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AN ADVANCED STRUCTURAL CONCEPT FOR THE NH90 COMPOSITE FUSELAGE

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ABSTRACT

During the last twenty years many structural parts of helicopter fuselages have been designed in composite materials, due to their excellent properties in weight, stiffness, corrosion resistance and damage tolerance behavier. On the MBB BO105, as a design of the sixties, only secondary structural parts are made of composite materials. In the seventies, the horizontal stabilizer and the fins have been developed as primary structural parts, for the BK117. The BO108, being the latest design of MBB helicopters, has the cabin, the subfloor shell and the stabilizers, which are all primary structure, made of composite materials.
All these experiences led to the BK117 FRP (fibre reinforced plastic) research program, a helicopter with nearly the complete airframe manufactured in composite materials (first flight: 1989) /1/.

Based on the experiences of these programs and similar programs in the other participating countries, the primary airframe structure of a new helicopter generation like the NH90 will be designed fully in composite material.

This paper will give an overview about the following aspects:

- Requirements from customers and authority side
- Design aspects (materials, structure concept, strength analysis)
- Manufacturing aspects (major module concept, description of the module: centre fuselage)

1. INTRODUCTION

The NH90 is a quatrolateral helicopter program, founded by the Ministeries of Defence of France, Germany, Italy and Netherlands.
The technical work is done by the Aerospace Industries of these countries under the national leadership of AEROSPATIALE, FOKKER, GRUPPO AGUSTA and MBB.

The NH90 will be developed in two versions, a Tactical Transport Helicopter (TTH) for the Army and a NATO Frigate Helicopter (NFH) for the Navy.
Starting from a common Basic Helicopter, these two variants will be developed mainly by adding the mission specific systems.

Some data of the Basic Helicopter are:

-	Weight class:	8 to 9 tons
-	Main Rotor diameter:	16 m
-	Total fuselage lenghth:	aprox. 16.1 m
-	Fuselage height:	aprox. 2.15 m
-	Fuselage width:	aprox. 2.6 m

Fig. 1-1 NH90 Mock Up

The results of research programs on composite helicopter airframes, performed at MBB, like the BK117 FRP, showed some remarkable differences compared to airframes in conventional design:

- up to 30% weight savings for experimental aircrafts (20% for serial production feasible)
- up to 70% reduction of parts
- manufacturing of huge composite components with a high level of integration
- assembly of these components in a relative simple integration rig, using of the shelf joining elements, like rivets and bolts.

These results show, that airframes in composite material are the concept of the future and therefore, as a logical step, will be applicated on the new generation of helicopters like the NH90.

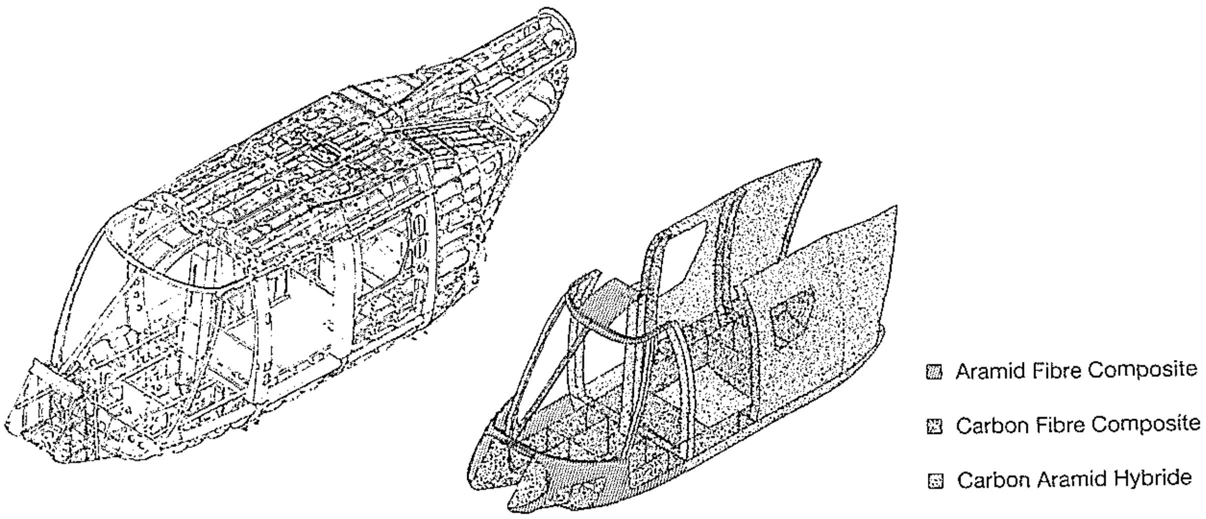

Fig. 1-2 BK117 FRP Research Program
Comparison of Conventional and Composite Ariframes

2. FUSELAGE CONCEPT

The NH90 fuselage features a cabin, with large dimensions and sliding doors on each side, a spacious cockpit and an avionic bay in between. In the rear section a ramp can optionally be installed. The fuel tanks are located in the subfloor structure.

