ANALYSIS AND FULL-SCALE CRASH TEST OF THE NH90 TRANSPORT HELICOPTER FUSELAGE

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Abstract

The NH90 contract between industry organisation NHI and customer organisation NAHEMA requires crashworthiness, based on MIL1290 and Weapon System Requirements. After the development of five prototypes from 1995 to 1999 and development of special crashworthiness features, the serial production of NH90 is ongoing. Delivery of the first NH90 is foreseen for 2004.

The overall crashworthiness requirements are: survivability of pilots and troops, limiting g-loads to tolerable load factors as given in the EIBAND diagram, prevent masses from disconnection from supporting structure and prevent post-crash fire. All detailed requirements are listed in a special NH90 crashworthiness requirement specification, based on MIL1290.

The procedure of the crashworthiness development logic is summarised in the crashworthiness substantiation concept. This outline takes requirements, contract conditions and further knowledge gained during development into account. Part of the development and substantiation process is the application of suitable calculation and simulation tools: KRASH, DYTRAN, RADIOSS and Mechanica Motion. These tools are used according to the specific needs and characteristics of the components under consideration.

Results of these simulations provided parameters concerning the required global crash behaviour of the helicopter. These inputs, e.g. strength requirements, necessary energy absorbing capacity in certain sections of the fuselage, load factors, desired force over time curves, etc., were used as design goals in the further development process. Tests were organised in a building block approach and provided material and component specific crushing data. Later component crash tests were used to tailor and verify simulation models. These component crash tests already included landing gears, tanks, fuselage structural components and equipment necessary to survive crash.

According to this guideline the development leading to the final qualification test for the centre fuselage structure protecting 14 troops in case of crash is presented. This final qualification test was performed successfully in October 2002, with a 6.1 t centre fuselage section of NH90, fully equipped with seats, tank and representative masses, including 14 Anthropomorphic Test Devices (ATD), in this paper just called person dummies. Evaluation of the success criteria after test showed, that the requirements were fulfilled.

Introduction

The NH90 is a military transport helicopter in the 10t MTOW range, depending on version. The development was initiated by the four nations: France, Italy, Germany and the Netherlands. In the meantime Portugal joined the NAHEMA consortium. The industries with Eurocopter, AGUSTA, Eurocopter Deutschland, Fokker/STORK-group are represented by NHIndustries. The helicopter has been developed in two basis variants: TTH (Tactical Transport Helicopter) and NFH (NATO Frigate Helicopter). During serial procurement further versions, based on these variants, are in the production line, depending on customers' needs.

Pic.1: NH90 Transport Helicopter, Prototype 4

Crash Requirements

Reference

The contract of NAHEMA with NHI requires crashworthiness for the NH90 helicopter, based on the US American specification MIL-STD-1290A (Military Standard: Light fixed and Rotary-Wing Aircraft Crash Resistance) and based on the NH90 Weapon System Development Specification, updated by the Contract Product Specifications (CPS) of NH90.

General

For the two versions Tactical Transport Helicopter (TTH) and NATO Frigate Helicopter (NFH) there exist some differences regarding structure and landing gear. Crashworthiness requirements apply for TTH for extended and retracted landing gear, for NFH for retracted landing gear only.

Crash Conditions

In the beginning of development the standard NH90 helicopter was a 8.7t helicopter. This helicopter shall be crashworthy for the following impacts:

- with extended landing gear – TTH tactical transport helicopter only – with max. crash velocity of 11 m/s vertically
- with retracted landing gear – both TTH and NFH with max. crash velocity of 8m/s vertically

Due to required weight increase for the serial helicopter the impact speeds were adapted:

- with extended landing gear - a 9.45 t helicopter shall be crashworthy in a vertical crash with 10.6m/s impact velocity
- with retracted landing gear – a 9.45t helicopter shall be crashworthy in a vertical impact with 7.7 m/s

The helicopter shall also be able to crash within a 15° pitch angle and a 5° roll angle. Also sideward and forward impact velocity components apply. All these requirements strongly depend on the size of the involved impact velocity components.

Crashworthiness Requirements

Crashworthiness for occupants can be summarised as:

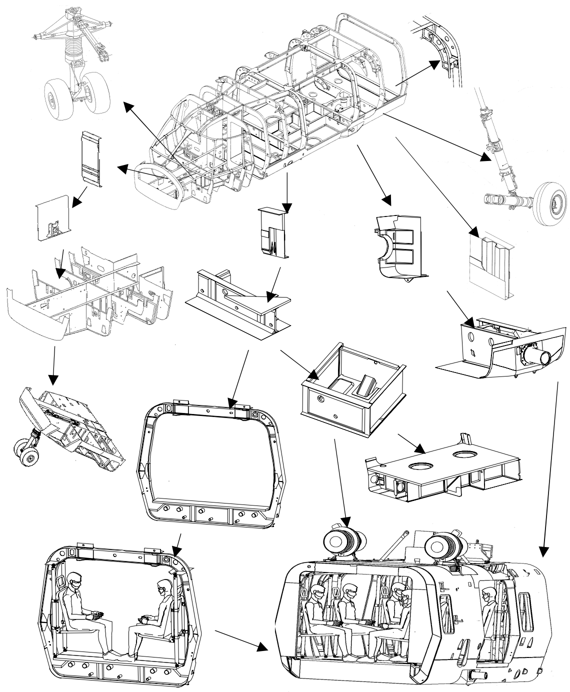
- Protection of occupants by reducing load factors to a tolerable level, at the same time providing crash energy absorption capability.
- Protection of occupants against a catastrophic failure of the structure as a consequence of heavy upper deck masses. These masses must be restrained and are not allowed to cause collapse of structure. The structure must protect occupants seated below.
- Protection of occupants against load, equipment or further masses, which could break lose and threaten occupants.
- Avoid a post-crash fire: The tank system must maintain tightness after crash.
- Occupants must be able to leave the fuselage after crash.

Crashworthiness Development Procedure

Pre-Design Phase

Early in the pre-development and development phase in the late 1980s simulations and parametric studies with the code KRASH concerning the global crash behaviour of the helicopter had been performed. At this stage the KRASH finite element model was a rather simple representation, but results of these simulations influenced the basic design of the structure and landing gear. In this way specific requirements regarding design capabilities were defined, e.g. values regarding energy absorption capabilities required in certain areas of the structure. Investigations of global kinematics, principal load distributions and load factors over time were done and had to be taken into account in the further design and development process.

