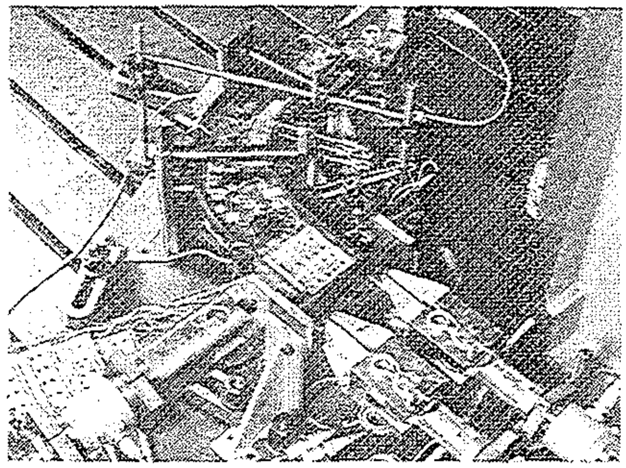

Figure 8.1: Static test upper corner

The test article was equipped with metallic fittings for support and load introduction. With this test being performed at room temperature the analytical dimensioning was verified.

Another important structural area is the main landing gear load introduction. This part has to be designed to sustain the loads resulting from the emergency landings (vertical speed 6.0 m/s) as well as crash conditions.
To substantiate the dimensioning of this area, a static test component consisting of the concerned parts of the side panel, the main landing gear shock absorber fitting and parts of two frames where the fitting is attached in between was defined.

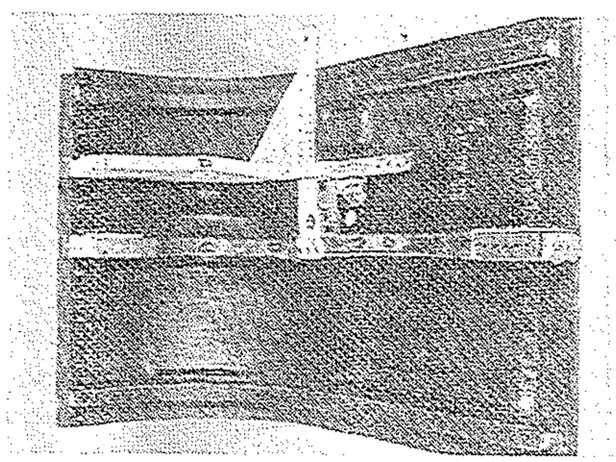

Figure 8.2: Main landing gear attachment test article

The test article was supported at the structural interfaces and the load was applied to the shock absorber fitting. The selected load case was the emergency landing condition.
The test was performed at an elevated temperature of 90°C. This condition was selected based on coupon test results for 75°C/85% r.h. and elevated temperature only. With this test the strength of this area was substantiated for this loading condition.

The biggest component tested up to now for the NH90 is the complete rear fuselage.
This part of the structure is characterised by the folding hinge area with a local load introduction carrying high loads and by 3-dimensional curved big NOMEX-CFC-sandwich areas mainly sized for global and local stability.
The purpose of this test was to substantiate the static strength of this part and to verify the Finite Element Analysis.
The part was supported in the forward area and loaded through a dummy, representing the tail structure, at the folding beams.

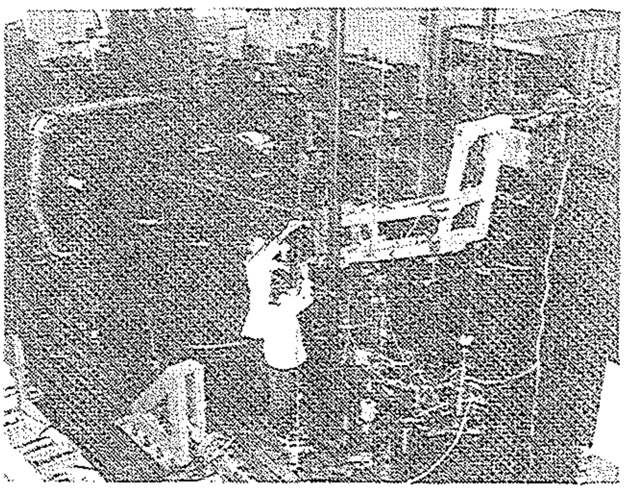

Figure 8.3: Test set-up rear fuselage static test

The applied loads were according to a yawing-manoeuvre introducing high lateral loads and a torque-moment resulting from tail rotor- and vertical fin thrust into the structure and a tail down landing condition with high vertical loads due to inertia effects mainly.
The tests were performed at room temperature and the effects of the extreme environmental conditions were accounted by analysis based on coupon test results.
The analysis of the measured strains and displacements showed good correlation with the FEM-analysis and strength of the component proved to be sufficient.