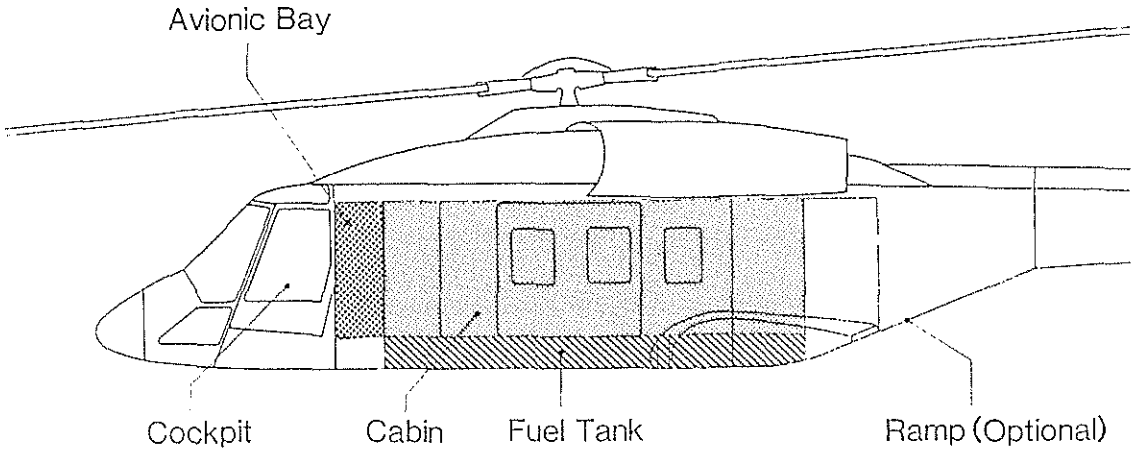

Fig. 2-1 Functional Layout of the *NH90 Fuselage*

The scheme of the structure takes into account the functional and operational aspects of the aircraft as well as the design features of a composite structure. The application of composite materials has a great influence on the structural layout of an airframe. It leads to a layout with also a remarkable reduction of frames and longerons, because these elements are only used as main load paths. To reduce the number of parts, skin panels for example can be designed as sandwich plates.
Fig. 2-2 shows the primary structure.

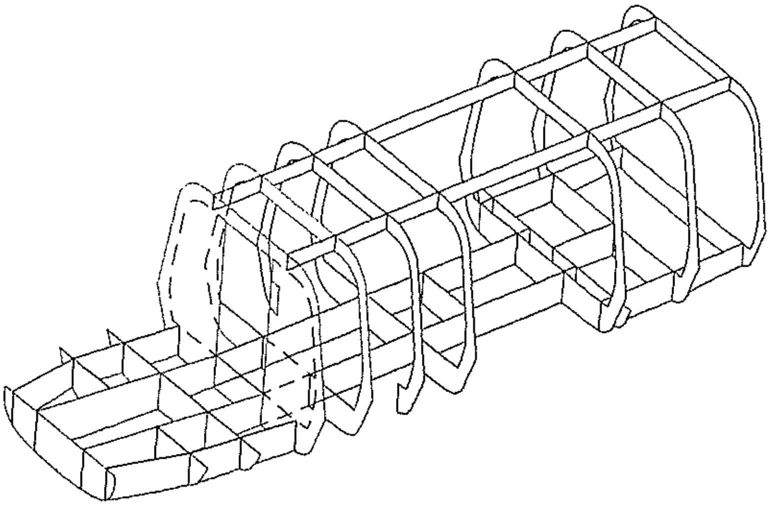

Fig.2-2 Primary structure

3. DEVELOPMENT ASPECTS

The majority of the immense number of initial conditions for the development of a new flight vehicle is faced with an immense number of requirements - on the aviation authority side as well as on the customer's. The basic requirements, mission roles and profiles, for which an aircraft is designed must meet certain design parameters, e.g. weight (load capacity), size, performances and basic flight-mechanical capabilities.
Regarding safety statistics of the past two decades and the hazardous enviroments imposed on the helicopter due to its mission task, one requirement which has gained more and more attraction and importance is the crashworthiness. Besides the general airworthiness, this has become a leading feature for the design and development in the field of composite structures.

3.1 Requirements and Regulations

The customer requirements define the design envelope. The application of authority regulations leads to a specific structural design complying with the load envelope and strength requirements.
In the following only those items are listed which are affecting the fuselage structure design concept.

AVATION AUTHORITY REGULATIONS		PURPOSES
FAR PART 29	AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY ROTORCRAFT	GENERAL AIRWORTHINESS
ADS-29	STRUKTURAL DESIGN CRITERIA FOR ROTARY WING AIRCRAFT	FLIGHT/ LANDING LOAD CONDITIONS FOR TTH
AR-56	STRUCTURAL DESIGN REQUIREMENTS (HELICOPTERS)	FLIGHT/ LANDING LOAD CONDITIONS FOR NFH
AC 20-107A	COMPOSITE AIRCRAFT STRUCTURE	MATERIAL AND FABRICATION DEVELOPEMENT STATE OF THE ART DESIGN PROOF OF STATIC/DYNAMIC STRENGTH OF COMPOSITE STRUCTURES
MIL-STD1290	LIGHT FIXED- AND ROTARY WING AIRCRAFT CRASHWORTHINESS	CRASHWORTHINESS DESIGN CRITERIA
MIL-HDBK-17B	POLYMER MATRIX COMPOSITES VOL.1 GUIDELINES	GUIDELINES FOR THE PHYSICAL, CHEMICAL, MECHANICAL CHARACTERISATION OF COMPOSITE MATERIALS

CUSTOMER REQUIREMENT	EFFECT/ RESULT
CORROSION RESISTANCE	FIBER COMPOSITE STRUCTURE
LOW MAINTENANCE EFFORT	FIBER COMPOSITE STRUCTURE, EASY ACCESSABILITY AND REPAIRABILITY
EXTENSIVE STRUCTURAL RELIABILITY/REDUNDANCY, LOW VULNERABILITY ON BATTLE DAMAGE	DAMAGE TOLERANT, FAIL SAFE DESIGN, CRASHWORTHINESS, OCCUPANT PROTECTION, FIBER COMPOSITE STRUCTURE
REDUCED IR/, RADAR DETECTABILITY	KINKED SIDE SHELLS (DIAMOND SHAPE)
NAVY STORAGE FOR NFH, AIRPORTABILITY	TAIL-, MAINROTOR FOLDABILITY, OUTER DIMENSION LIMITS
LOADABILITY OF GROUNDVEHICLES	REAR RAMP CONSTRUCTION INTERNAL DIMENSION LIMITS
HIGH PAYLOAD/WEIGHT RATIO	FIBER COMPOSITE STRUCTURE
CRASHWORTHINESS	ENERGY ABSORPTION CAPABILITY OF SEATS, SUBFLOOR STRUCTURE, LANDING GEAR

3.2 Material Selection

The approach to a well balanced material selection is based on the following aspects

- Fulfillment of requirements (see chapter 3.1)
- Experience on development, manufacturing and certification procedures on rotorblades, BK117-, BO108 composite fuselages
- Good static and fatigue behaviour of composites, even in riveted/bolted joints (Fig. 3-2 to 3-6 show results, based on coupon tests)
- Specific material properties influenced by fiber type combination (hybrid) and fiber orientation gaining characteristics from quasi-isotrop to anisotrop, superior crushing behaviour (see chapter 3.4.2).
- available, verified tools for analytical investigation which are linear stress and nonlinear crash computation programs.

