Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

NLR-TP-2002-110

Increasing the survivability of helicopter accidents over water

L.C. Ubels and J.F.M. Wiggenraad

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2002-110

Increasing the survivability of helicopter accidents over water

L.C. Ubels and J.F.M. Wiggenraad

This report is based on a presentation held at the First European Workshop on Survivability, at Air Base Cologne-Wahn (Germany) on 26-28 February 2002.

The work has been executed partly as part of NLR's Basic Research programme.

Customer:	National Aerospace Laboratory NLR
Working Plan number:	S.1.A.3
Owner:	National Aerospace Laboratory NLR
Division:	Structures and Materials
Distribution:	Unlimited
Classification title:	Unclassified
	February 2002

Contents

Abstract 3

1 Introduction 3
1.1 Water impact 4

2 Tensor-skin concept 5
2.1 Introduction 5
2.2 Dynamic impact tests on tensor-skin panels 7

3 Crashworthy helicopter sub-floor structures 8
3.1 Sine-wave beams 8
3.2 Dynamic impact test on sub-floor box 9

4 An example: a crashworthy commuter structure 10
4.1 Dynamic testing at CEAT (Centre d'Essais Aeronautique de Toulouse) 11

5 Conclusions 13

6 References 13

13 Figures

(13 pages in total)

INCREASING THE SURVIVABILITY OF HELICOPTER ACCIDENTS OVER WATER

L.C. Ubels and J.F.M. Wiggenraad

National Aerospace Laboratory NLR
Voorsterweg 31
8316 PR Marknesse
The Netherlands
Email: ubels@nlr.nl / wigg@nlr.nl

Abstract
Many aircraft accidents are potentially survivable, because they take place at low velocities and at low height. This applies in particular for helicopters. Hence, an increase in survivability of helicopter accidents has been pursued for the last two decades, especially by the military, by requiring an increased crashworthiness of these vehicles. These requirements were formulated in MIL STD-1290. The structural solution has been found in a combination of energy absorption mechanisms in the landing gear, the sub-floor structure and the seats. Since a few years, the MIL-STD requirements have been released, and safety requirements are now part of a trade-off process with performance and cost.
In recent years, it has been noticed that the structural solutions developed to obtain sufficient crashworthiness of helicopters over land, do not fully apply to accidents over water. It is clear that, for instance, the landing gear will not function as a crash absorber in such accidents. Also, the sub-floor structure might fail in a different mode, bypassing the intended energy absorption mechanism. Since a few years, the US Navy supports a research programme to study this crash scenario.
NLR has been working on a novel concept to compensate for the decreased crashworthiness of helicopters over water: the development of a structural concept for sub-floor structures, which have a better chance of surviving impacts on water. This concept is based on energy-absorbing sine-wave beams and a new skin panel configuration: the tensor-skin panel. This panel will not fracture but deploy during a water impact, and will be able to transfer impact loads to the sub-structure which is intended to absorb the energy. The presentation will illustrate the development of this concept, and the future prospects.

1 Introduction

Looking at helicopters accidents in the last 18 year, there is a rather high number of water impacts. In the UK, 25% of the helicopter accidents were related to water impacts or forced landings on water. In the US, 11% of the accidents were water impacts (ref. 1).

A water impact is a severe crash scenario. Looking at the occupants, 29% of the injuries were fatal and 10% were serious. Even when drowning is considered, this could be the consequence of worse crash behaviour of the structure. There is no significant decrease in fatal injuries, when the last ten years are compared with the period 1982-1990.

Improvements of the crash characteristics of the sub-floor structure of a helicopter fuselage are needed to reduce the number of injuries. The current sub-floor structures and landing gears do not operate well in water impact conditions.

Most energy absorbing mechanisms in helicopter structures are based on impact on land. During an impact on land the crash energy will be absorbed by the landing gear, the occupant seats and the sub-floor structure (fig. 1a).