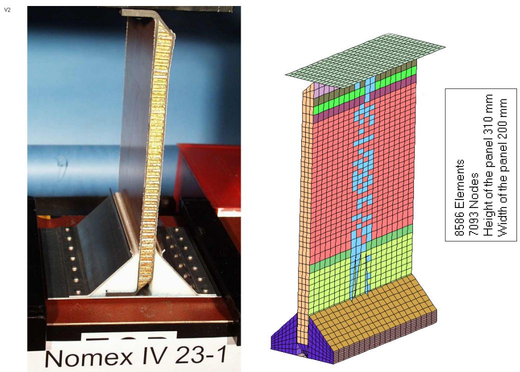
Development Tests



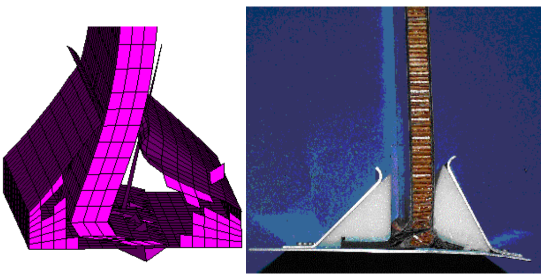
Pic.2: Tests: “Building Block Approach”

A complete test program regarding crash behaviour of crash relevant components had to be established: sub-floor structures, frames, landing loads introduction elements, landing gears, tanks, further special equipment necessary to provide crashworthiness. The most important elements out of the structural test program are represented in the “building block approach”:

- Specimen tests to establish energy absorbing capabilities of different structural designs, establishing repeatability of the crushing process



Pic.3: Specimen crash test and simulation



Pic.4: Specimen crash test and simulation

- Sub-component tests regarding special features as joints, load introduction brackets, hard points with integrated special crash features or structural components providing strength also under crash loads and crash conditions
- Sub-component tests of load limiting devices
- Component tests (tank environment, landing gear attachments, frames etc.) to check behaviour of the component regarding integrity as far as required, and/or to show crash energy absorption capability.

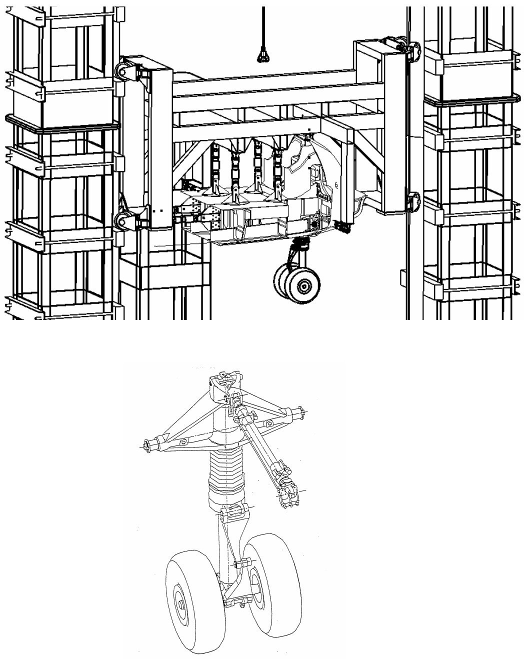
Pic.5: Component Crash Test: Frame 6

Qualification Tests

The final qualification crash tests are intensively prepared with the simulation tools. These tests are:

nose landing gear tests with the max. required vertical impact velocity, including crash relevant cockpit structure.

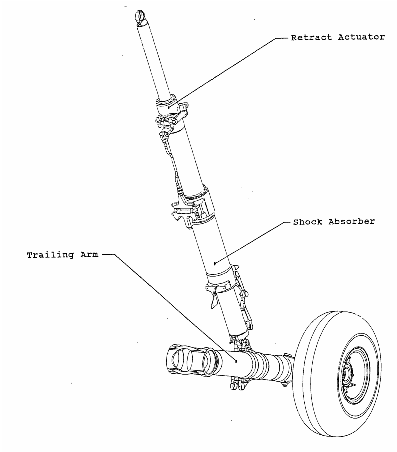
- Nose landing gear (NLG): a composite crash tube integrated into the nose landing gear limits loads and absorbs energy. In the end of the crash phase the nose landing gear retracts into the nose landing gear bay.



Pic.6: Nose Landing Gear Test

main landing gear tests with the max. required vertical impact speed

- Main landing gear: The hydraulic fluid of the retraction actuator penetrates an opening crash valve in the main landing gear, that limits loads and absorbs energy while retracting.



Pic.7: Main landing gear

Centre fuselage crash test with the max. required vertical impact speed with retracted landing gear:

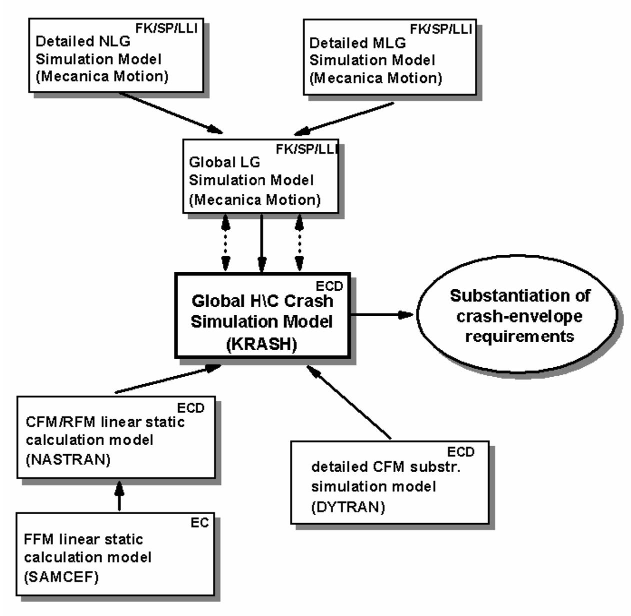
- crash test of the fully equipped centre fuselage module, representing a crash with retracted landing gear at max. required impact speed, as described in this paper.

Crash-Simulations

According to contract and specification requirements, the crash qualification is done by simulations, supported by tests.

By test only one specific crash condition can be tested. This is one singular case out of the required crash envelope, defined by parameters such as MTOW, velocities and angles. The envelope must be qualified by simulations. Tests of even a few points of this crash envelope alone do exclude themselves due to cost and time reasons.

A crash substantiation concept was developed by industry to describe the development logic and qualification procedure required for crashworthiness of NH90. Here the extent of simulations and the codes intended to be applied is described. The codes applied did depend on the specific experiences that different companies had with there specific helicopter components and computer codes. Computer codes used were KRASH, DYTRAN, RADIOSS and Mechanica Motion.