The evaluation of these items lead directly to the proposed composite fuselage concept.

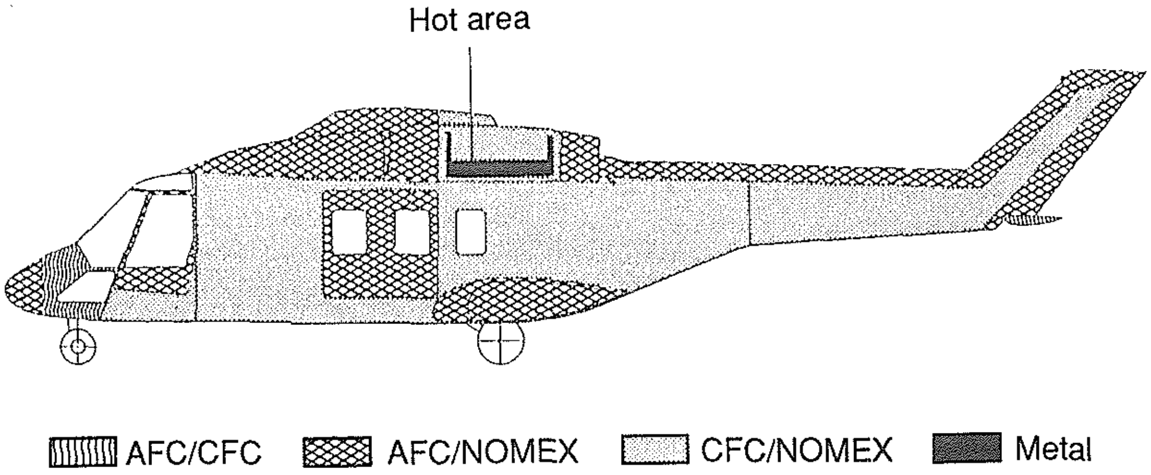

Fig. 3-1 Materials Selection

The properties of the various composite materials themselves are well known and available in many publications. In addition, the behavior of joints of composite components has to be taken into account. Fig. 3-2 to 3-6 show basic results of coupon tests.

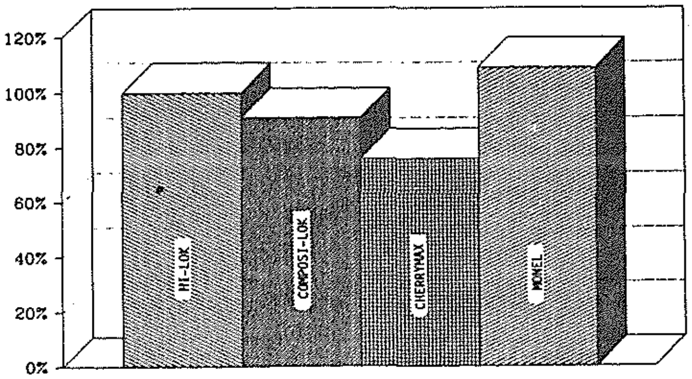

Fig. 3-2 Strength of rivet joints in CFC (various fasteners)

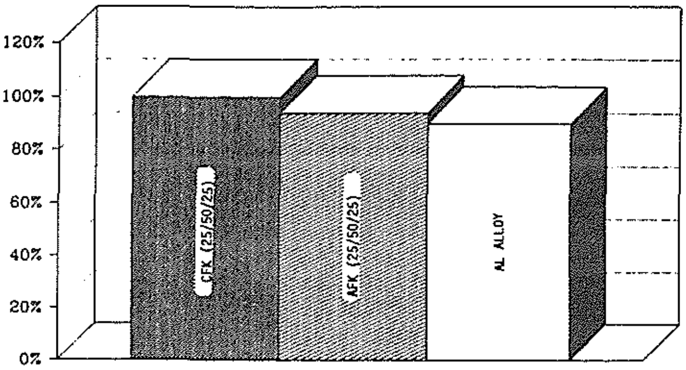

Fig. 3-3 Strength of rivet joints in different materials

With respect to the excellent specific strength (strength/specific gravity ratio) of the carbon fiber (Fig. 3-5) CFC is dominating the material concept. Monolithic application of CFC on frames and longerons. CFC/Nomex sandwiches for primary structure panels, except hot section (Titanium) and cockpit/cabin floor (AL-alloy sandwich). Secondary structure like doors, covers and cowlings are AFC/Nomex sandwiches (Fig. 3-1).