In the future, the use of fibre-reinforced composite material in helicopters will increase. In this respect, NLR has participated in a range of European research projects to develop several energy-absorbing concepts for sub-floor structures of composites. These projects focused on prediction techniques, on crashworthy sub-floor structures in CRASURV (ref. 2), on fuselage concepts for helicopter crashes on water (CAST, ref. 1) and on high velocity impact on composite aircraft structures (CRAHVI, ref. 3).

1.1 Water impact

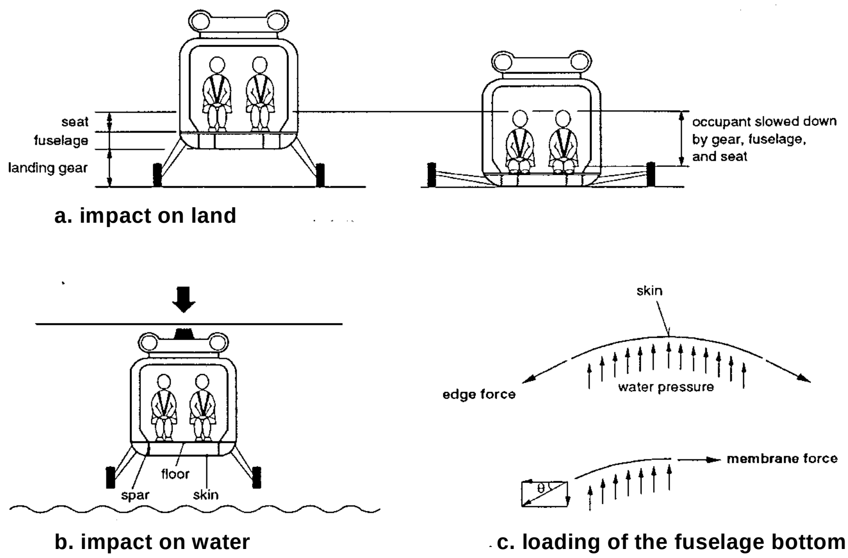

Figure 1 Loading of a sub-floor during water impact

During a water impact the landing gear will absorb little or no crash energy. Most of the crash energy has to be absorbed by the sub-floor structure (fig. 1b-c). During a water impact it is important that the outer skin should not fail. A skin panel does not absorb a large amount of crash energy, but failure of the skin would cause a direct loading of the floor and the occupants seats.

Secondly, when a water impact has a rather large forward velocity, skin rupture would cause large decelerations. It is important to prevent skin failure, because the skin is needed to load the beams in the sub-floor structure. The beams of a sub-floor absorb the largest amount of crash energy (fig. 2).

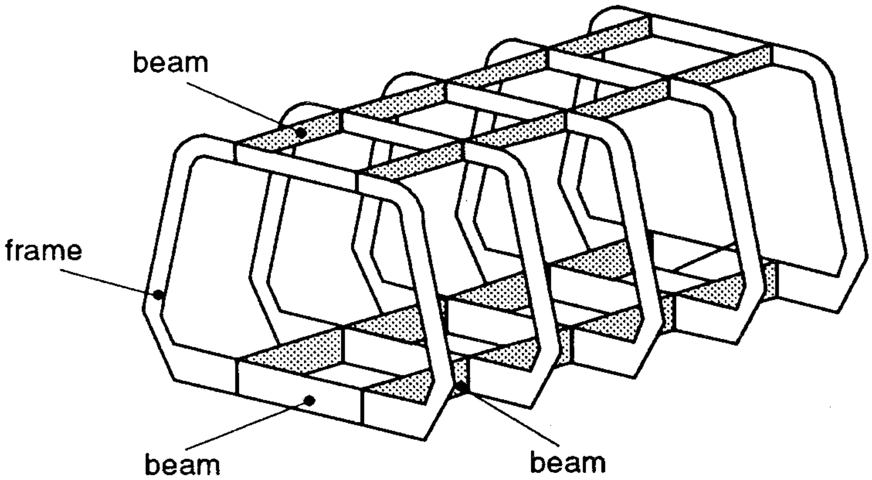

Figure 2 Helicopter structure

2 Tensor-skin concept

2.1 Introduction

Most composite materials have a low failure strain. Therefore, they are limited in their capability to sustain and transfer the pressure loads during a water impact.
Load transfer to the beams of a sub-floor is only possible if the skin is able to withstand a large deflection during the water impact. This mechanism can be achieved with a ductile material, but not with a brittle composite. Before the deflection of the skin panel is sufficient to load the beams of the sub-floor, the composite skin already failed because the maximum failure strain was reached.