Pic.8: Simulation Models

Simulation Tools

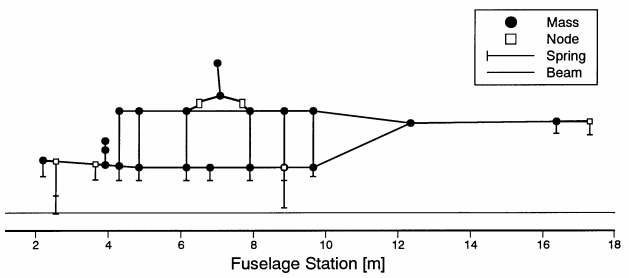
Main tasks of the simulation tools are:

- Global models:
  - to simulate the global behaviour of the helicopter
  - to study the influence of system parameters
  - to investigate critical crash conditions regarding load factors and structural loads
- more detailed component models:
  - to investigate components relevant for crash, e.g. landing gear, single frames, etc.
  - preparation of component crash tests
- very detailed sub-component models:
  - to investigate load introduction elements
  - to simulate triggers
  - to investigate load limiting devices

The following tools were used:

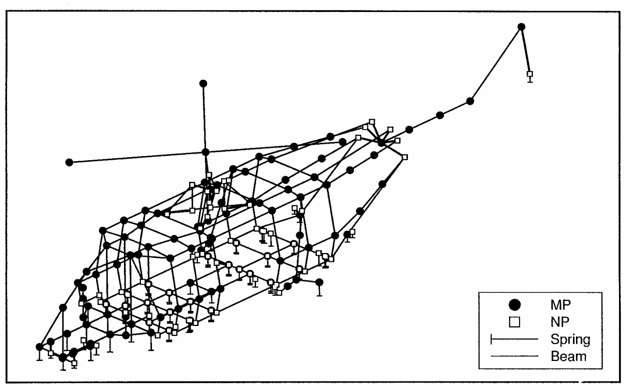
KRASH: is used for global model simulation. Main elements of this simulation tool are:

- mass points to describe mass distribution and inertias
- beam elements representing structural characteristics
- spring elements as contact elements to crash surfaces



Pic.9: Pre-development KRASH 2-d model

Pre-simulations had been done with a simple 2-dimensional model. During component testing main characteristics of this model were adapted and, if necessary, a redesign of certain crushable areas of the helicopter structure were performed.



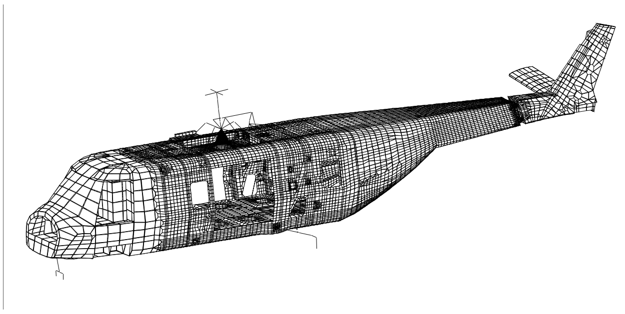
Pic.10: Current KRASH 3-d model

Leading up to qualification, the global KRASH model was significantly improved, by implementing more details at locations, where additional results were needed, improving mass distribution and calibrating spring characteristics according to test results. The KRASH beam-mass-spring model was verified by the now existing static NASTRAN model regarding stiffness and eigenforms.

DYTRAN: Since the global KRASH model can represent failure characteristics only by definition of the provided spring characteristics, failure modes and failure loads have to be known in advance. Since this is not the case for more complicated assemblies or components which can show strength or stability failures and not predictable failure propagation, a more detailed tool has to be applied.

DYTRAN

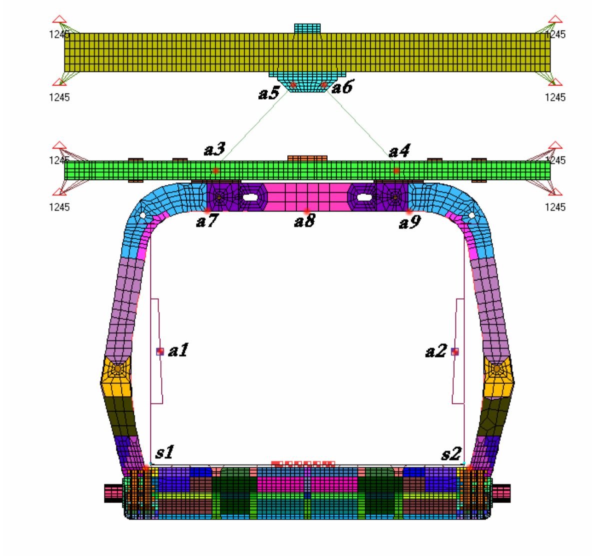
- regarding elements, nodes etc. this code incorporates similarities to the NASTRAN code. NASTRAN is used for NH90 fuselage static and dynamic analysis. The available detailed NASTRAN FE-model of the NH90 fuselage structure, already verified by tests, supported the application of DYTRAN.



Pic.11: NASTRAN FE-model

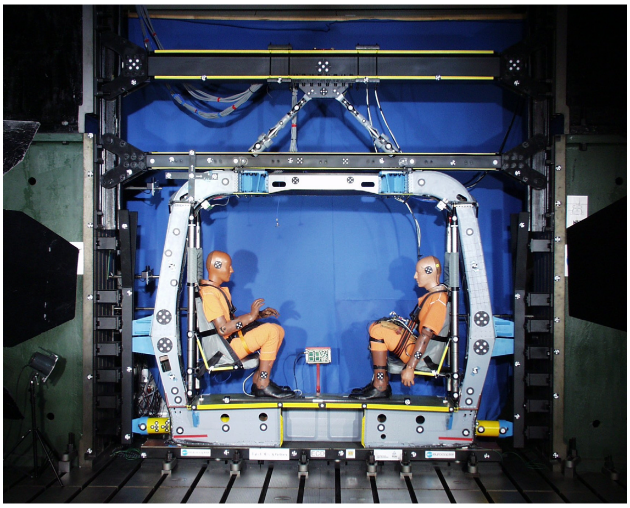
- includes also composite material properties and to a certain extent composite failure criterias, which enables stepwise degradation of material properties during crash simulations including internal load redistribution.

DYTRAN is used as a detailed model. In the beginning it was used to support frame wise the design of crashworthy frames, models were calibrated by frame drop tests. To prepare crash tests accurately, separate simulation models had to be created to investigate boundary conditions of tests and their influence on the test article and predicted test results.

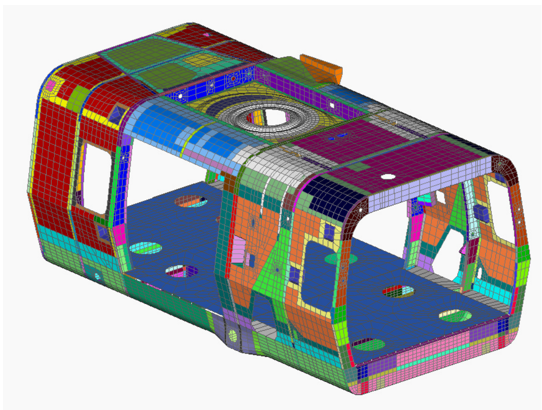


Pic.12: Frame crash test DYTRAN model

Pic.13: DYTRAN Frame crash test simulations



Pic.14: Frame crash test



Pic.15: DYTRAN FE model of centre fuselage crash test article

Later DYTRAN was used to prepare and confirm the crashworthy design of the centre fuselage module for crash test.