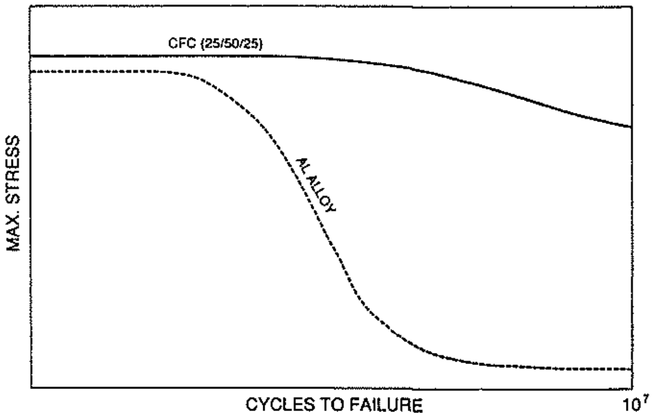

Fig. 3-4 Fatigue strength of rivet joints (HI-LOK)

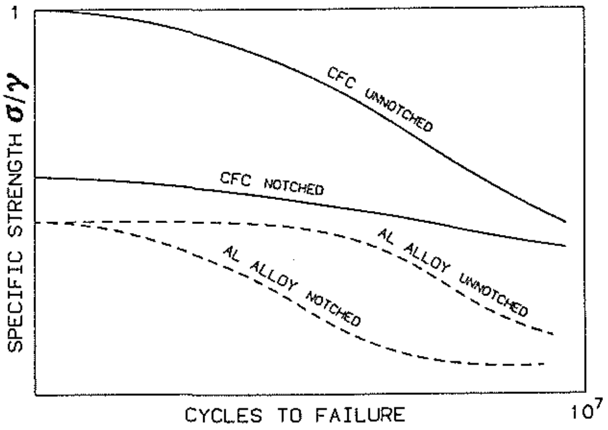

Fig. 3-5 Specific strength of notched/unnotched mat.

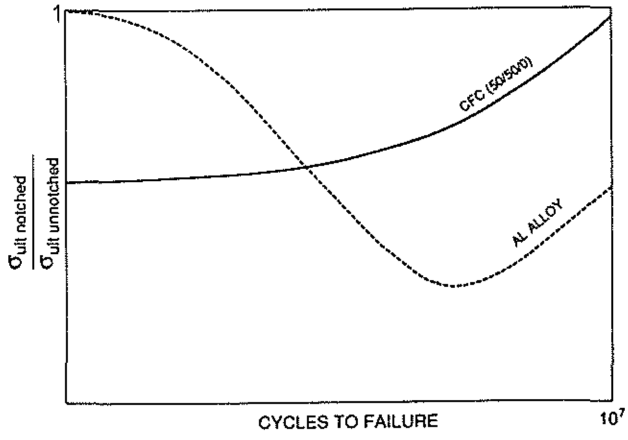

Fig. 3-6 Influence of notches on fatigue strength

The design requirements for limited total height and maximum internal volume limit the subfloor height which is the key parameter for fuselage crashworthiness. With respect to this and the demand for a good efficiency of crash energy absorption a carbon/aramid hybrid subfloor structure, will be the most likely selection. Static and drop test series of representative subcomponents varify the good characteristics of energy absorption.

3.3 Airframe Structure Concepts

The basic structure concept of the fuselage primary structure contains the subcomponents frames, longerons and sandwich panels.

The subfloor structure has to perform two different tasks

- load distribution between the undercarriage during landing cases (covers the smaller flight case loads)
- crash load absorption by crushing of the webs of the subfloor structure.

These requirements lead to a subfloor structure with sine wave beams which provides general structural continuity. Furthermore, two keel beams act as skids in a forward crash case. The crash energy is absorbed by crushing of the sine wave web. The sine wave design provides a high energy absorption capacity by fracture mechanics (fiber/matrix failures, delamination combined with bending fractures) compared to flat panels which exhibit failure by instability (local/global buckling).

Hard points to support the heavy mass items are located preferably on intersections between frames and longerons. The landing gear and the main gear box attachments are equipped with load limiting devices on the interface to the fuselage in order to prevent penetration of fuel tanks or cabin. The main landing gear axles are positioned to allow maximum stroking beneath the hardpoints.

An extensive use of weight/cost efficient sandwich structure compared to stiffened monolithic shells is made.

3.4 Investigations During Preliminary Design Phase

Analytical and experimental investigations have been performed to validate the composite fuselage structure concept in the first design loop. A first stress analysis was performed using a preliminary FE-model (Fig. 3-7) and postprocessors to check the interal load distribution and analyze the deflections (Fig. 3-8). The nonlinear structure program KRASH will be a helpful tool for next design phase (Fig. 3-9).

3.4.1 Analytical Investigations

A FE-model was created which contains a suitable meshing for this early predesign phase: 4670 degrees of freedom, 790 nodes, 240 axial load-, 450 bending-, and 870 membrane/plate elements (Fig. 3-7).