The NLR developed a concept which is based on a composite skin (ref. 4). The skin can unfold and deflect before the membrame forces build up and then load the beams of the sub-floor. The concept uses the Poly-Ethylene fabric Dyneema. The fabric is impregnated with epoxy resin. After testing several composite materials and reinforcements, Poly-Ethylene was the only reinforcement which was able to withstand the large deformations without fibre breakage.

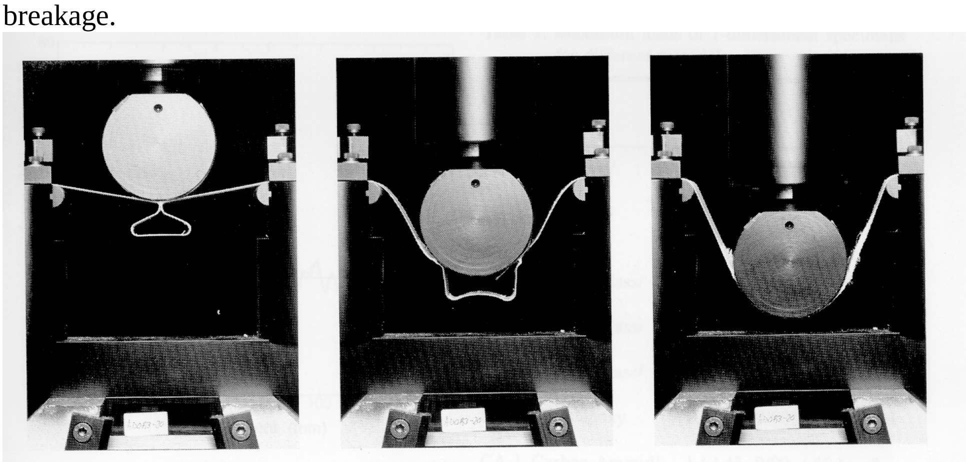

Figure 3 Testing of 1-dimensional tensor-skin specimen made of Dyneema

The development started with “unfolding” tests to study the behaviour of different geometries and materials. These tests were performed on simple strip specimens with a one-dimensional loop (fig. 3). The next step was the development of a two-dimensional plate specimen, with tensor loops in two directions.

The Poly-Ethylene (PE) fabric has limited mechanical properties and should be applied in combination with other materials. An obvious combination for a helicopter skin panel is a sandwich structure. A PE core was combined with two composite faces of aramid epoxy and aramid/carbon epoxy (fig. 4).

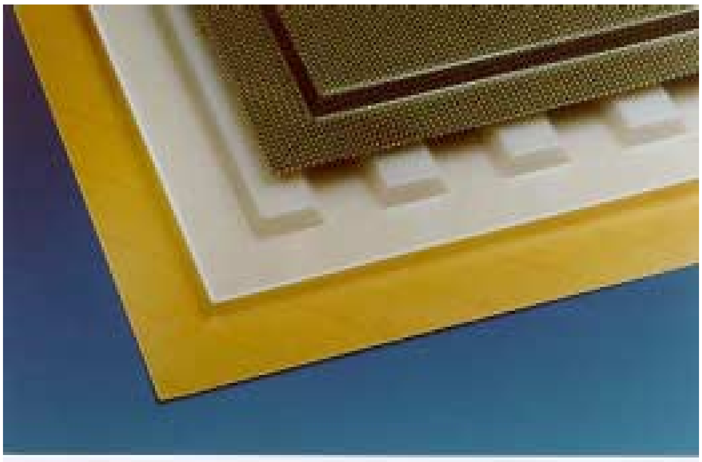

Figure 4 Lay-up of a tensor-skin panel

The core is a corrugated plate, made of PE-fabric and embedded in epoxy resin. It is a single core, with the fold in one direction. Testing of this one-dimensional configuration showed that the deflection in the opposite direction was sufficient to load the beams of a sub-floor.