Further simulation tools used for NH90 are**:**

<u>Mechanica Motion</u>

- for a global helicopter tool to simulate landings and crashes regarding landing gear characteristics
- for separated detailed landing gear simulation models to investigate landing gear characteristics
- to prepare separate nose landing gear and main landing gear test over the whole landing and crash impact velocity envelope

<u>RADIOSS:</u>

- for detailed crash simulations of structural components in the cockpit fuselage module
- for detailed preparations of nose landing gear crash test including crash relevant structure of the cockpit fuselage module

<u>Centre Fuselage Module Test Definition</u>

Crash test qualification procedures were agreed by both the customer and industry. This agreement took into account industry experience, simulation abilities, cost of tests, schedule of development and delivery date of the serial helicopter.

These qualification tests include crash tests with the nose landing gear and main landing gear, and a structure crash test of the centre module of the fuselage. This centre module is one of the most important parts of the fuselage, since it

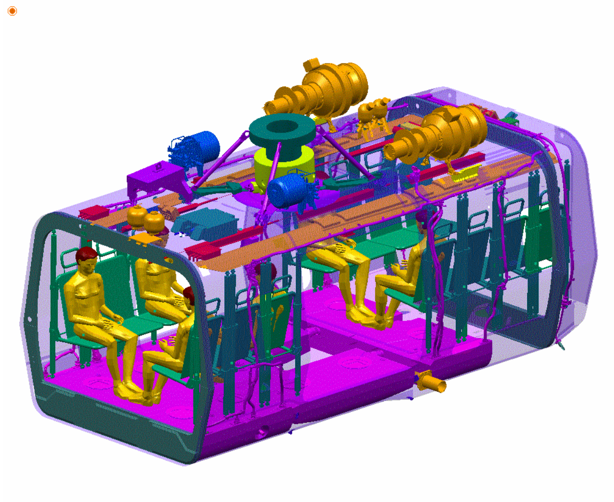
- includes the 14 occupants with their crashworthy troop seats
- Supports all the heavy upper deck masses
- Includes the tank in the sub-floor area of the fuselage and at the same time provides a crushable zone in the sub-floor area

The centre fuselage module was tested for practical reasons without landing gear, such representing crash conditions either with retracted landing gear or representing the crash phase after energy absorption by the extended landing gear. This means a fuselage impacting the ground. The fuselage impact phase being the more critical phase for the occupants, since this phase contributes much higher load factors and requires more special load limiting and energy absorbing devices compared to the landing gear crash phase.

The centre fuselage crash test done for NH90 covers both helicopter versions TTH and NFH, since a crash with retracted landing gear applies for both. All the components and systems of the fuselage, relevant for crashworthiness, as fuselage structure, tank system and seats are almost identical.

Description of Test Article

The Test article is the centre fuselage module of NH90, including the full area of the sub-floor with the complete tank-system, including all upper deck mass items of significance, and including all occupant seats.

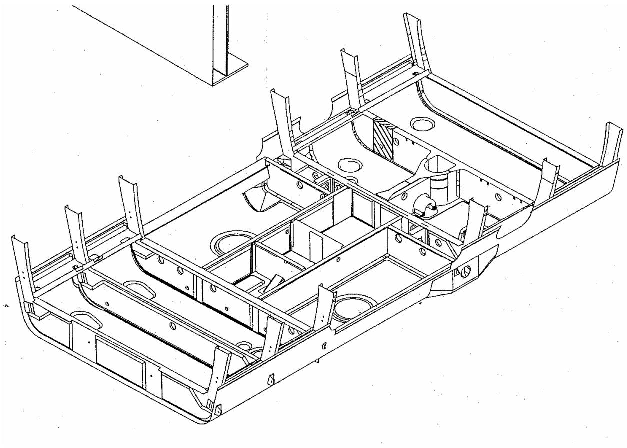


Pic.16: Centre fuselage Module for Crash Test

Fuselage Structure

The fuselage structure of NH90 consists of monolithic CFRP frames, CFRP/NOMEX sandwich shells, an aluminium sandwich cabin floor, and metallic load introduction brackets.
Regarding crashworthiness the fuselage incorporates two main characteristics:

- The fuselage provides a crash zone in the sub-floor area to limit loads and a sufficient stroke
- The sub-floor part of the frames is a sandwich design with triggers and energy absorption capability
- The pintle axle, integrated into the sub-floor structure, represents a hard point in the crash zone and is capable of moving upwards during the impact of the fuselage structure

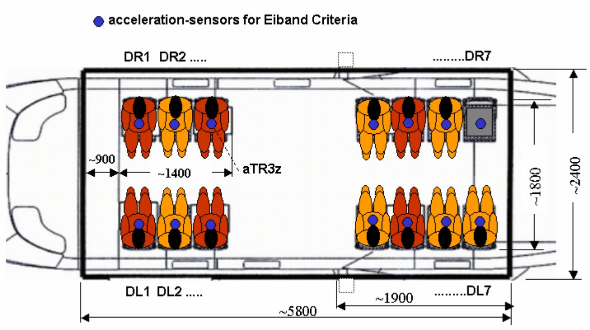


Pic.17: sub-floor structure

- Fuselage structure above floor level must keep its integrity providing protection for occupants in the cabin by supporting the upper deck masses and providing sufficient strength for troop seat connections

Troop Seats

In case of crash troop seats must resist the occurring loads without failing. Seats incorporate an energy attenuation device, which limits loads in vertical direction to a load level, survivable by occupants. Further load components will be sustained by the four point 4-point-safety belt system.



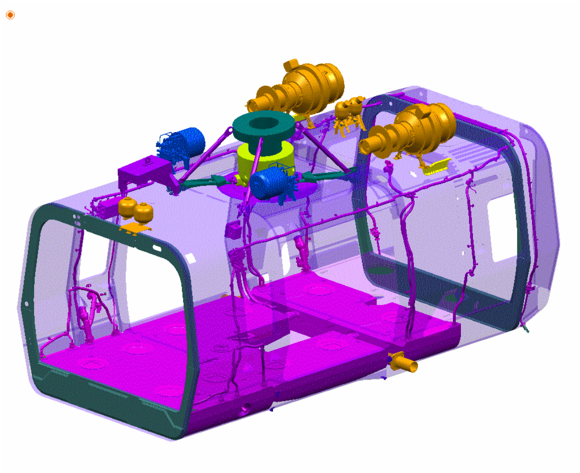
Pic.18: location of 6 Hybrid II person dummies

Pic.19: Person dummies in test article

The stroke of all seats was measured before and after the test. The troops were represented by 13 person dummies (originally planned 14 person dummies), 6 of which equipped with accelerometers (Hybrid II dark in the picture). One pure-mass dummy of 80kg was installed on the aft right seat, to enable the opitcal monitoring of frame 11, otherwise the person dummy would have covered frame 11.
Accelerometers were located below all seat pans for Eiband measurements.
14 fully crashworthy seats were installed in the CTA..