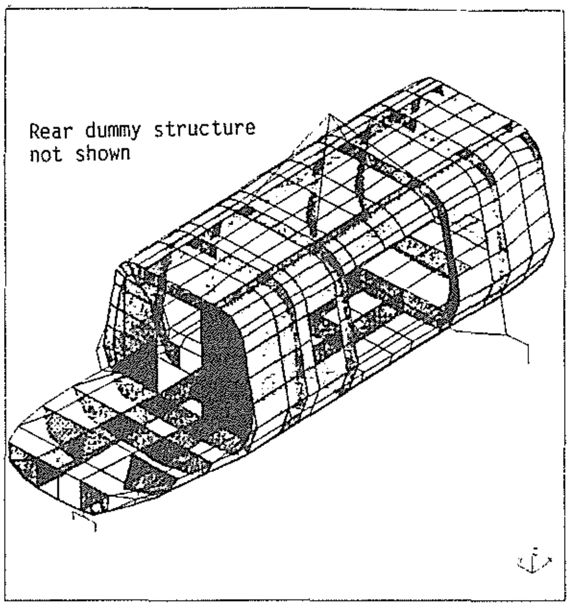

Fig. 3-7 FE-model

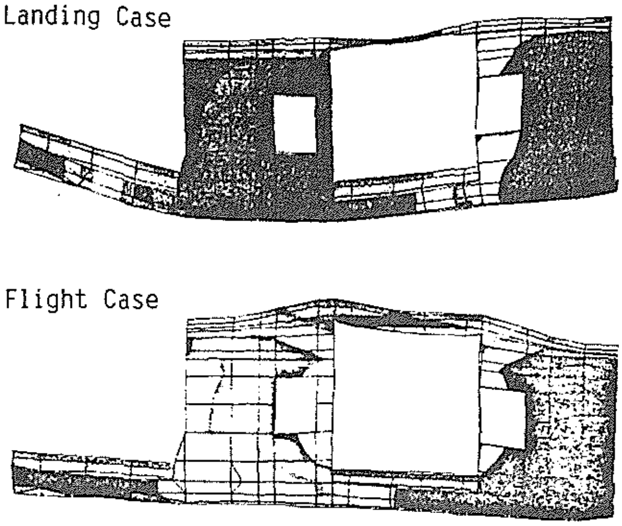

Fig. 3-8 Deformations of FE-model

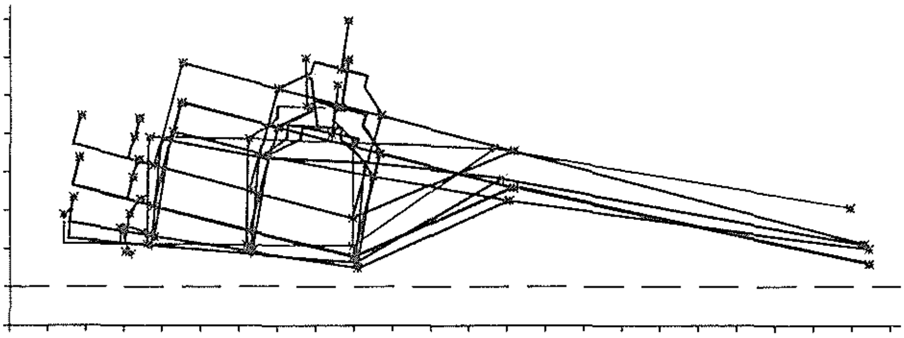

Fig. 3-9 2-D KRASH-model, sequence of motion and deformation

3.4.2 Experimental Investigations

A considerable number of coupon tests of joints and splices have been conducted determining the allowables under the variation of rivet/bolttypes, sheet materials (CFC, AFC) and environmental conditions (temperature, humidity). A short excerpt from this test program is shown on figures 3-2 to 3-3

Crash energy absorption characteristics were investigated on keel beam samples and keel beam/frame intersections in static load and dynamic drop tests. Special attention were put on the high load peak at the beginning of the web crushing because this means high accelerations. Improvements on reducing the initial impact peak have been performed by optimizing the fiber orientations, hybrid (CFC, AFC) lay-ups and application of notches as crushing triggers. Fig. 3-10, -11 show the design and the force/deflection characteristic of a representative keel beam section with the sine wave. One of the many future tasks in the next development phase is to obtain, as close as possible a peak/average ratio of 1.