During normal operation, a skin panel of a helicopter is mainly loaded in in-plane shear. In-plane shear tests on NLR’s tensor-skin panels showed that the panels are able to carry structural loads (fig. 5, ref. 5).

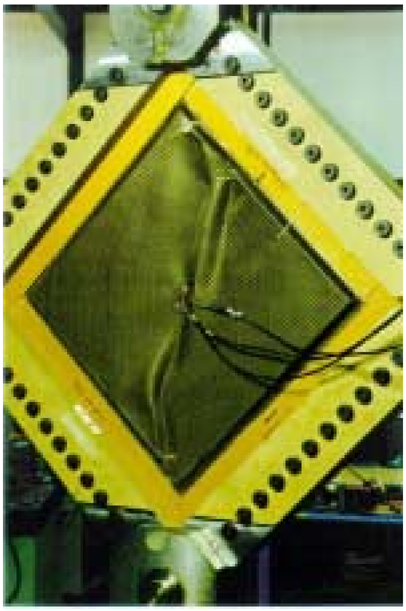

Figure 5 In-plane shear test on tensor-skin panel

2.2 Dynamic impact tests on tensor-skin panels

In three specimens different core configurations have been realised. While one of the specimens was built with a conventional sandwich design with a 16 mm thick Nomex honeycomb core, two other panels were made using a corrugated core made of Dyneema layers.

In one specimen this core was made of two layers of Dyneema fabric and in the other tensor-skin specimen, a thicker core with three layers of the same material has been used.

The dynamic tests on the tensor skin panels were performed in DLR's drop tower facility (DLR is the German aeronautical research institute). The skin panels were fixed in a very stiff steel test frame. This frame was fixed in the centre of the load-reaction platform of the drop tower. A hemispherical impact head with a radius of 150 mm (fig. 6) was fixed to a lightweight steel frame which is guided on either sides of the drop tower (ref. 6).