Tank System

The tightness of the tank system and avoidance of a post crash fire to ensure safe evacuation for occupants are the basic requirements for the tank system regarding crashworthiness. Also as a consequence of crashworthiness requirements the tank system developed to a complicated system. 7 to 8 crashworthy tank bladders are located below the cabin floor and in-between the structural sub-floor frames of the helicopter structure.



Pic.20: tank system

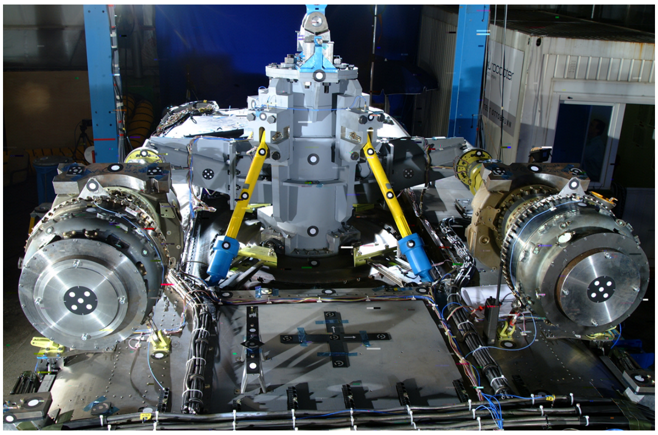
The main elements of the tank system are the flexible tank bladders, tested according MIL requirements in separate drop tests together with the original composite structure, to demonstrate tightness also in the real environment. Flexible tubes allowing movement of the bladders with respect to each other including special shut off valves and blocking connections in case of a leak.

The tank system was filled with water to an extent representing the take-off mass for a defined standard transport mission.

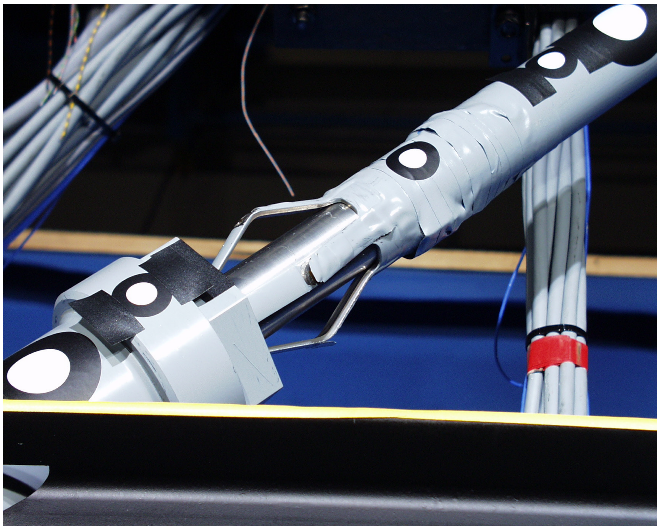
Masses

The following masses were represented:

- APU mass dummy with serial attachment
- MGB mass dummy with serial MGB struts, including load limiters



Pic.21.: upper deck masses and MGB struts

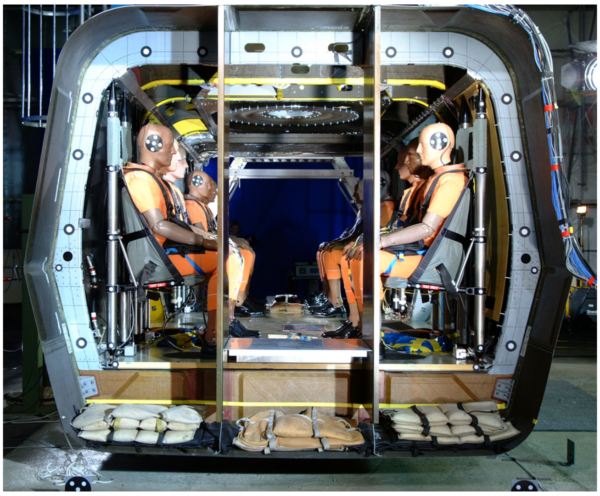


Pic.22.: MGB struts with load limiter activated

- Fire extinguisher mass dummy
- Engines represented by dummy engines with housings close to reality with an internal mass dummy
- Engine dummy installation with gimbal joint, torque tube, and engine struts close to serial status
- Further smaller upper deck masses of structure (cowlings, fire walls,..) and equipment (cables etc.) were represented by simple masses

Further masses were integrated into the test article:

- Masses of fuselage rear module and cockpit module, acting on the energy absorbing capability of the sub-floor structure, had to be taken into account
- Balancing masses had to be located on the bottom shell, thus not influencing crash test results



Pic.23: balancing masses on bottom shell

<u>Crash Test Conditions</u>

The qualification test done with the centre fuselage module had two main objectives:

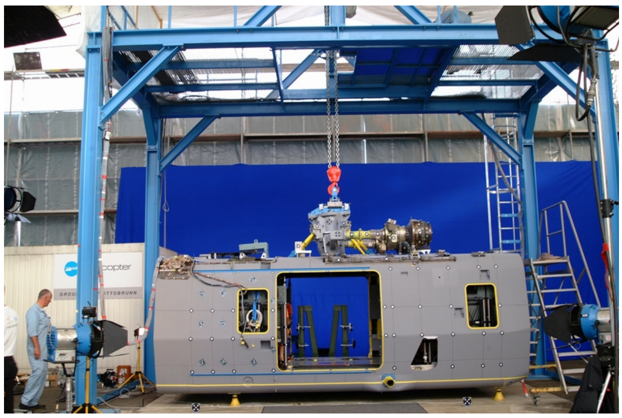
- Verify (and calibrate) the simulation model, intended for qualification of the whole crash envelope of the helicopter
- Show compliance with success criteria, defined for this qualification test

Since it was already decided, to test the centre fuselage module alone, excluding cockpit module, rear module and landing gears, the configuration of the centre fuselage module for crash test was defined:

- The test article represented the centre fuselage module
- For stability reasons a limited dummy structure of cockpit module and rear module were attached
- Full upper deck mass representation by dummy masses or dummies (e.g. engine dummies)
- Fuel system had been integrated as far as tightness was concerned
- Fuel mass to be filled into the sub-floor tanks: it was decided to test the worst case, this means max. mission fuel mass, represented by water
- Troops and troop seats: according to a defined transport mission 14 crashworthy troop seats with dummies were placed inside the cabin
- Lift, not introduced into test, had been taken into account by definition of main gear box dummy mass

Impact conditions for the crash test were defined:

- According to our reference NH90 helicopter with a MTOW of 9.45t the resulting mass of the centre fuselage module was 6.3 tons.
- In case of a crash with extended landing gear the LG will reduce the impact velocity of a 9.45t helicopter from 10.6m/s to approximately 7.7m/s. This speed was applied in the test.
- The same speed applies for a crash with retracted landing gear. The 7.7m/s vertical impact velocity corresponds to a drop height of 3m.
- To ensure comparability with simulation models, a pure vertical impact was done.
- A special rig had been designed to provide the prescribed test conditions. A crane was included to be able to lift the test article to the required drop height.