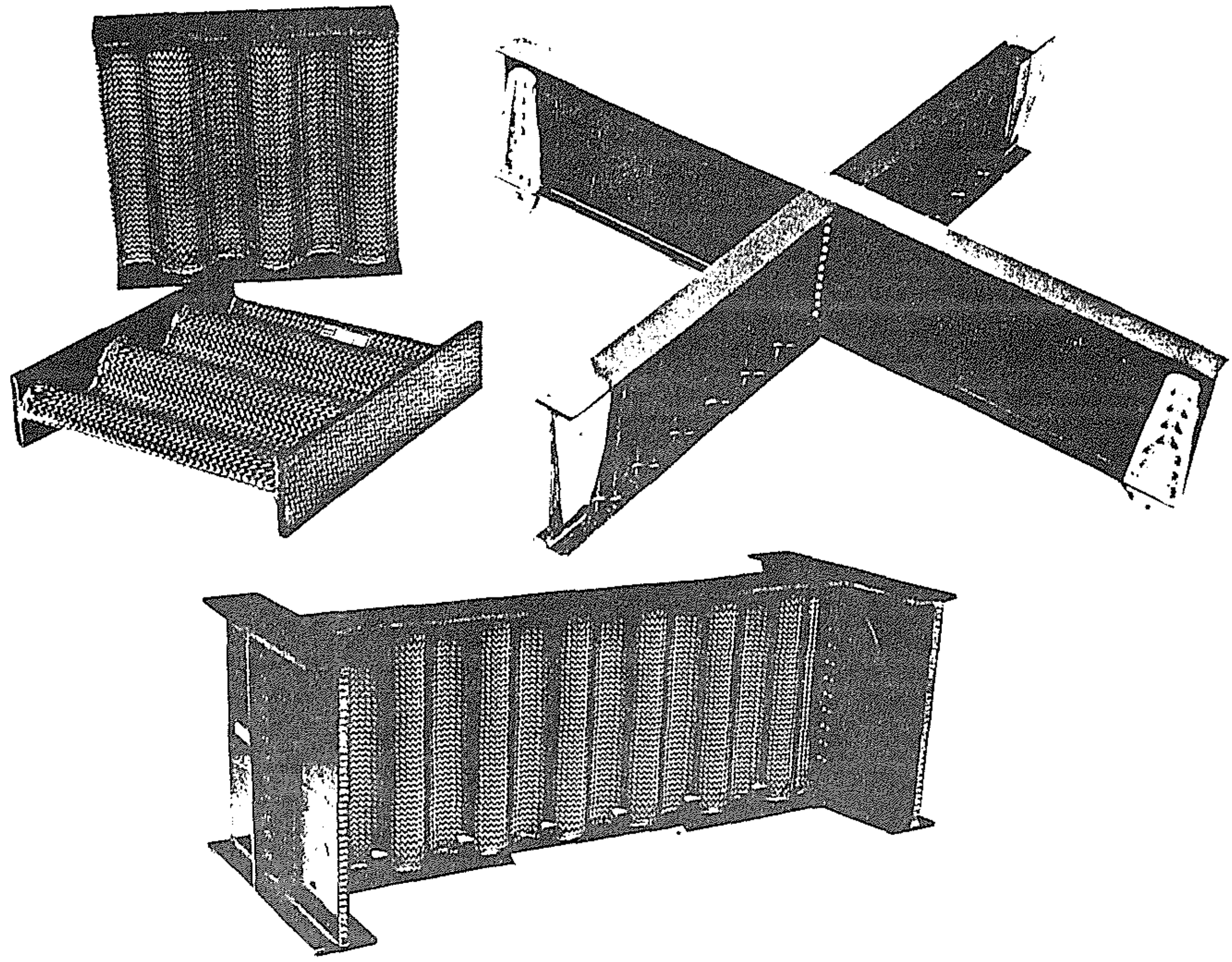

Fig. 3-10   Sine wave samples of static and crash drop tests

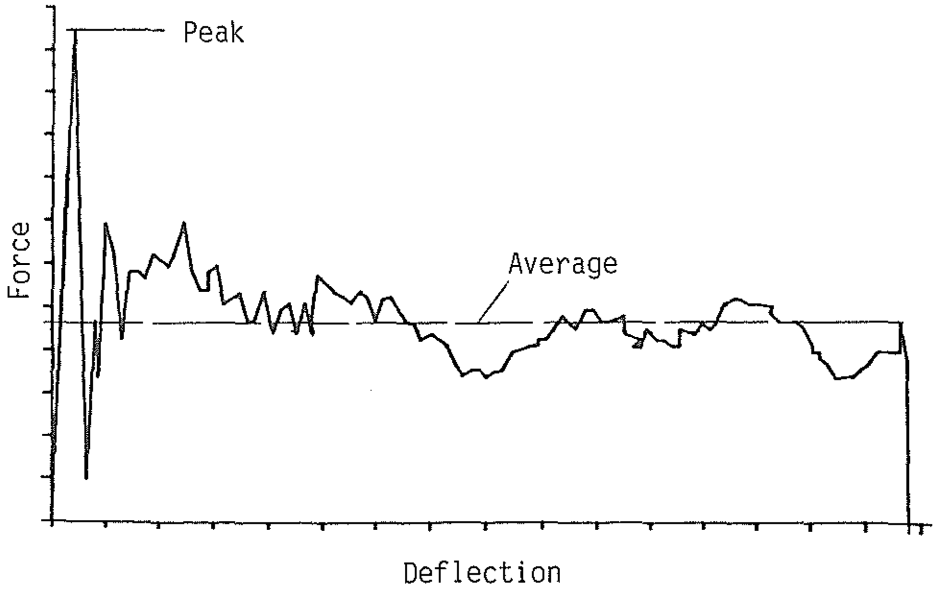

Fig. 3-11   Force-deflection characteristic of a drop tested sine wave sample

4. MANUFACTURING ASPECTS

4.1 Major Module Concept

The fuselage of the NH90 is separated into four functional parts, so-called modules. These modules are:

- Cockpit
- Center Fuselage
- Rear Fuselage
- Tail Section

The concept of functional modules alows the manufacturing of parts of the fuselage at different companies, according to the workshare of the NH90 program.

To minimize the efforts for the final assembly of the fuselage, these modules are already equipped as much as possible with electrical wires, hydraulic lines and subsystems. After testing these modules at the manufacturing location, they are delivered to the assembly line and ready for final assembly (Fig. 4-1).

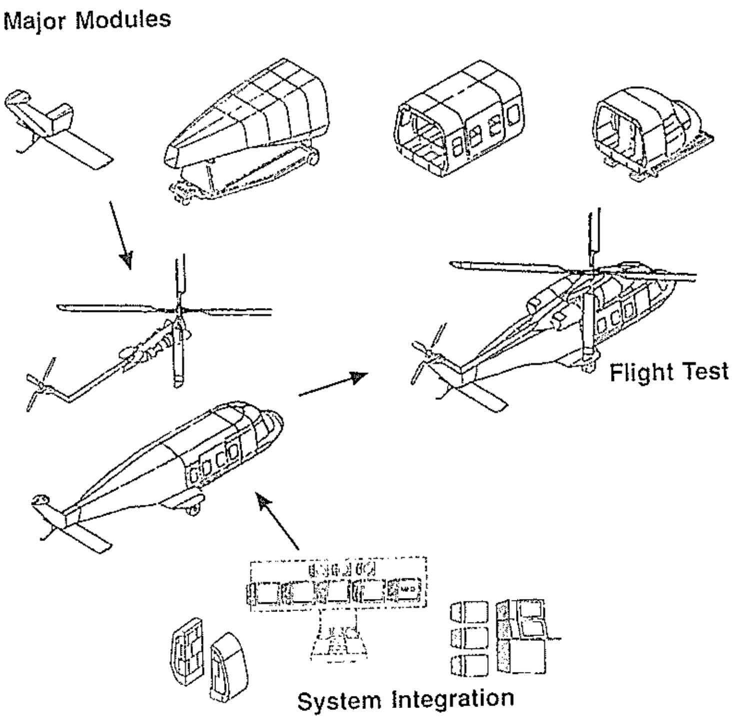

Fig. 4-1 Major Module Concept

4.2 Modul: Center Fuselage

The center fuselage, being a complex module, has been taken as an example to be described in detail in the following chapter (Fig. 4-2).

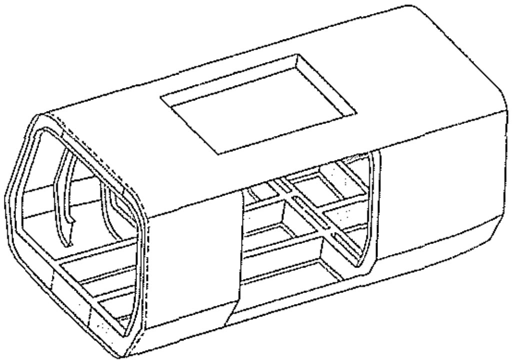

Fig. 4-2 Center Fuselage

Investigations on the area of manufacturing methods showed, that compared with a totally differential manufacturing method, the breakdown of this module into the components

- Upper deck
- Side Panel
- Subfloor Panel

will be a good compromise between weight, manufacturing costs and tooling effort (Fig. 4-3).