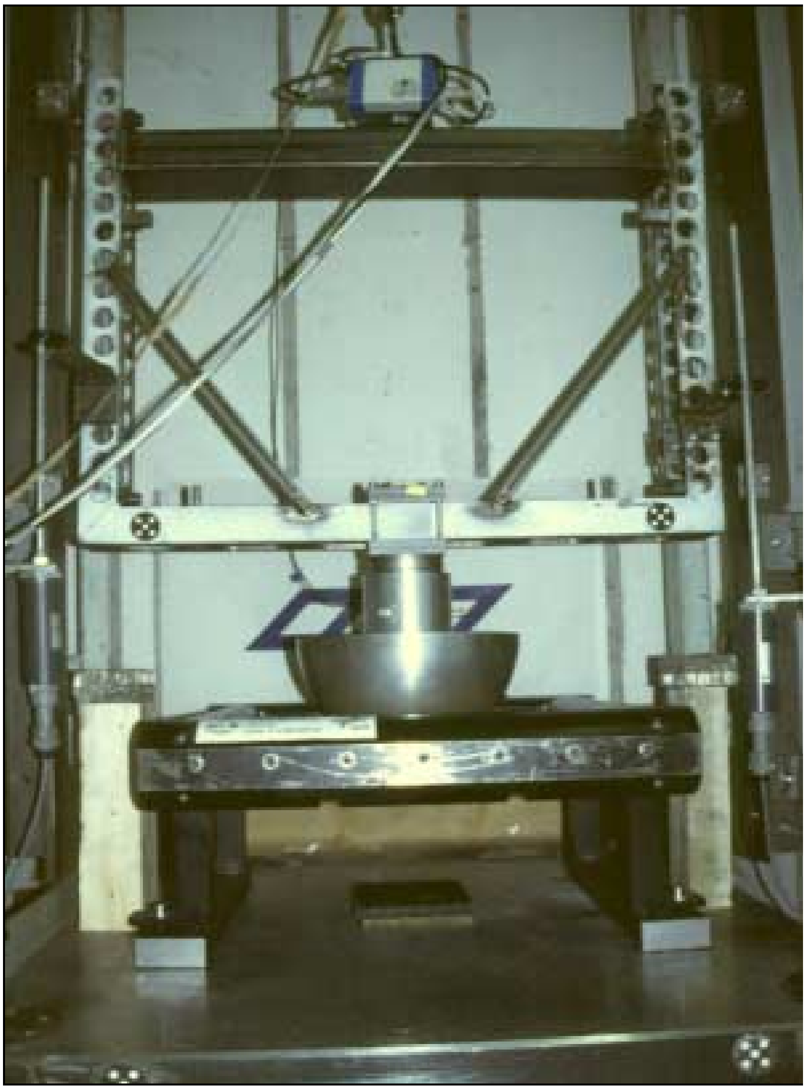

Figure 6 Test-frame and impact-head in DLR's drop tower

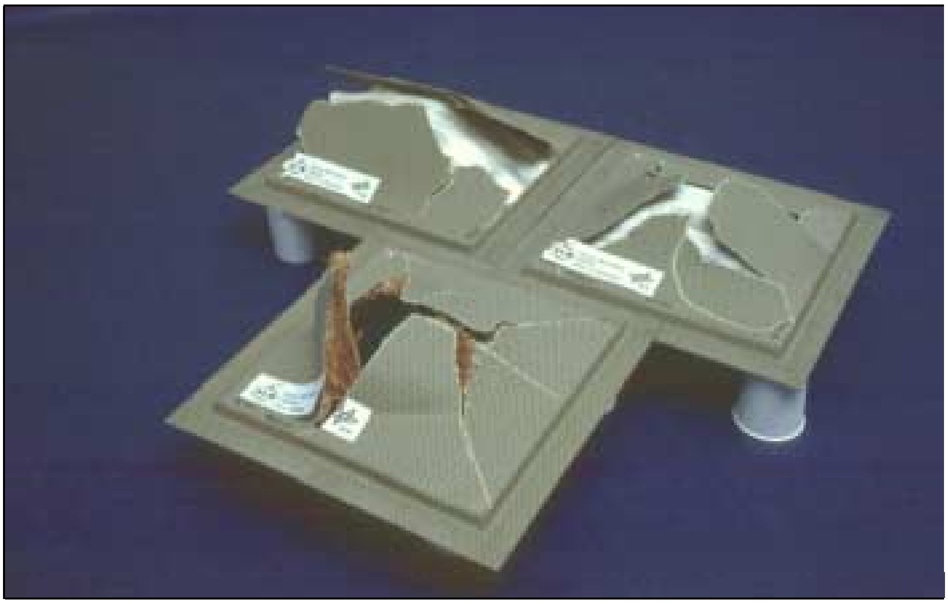
Figure 7 Tensor-skin panels after dynamic impact test (DLR)

In figure 7, the three panels are shown together. The largest damage was found in specimen with the conventional sandwich design (foreground). The two panels with the corrugated Dyneema core looked similar with the exception of the core failure in the tensor-skin panel with the two-layer Dyneema core (background, left). The deformation of this panel was larger than in the tensor-skin specimen with the three-layer core and therefore the fracture might be caused by geometric constrains (stretching of the Dyneema core).

Evaluation of the results shows that the configuration with three layers of Dyneema (background, right) in the core gives the best results. In this test the maximum energy absorption was combined with the smallest total deflection.

3 Crashworthy helicopter sub-floor structures

3.1 Sine-wave beams

The sine-wave beam concept has been shown to be very well suited for absorbing energy during a crash, while it is fairly efficient in carrying the shear and bending loads during normal flights. The sine-waves in combination with the tensor skins, could be a crashworthy concept for the sub-floor structure of a helicopter in case of impact on water (fig. 8).