Pic.24: Test article and rig

Pre-Test Simulations

The impact speed out of the requirements was directly applied to the test. The defined helicopter weight is valid for the complete helicopter including cockpit, rear etc. and had to be adapted to the test article. Since the serial configuration was known, according to this configuration the test article was equipped.

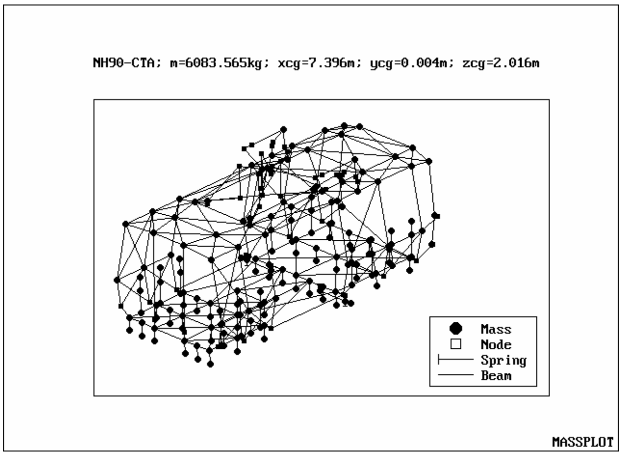
Verifying Test Set-up: Differences in-between real crash conditions and this test set-up had to be taken into account through pre-test simulations:

- Influence of lift L/W=1: lift was not applied in the crash test. The influence of missing lift had to be taken into account by reduction of masses.
- Influence of masses of cockpit fuselage module and rear fuselage module: these modules including equipment were not attached in this test, but kinetic energy of part of these masses is absorbed by the sub-floor structure of the centre fuselage.

These simulations were done with the KRASH simulation model. A model of the complete helicopter without landing gear, but pintle axle included in the sub-floor area, was directly compared to a model representing the centre fuselage module as to be prepared for the test. This model contained:

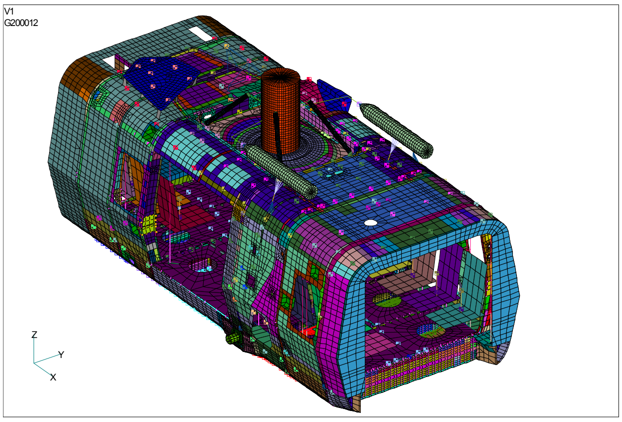
- 189 node points with mass points
- 59 node points alone
- 362 internal beams
- 43 external springs

Some results of these simulations had to be tuned, especially loads of frame, loads and strokes of main gear box load limiters, strokes of sub-floor structure. This tuning was done by applying/reducing masses accordingly.



Pic.25: KRASH FE-model of Centre Fuselage Module

Detailed Check of Risks: A detailed DYTRAN model of the centre fuselage was used, to define the structural components during design process. The same tool was used, to simulate the centre fuselage for the intended drop test. Influence of masses in the tank area, inside cabin area, upper deck area were studied in detail.



Pic.26: DYTRAN-FE model of Centre Fuselage Module

According to characteristics of DYTRAN simulation results for the composite material, areas of failure could be clearly identified. Also areas of instability could be identified. The difficulty is, to predict the behaviour of the whole structure after failure of the stiff and brittle material under a highly dynamic load distribution, as it occurs during crash due to the impact impulse and loads introduced by sudden ruptures and failures. Thus the prediction of the behaviour of this structure after the identified failure or instability phenomenon is difficult and not conclusive.

Risk Assessment

These risks were compiled in a risk table, possible consequences of these risks were deduced and evaluated according to the survivability of the occupants and the success criteria defined in co-operation with customer and officials. Examples of these risks are:

- dynamic torsion movement of frames during impact. It could not be clearly predicted whether these frames would fail in way catastrophic for the fuselage and occupants or not. The risk assessment produced a decision to improve the design for principle load carrying frames to reduce this torsion deflection.
- High peak loads resulting from highly dynamic movements of engines and drive shafts connecting engines to main gear box and causing high peak loads on frames. These highly dynamic movements resulted from a unsymmetrical fuselage stiffness supporting

these components. The introduction of a special load limiter, intended to limit peak loads resulting from these predicted movements, was decided.

Measurements

Measurements done during the crash test had three main intentions:

- document possible occurrence and data of unexpected failure, to enable later analysis of failure reason
- document data, necessary to meet success criteria harmonised with customer/officials
- document data to verify and calibrate simulation models

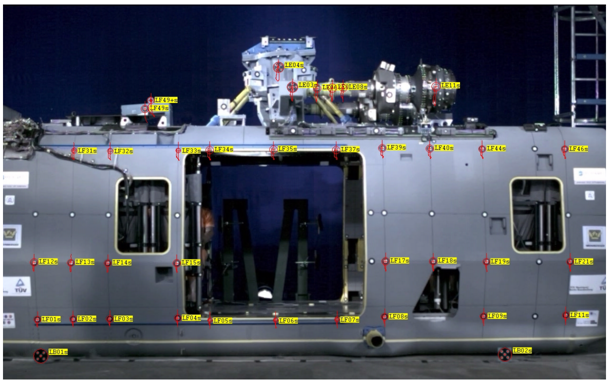
Detailed Measurements

Measurements done:

- strains over time
  - on structural components as frames, shells, etc.
  - on load introduction elements as MGB struts, brackets of upper deck masses representing APU, engines etc.
  - on seat poles of troop seats
- accelerometers
  - on masses of the upper deck
  - all 14 seat pans of troop seats according to Eiband criterion evaluation
  - 6 out of 14 person dummies (Hybrid II) equipped with 3 uniaxial accelerations in 3 locations of the dummy and with spine force measurements (Hybrid II)
- displacement measurements
  - stroke of seat pans
  - stroke of upper deck load limiter
  - measurements on sliding door cut-out
  - measurements of cabin volume
  - torsion movement of frames (torsion stability) with displacement of inner flange
- impact velocity
- pressure measurements on structural contact surfaces to tank bladders