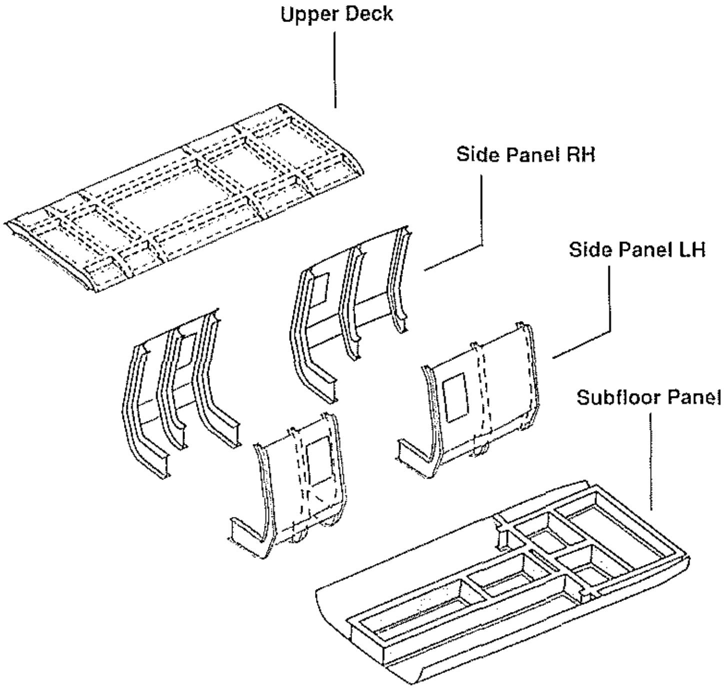

Fig. 4-3 Components of the Center Fuselage

4.3 Manufacturing of Components

In the following chapter, possible solutions of the manufacturing of the center fuselage components are described, based on the experience with the BK117 FRP research program.

4.3.1 Upper Deck

The upper deck is a component with a lot of interfaces to other systems. In this area the main gearbox, the engines and most of the hydraulic and electric lines are located. To fulfill all these interface requirements, the possible manufacturing steps for the composite parts of this component are as follows:

- Separate manufacturing of the frames and beams in steel molds.
- Bonding and partial rivetting of these parts in a separate rig to make shure, that all interface-points are correct.
- separate manufacturing of the skin in a CFC-composite mold.
- Bonding the frame structure to the skin
- In the area of the engines, the composite structure is heatprotected by a ceramic sheet covered with a Titanium sheet. This Titanium sheet is part of the firewall.

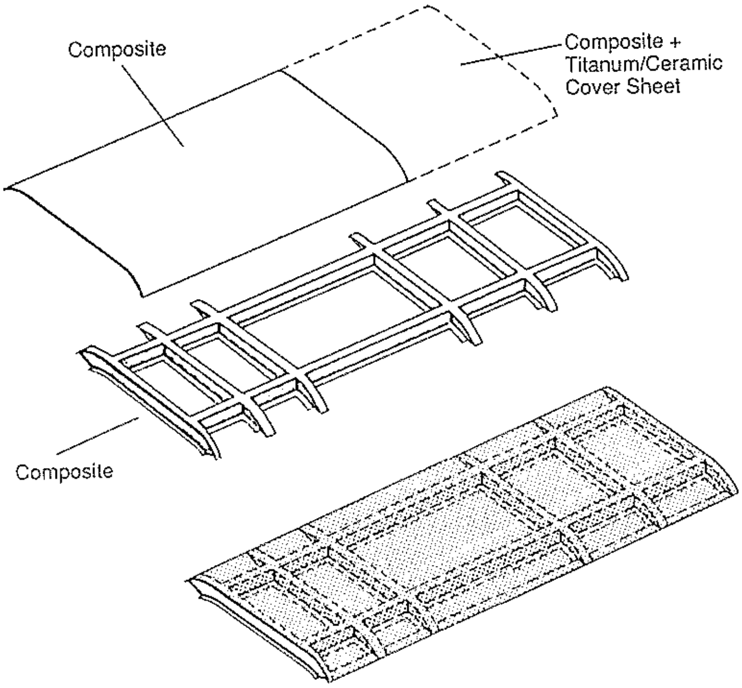

Fig. 4-4 Structure Architecture: Upper Deck

4.3.2 Side Panels

The side panels are divided into a front and rear section. This sections consist of a CFC-Nomex skin and segments of CFC monolitic frames. These components are manufactured in one shot by co-curing, in a CFC-composite mold.

For the prototypes, the frames and skins are manufactured separately and co-bonded

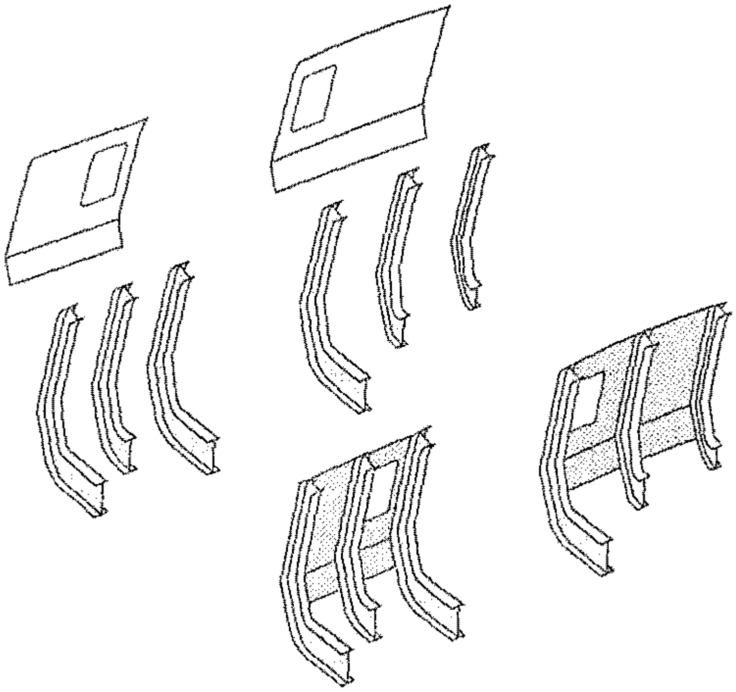

Fig. 4-5 Structure Architecture: Side Panel

4.3.3 Subfloor Panel

The Subfloor Panel is a component with a similar complexity of interfaces like the upper deck, so the manufacturing method is the same:

- Separate manufacturing of the frame and beam segments in metal molds.
- Separate manufacturing of the skin in a CFC-composite mold.
- Bonding and rivetting (on areas with high loads) the frames and spares in a special rig, to guarantee proper interface points.
- Bonding the frame structure to the skin

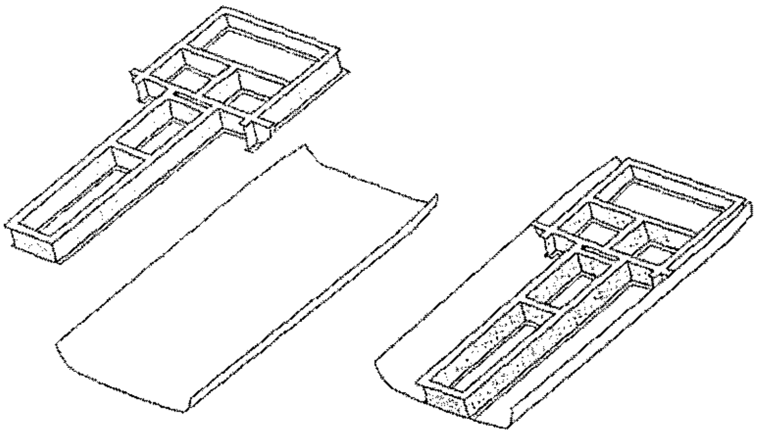

Fig. 4-6 Structure Architecture: Subfloor Panel

4.4 Assembly of the Center Fuselage

Due to the fact, that the components

- Upper Deck
- Side Panels
- Subfloor Panel

are manufactured as relative stiff pre-integrated parts, the fixing of these components in the integration rig can be done with minimum effort (Fig. 4-7).

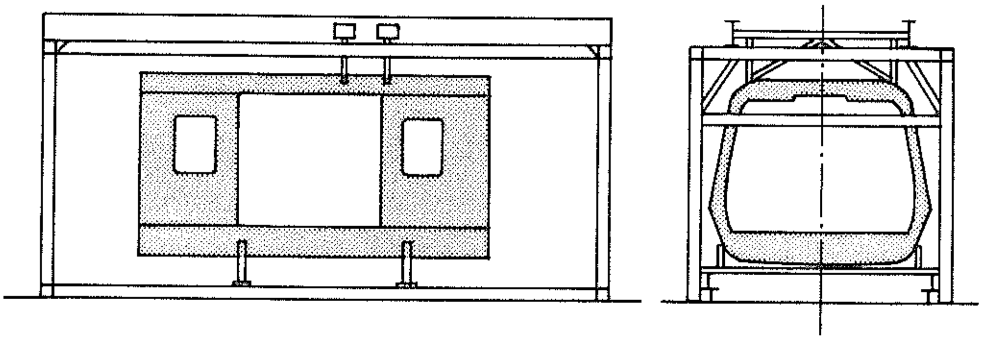

Fig. 4-7 Integration Rig (Principle Solution)

4.4.1 Structural Joints

A problematic area of structural joints is the connection between the main components of a module. In principle, these joints can be realized by bonding, which is a non dismantling solution, but in case of damage or modifications during the helicopters life cycle, rivetted and bolted joints allow dismantling of these components.
Investigations on the basis of coupon tests showed, that this joining method, using the same rivets as used on metal design, gives good results in statical as well as in fatigue behaviour.

The joints between frames and beams are designed in a similar way like metal structure, using joggles and overlapping sparcaps. These parts are connected with "Hi-Locks" (Fig. 4-8).

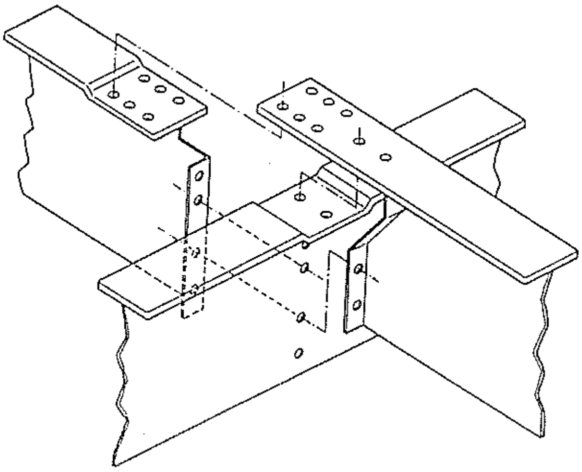

Fig . 4-8 Structural Joint

5. CONCLUSIONS

The application of composite materials on helicopter airframes, starting twenty years ago with secondary structural parts and substituting the metal design of more and more primary structural parts, leads, as a logical step directly to a fully composite airframe.
The basical aspects of structural analysis and manufacturing of composite airframes are sucessfully demonstrated with several research programs, e.g. the BK117 FRP.
With these experiences, industry is prepared to design and manufacture the NH90 airframe with this concept, suitable for a helicopter of the future.

6. Reference

/1/ A. Engleder, W. Koletzko, The Development of a Composite Helicopter Fuselage as Exemplified on the BK117, Paper presented at 14th European Rotorcraft Forum, 1988