Within the framework of the Brite Euram programme CRASURV, and based on sine-wave crush studies (ref. 7), a generic sub-floor structure was developed consisting of sine-waves attached to each other by cruciforms. In a typical helicopter subfloor structure, a hard point is formed by the connection between the longitudinal beams and the lateral frames. During a crash, such hard points result in a high peak load to the structure and could injure the occupants. Therefore it is important to reduce the stiffness of this connection. Using specially shaped angle brackets to form this connection can do this.

The longitudinal and transverse sine-wave beams were connected by cruciforms (fig. 8) from the same material. The cruciforms were not designed to absorb large amounts of energy; they were designed to be soft in compression and maintain only stability between the sine wave beams.

The sub-floor boxes were designed to absorb the impact energy by crushing of the energy absorbing sine-wave beams. The beams were fabricated from carbon-aramid fabrics, where the carbon was to be fragmented and the aramid was used to maintain post-test integrity. A trigger mechanism was used to reduce the peak load, and to initiate crushing in the sine waves.

Figure 8 Helicopter sub-floor box, sine-wave beam and cruciform (clock-wise)

3.2 Dynamic impact test on sub-floor box

The NLR sub-floor box was dropped on rigid surface, by DLR (ref. 8), with a speed of 9.23 m/s and an impact energy of 21.3 kJ (fig. 9). The sine wave beams showed a good crushing behaviour. The ply drop-off trigger worked perfectly, the fracture lines ran straight along the trigger lines and a lot of fragmentation of the carbon material was initiated. The aramid plies kept the material together and sufficient structural integrity was maintained.
Some bigger parts in the intersection area broke loose, especially in the outward parts of the transverse beams. These parts just broke in bending and no fibre fragmentation (crushing) was found.

Figure 9 NLR sub-floor box after dynamic impact (DLR)

4 An example: a crashworthy commuter structure

As an example of a full-scale demonstrator, a commuter fuselage section was built also in the framework of the Brite Euram project CRASURV (fig. 10). Several crashworthy structures are combined in this composite demonstrator, which was built by the NLR.

Most of the components were dynamically tested and before testing numerical simulations were made to predict the crash behaviour (ref. 9).

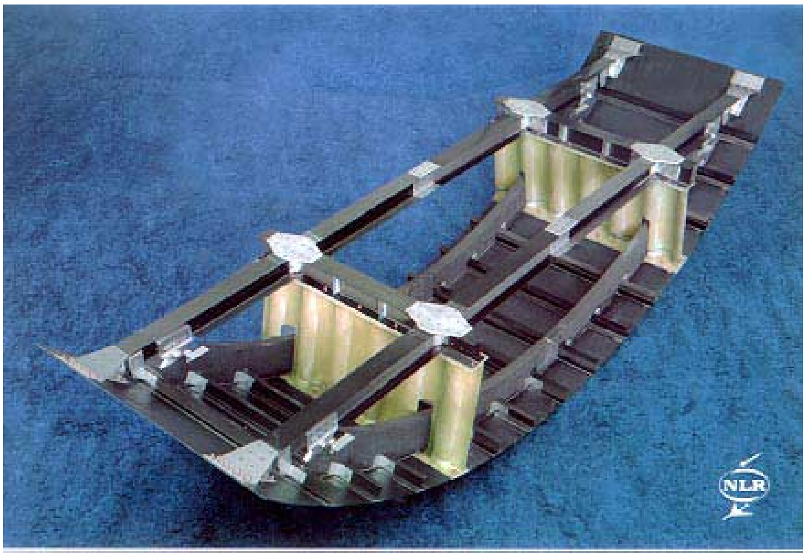

Figure 10 Full composite crashworthy commuter fuselage

The final assembly of the commuter sub-floor structure consisted of a number of pre-cured parts, which were bonded together, while some parts were also bolted together. The composite parts were the skin (two plates joined together by adhesive bonding along the impact line), with secondarily bonded I-shaped stringers, four C-section frame halves with bonded and bolted splice plates, two sine-wave beams, two lateral floor I-beams, each consisting of four parts, and two rail tracks on top of the sine-waves, of similar cross section as the floor beams.