Another major load introduction area into the fuselage structure is the main gearbox (MGB) attachment area. This area is the 'support structure' for the fuselage for all flight conditions. To verify the static strength and the Finite Element model of this area, a test with a component consisting of the MGB-attachment and some surrounding structure to enable the support of the component as well as to ensure a realistic load distribution in the test article itself is in preparation.
The test article is supported at its boundary at the frames and longerons and loaded through a MGB-dummy to get a representative load distribution.

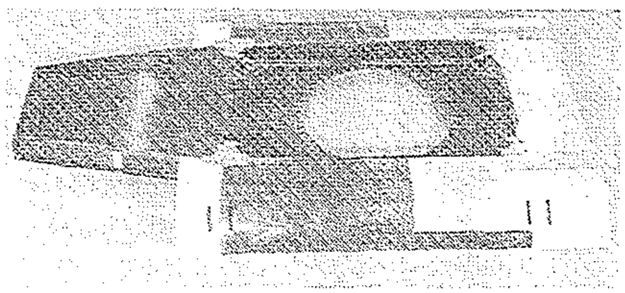

Figure 8.5: MGB-attachment test article

The loading is according to a pull-up load case where the highest loads in the MGB-struts occur. The test will be performed generally at room temperature while applying elevated temperature locally to the critical area.

At the end of the development phase a static test with a complete fuselage primary structure will be performed for several loading conditions.

The aim of this test will be the

- experimental substantiation of load cases
- verification of analytical work (dimensioning, analytical models like FEM)
- substantiation of impacts and allowable manufacturing discrepancies.

The test article will be a complete fuselage primary structure without doors, sponsons and horizontal stabiliser. It will include artificial allowable manufacturing defects and barely visible impacts.
Due to the size of the fuselage structure the test is foreseen to be carried out at room temperature/ambient conditions. A sketch of the test set-up is shown below.

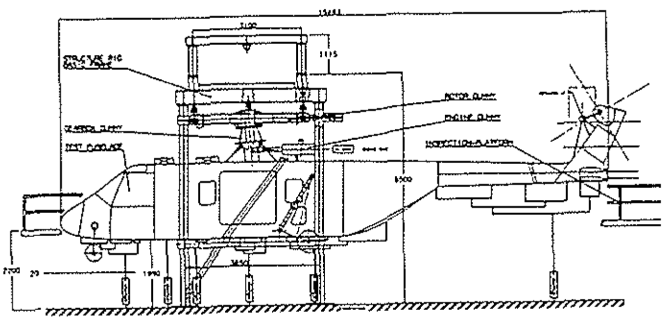

Figure 8.6: Complete fuselage test set-up

10. Crashworthiness

10.1 General approach

The aim of the crashworthiness design is to provide the required level of survivability for crew and passengers during specified crash impacts.
Therefore the helicopter has to provide features like

- sufficient total energy absorption and structural integrity
- adequate 'energy-workshare' and functioning of related subsystems like landing gear, fuselage and seats

For the overall crashworthiness the fuselage structure has to contribute to the global energy absorption and to provide the structural integrity.
The energy share to be taken by the subsystems is defined based on helicopter crash impact simulations with the semi-empirical computer code KRASH.
Also for crashworthiness substantiation will be done by analysis based on test results.
The analysis will be performed by means of a KRASH analytical model that will be based on and verified by mainly drop test results on different levels. With the verified model then the complete crash envelope will be substantiated.

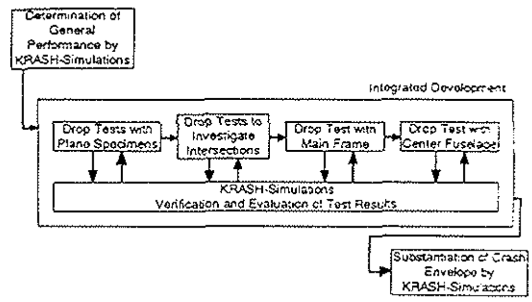

Figure 10.1: Crash substantiation approach

10.2 Test philosophy

With respect to crashworthiness the fuselage structure has to be optimised to provide the required energy absorption within a limited subfloor stroke while keeping the resulting accelerations as low as possible.
Also for crashworthiness testing (mainly drop tests) the 'building block approach' is used for

- determination of characteristics of structural subfloor elements (sandwich, intersections) to get KRASH-input data as well as to optimise their characteristics
- investigation of component behaviour (e.g. main frames) in order to verify analytical results with respect to energy absorption and structural integrity
- performing a full scale test with the centre part of the fuselage to substantiate the proper functioning of the structure and to verify the analytical model in

order to have a qualified tool for the substantiation of the complete crash envelope.