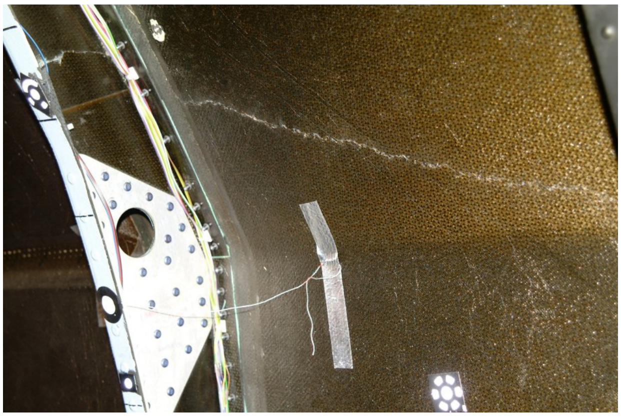
Measurement techniques used:

- optical markers for 3 dimensional digital motion analysis on all points of possible interest. These points could be, if required, selected after the test and postprocessed with respect to displacement, velocity and accelerations. This method had been used before with component crash tests with good experience. Results of accelerometers and optical measurements could be compared in some suitable locations.



Pic.27: markers for digital motion analysis

- Photogrammetry measurements
- devices to mechanically measure deflections in selected locations, e.g. by string measurement technique



Pic.28: String measurement technique

- 12 colour high speed cameras (2000 pictures per second)
- pressure measurements in tanks through folios

Success Criteria

Before the test a set of criteria to be measured or to be clearly observed were defined.

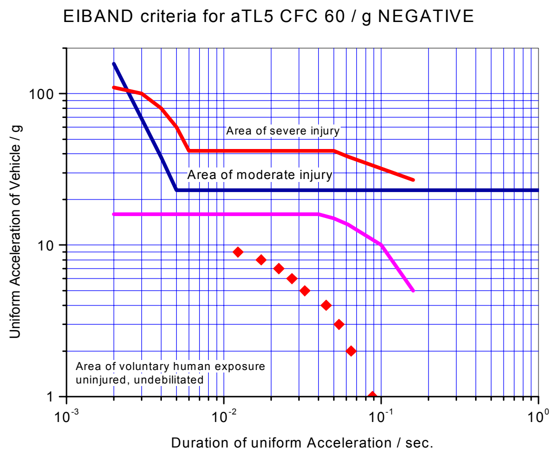
Definition of Success Criteria

- no moving masses that could pose a hazard to passengers (upper deck masses, equipment)
- survivability according to load factor limitations for passengers given by Eiband diagrams
- no leakage of fuel
- functionality of troop seat and fuselage interface
- no uncontrollable behaviour of pintle axle (hard point)
- volume of cabin not to be reduced by more than 15%

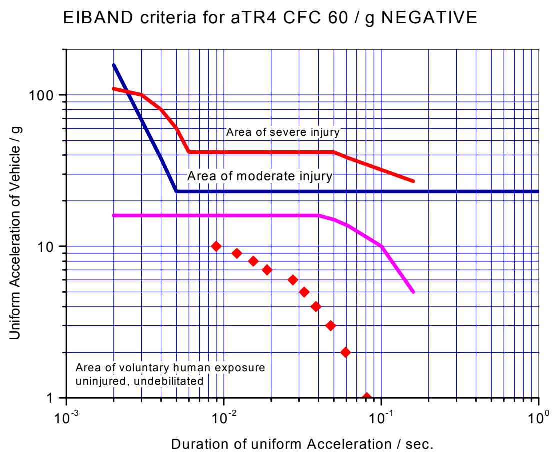
Evaluation of Success Criteria after Test

no endanger of passengers by moving masses (upper deck masses, equipment)
No failure of mass attachments had been observed and no upper deck mass penetrated the structure into the cabin

survivability according to load factor limitations for passengers given by Eiband diagrams
The objective was to stay below the area of severe injury. As can be seen in the figures the measurement data stays inside the area of voluntary human exposure of test persons, uninjured. The area of moderate injury is not even touched.



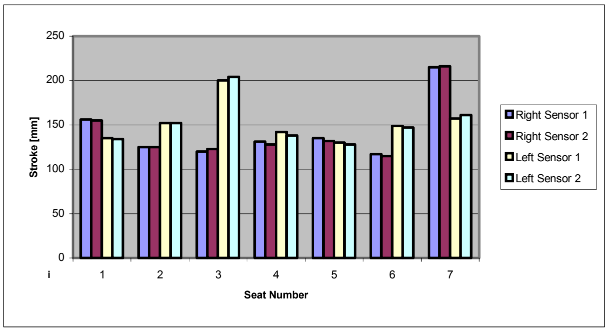
Pic.29: Eiband Diagram of a Person Dummy



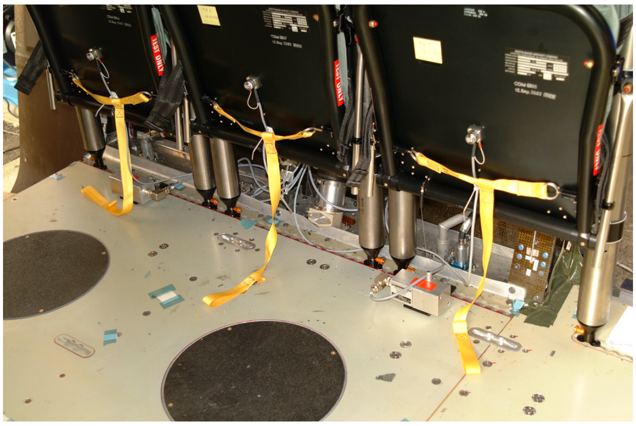
Pic.30: Eiband Diagram of a Person Dummy

The data acquired from the especially equipped dummies (Hybrid II) was used to compare the lumbar spine force with the requirements for civil helicopters. The maximum measured spine force value was –5.7 kN, max. allowed by civil regulations JAR/FAR 27.562 is –6.68 kN.

Functionality of troop seat and fuselage interfaces:
All seat strokes are inside the provided range:
The maximum seat stroke is approx. 220mm for the seat loaded by the 80kg mass alone, seats loaded with person dummies show max. strokes of about 200mm, average is about 150mm. The available seat stroke for troop seats is around 300mm. It can be noted that 80 kg concentrated mass has larger concentrated effect on seat stroke.