Aluminium brackets were used for the hinges, the connection between the ends of the floor beams and the skin, and the connections between the floor beams and the seat tracks. The connections between sine-waves and skin, and between frames and skin were bonded and also bolted.

4.1 Dynamic testing at CEAT (Centre d'Essais Aeronautique de Toulouse)

To simulate the masses of occupants, seats, and the upper part of the fuselage, the structure was loaded with 40 kg at a position near the skin, and with 300 kg above each sine-wave beam. Part of the guidance system also contributed to the load above the hinge. To avoid tilting of the inner and outer masses, two stiff beams were used to connect the two masses. The 300 kg mass located above the sine-wave beams was distributed along the full 800 mm length of the beams. The structural mass was 720 kg, including the 30 kg mass of the specimen (fig. 11).

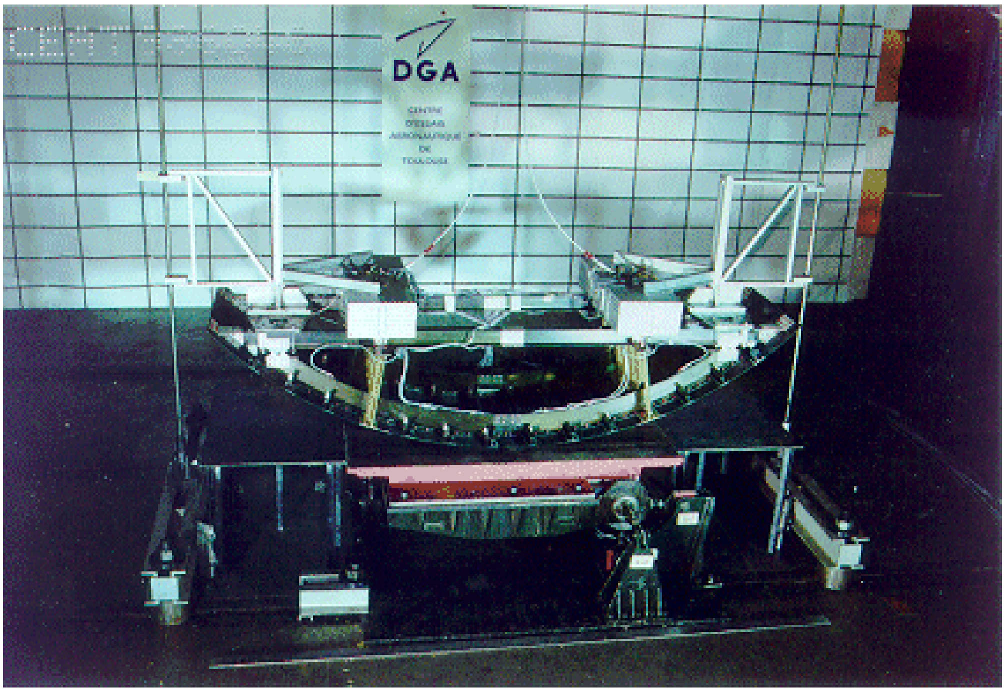

Figure 11 Complete test set-up for dynamic impact test of NLR's commuter (CEAT)