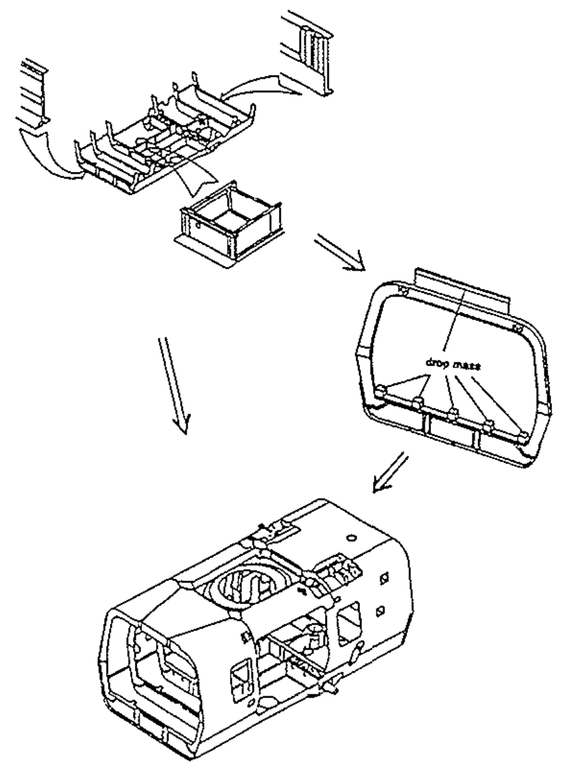

Figure 10.2: Crash testing approach

10.3 NH90 crash testing

The main share of energy absorption within the fuselage structure has to be taken by the centre fuselage structure. Therefore the testing approach will be outlined based on this structure module.
First the basic development work was started on the element level to get structural concepts fulfilling the requirements with respect to energy absorption and crushing characteristics. In these tests also the development of failure trigger mechanisms, to keep the initial failure peak low, are included and concepts ensuring overall structural integrity during crash impacts are considered.The test specimen were plane vertical elements as shown below.

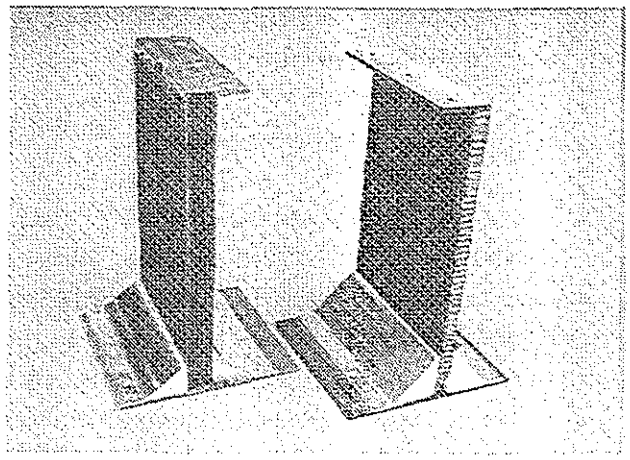

Figure 10.3: Sandwich elements

The typical results gained from drop tests with these parts are load-stroke-curves which are used to check the behaviour and to verify the initial assumptions included in the analysis. An example for such a curve is shown below.

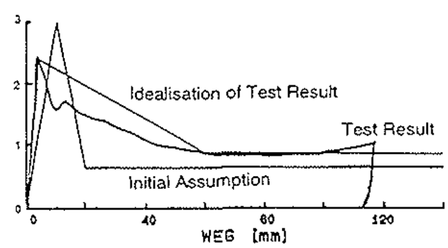

Figure 10.4: Load-stroke(WEG)-curve NOMEX -sandwich element

Testing of these elements is completed today to a large extent.

In the next step of the testing the characteristics of structural intersections will be determined and developed to fit into the overall concept. Then the basic data for the crushing characteristics of the subfloor structure will be available.
The next step in the test program will be the complete frame testing to verify the results of the previous tests concerning crushing characteristics in the subfloor area

and to investigate the overall integrity of the structure during crash impacts.

Finally a drop test with a complete centre fuselage section will complete the crash related fuselage structure testing.

This test article will consist of the

- energy absorbing subfloor structure
- crash resistant cabin structure
- dummies for high masses
- fuel tank bladders
- cargo dummies
- pintle axles of the main landing gear (potential 'hard points').

The aim of this test will be the substantiation of the structural behaviour for a defined impact condition as well as the verification of the structural simulation model.

11. Summary

The structural substantiation by analysis based on test evidence is generally an accepted procedure. The testing according to the 'building block approach', where each test is defined according to the appropriate purpose, is widely used throughout the aerospace industry.

Together with the experience already available at EC this approach presented for the testing and substantiation of the NH90 fuselage primary structure is an efficient way with respect to technical risk, flexibility, time and costs .

References

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