Pic.31: max. seat strokes measured



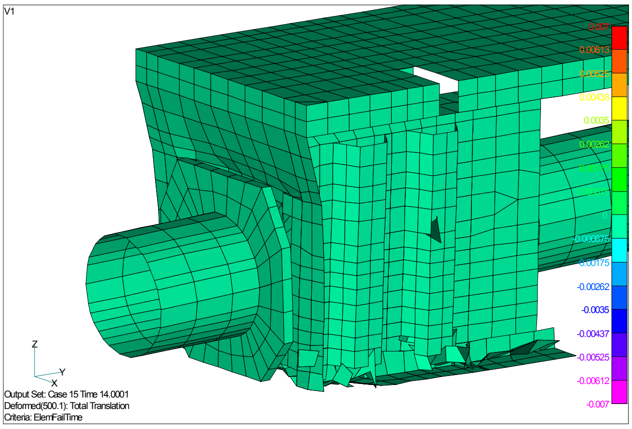
Pic.32: No damage was found in the interface between the seat poles and the floor panel

no leakage of fuel: A small volume of water leaked from the tanks directly after the test. This was caused by a misplaced seal in one dump valve. 9 more valves identical to the failed one had been installed and worked properly without leakage.

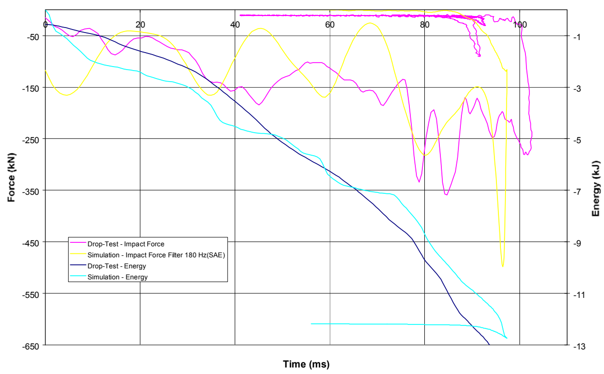
No uncontrollable behaviour of pintle axle (hard point): It was predicted by simulations that the capability of the pintle axle to move upwards would not be necessary for the crash conditions of this test. This capability had been demonstrated by a separate component crash test.

Pic.33: Pintle Axle after test: available stroke below was sufficient

Also this special feature had been prepared during development process by separate tests and simulations. The simulation especially done for the test shows relative good agreement of the impact force over time and the derived energy absorbed in simualtion and test.

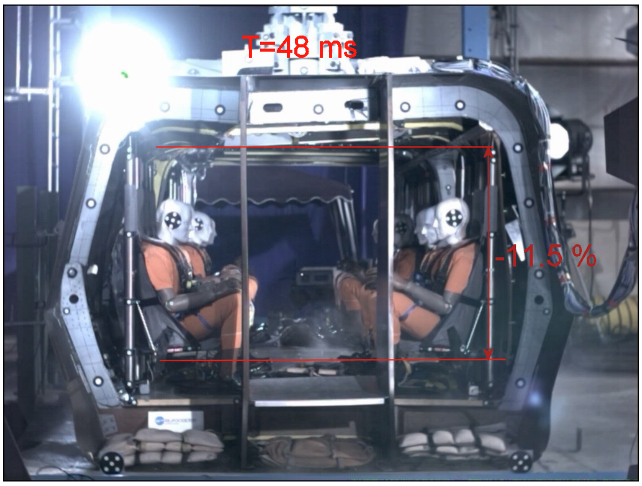


Pic.34: Pintle Axle crash simulation



Pic.35: Comparison of loads: test and simulation. Upper two curves: impact load. Lower two curves: absorbed energy.

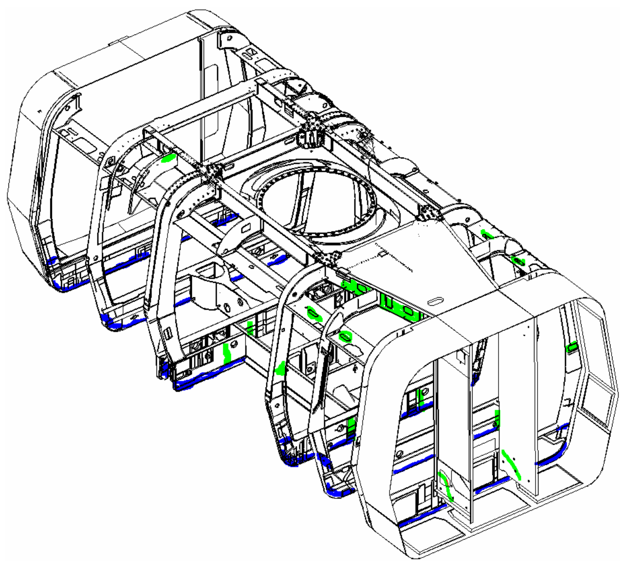
volume of cabin not to be reduced by more than 15%: According to measurements, done out of the high speed pictures, this limit was by far not reached.



Pic.36: cabin volume reduction measurement

Damage assessment: A damage assessment was done after the test. Two groups of damage were observed:

- intended respectively expected damages (marked in blue)
- damages not to be avoided, but not intended (green)



Pic.37: damage assessment after test

The first group of damages had to take place, otherwise the intended crash sequence and load level of cabin structure would not have provided the required parameters characterising crashworthiness. The intended damage occurred in the crushing zone of sub-floor frames.

Pic.38: Damages in sub-floor frames energy absorbing zone

Intended cracks in the lower frame corners were observed. These cracks result from the outer downward deflection of the cabin floor (aluminium sandwich) and have to occur, not to introduce additional moments in the highly loaded frames. To hold such cracked frames in place, additionally crack stoppers had been introduced to guide the frame and enable further z-load transfer and protection of occupants against upper deck masses.

Pic.39: Crack and crack stopper in lower frame corner

Conclusion

NH90 crash development experience shows: an extensive number of crash tests is necessary to develop and confirm crashworthiness. Simulation reduces the amount of testing but will not altogether replace it.

A test is carried out in a few seconds, but requires months of preparation. Measurements and high speed films can not cover all possible aspects and information required, when something goes wrong. With a crash test only one crash condition can be tested, further conditions must be covered by simulations.

Thus only simulations can provide predictions on the crash requirement envelope. Simulations are necessary to do parametric studies, define the global design of a helicopter, prepare tests. It is prerequisite that simulation models are calibrated and confirmed by tests. Depending on the quality of the simulation tool and the experience with this tool, a risk assessment of crash behavior can be done. It is extremely difficult to predict the consequences of a global failure with the applied simulation tools, it is possible to identify risks and risk areas and to minimize those risks by introducing design modifications.

In case of NH90 centre fuselage module crash test these pre-simulations including risk assessment have been done successfully. In spite of some unexpected local failures a global catastrophic failure was excluded. The test confirmed the crashworthy design of the NH90 fuselage.

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