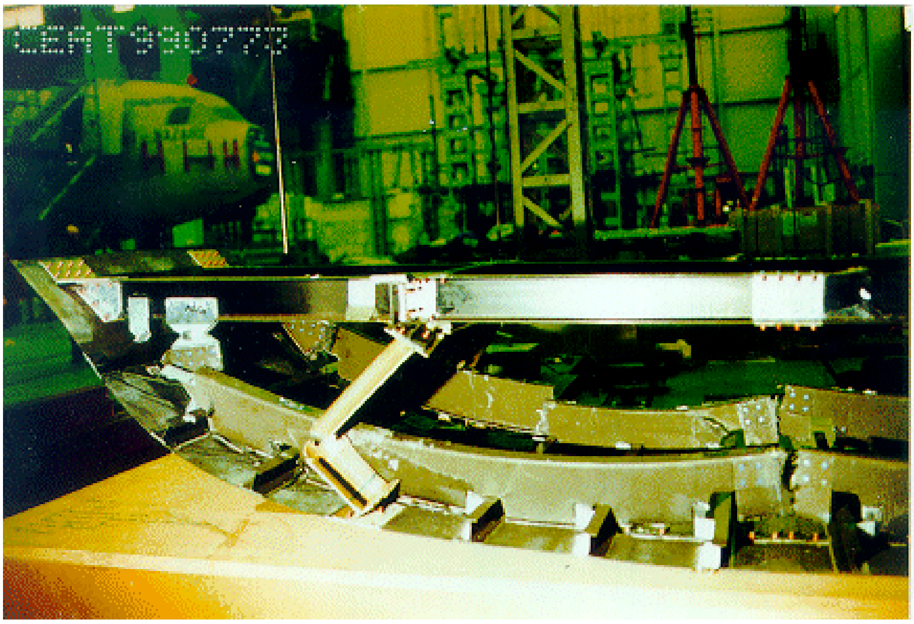

Figure 12 Commuter after impact test (masses are removed) (CEAT)

The actual impact velocity was 7.09 m/s, the energy at impact 19866J. At the first impact, the splice plates which connected the two halves of the frames did fail as predicted (after 7 ms) .

The sine-wave beams hit the ground at an angle of 10 degrees. The outer parts of the sine-wave beams (outside the two frames) broke away at about the same time as the failure of the trigger mechanism. However, the sine-wave beams did not crush, but bent outwards until they were stopped at the next stringers (fig. 12). They did not absorb a significant amount of energy. As a result, high forces were transferred to the lower flanges of the seat tracks, leading to distortions and fractures.

The overall energy absorption was very low, and not by the mechanisms intended.

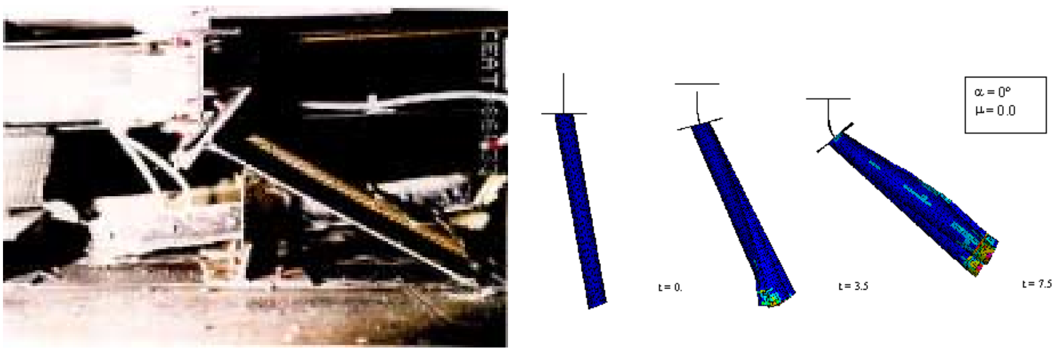

Figure 13 Post-test simulations of sine-wave beam of commuter (CEAT, Alenia)

However, the experimental data were useful to modify numerical models, and to validate the code developments (fig. 13).

5 Conclusions

In order to increase the crashworthiness performance of helicopter fuselage, NLR developed several crashworthy design concepts. A complete sub-floor structure, with energy-absorbing sine-wave beams and cruciforms was designed and tested.
In order to prevent skin failure and increase the performance of an energy-absorbing sub-floor box, the tensor-skin concept was developed and evaluated for water impact in the CAST programme.
The dynamic impact test on a full-scale, crashworthy demonstrator showed that the current design and simulation techniques should be improved. At this moment, experiments are still needed to validate simulation models.

6 References

1. “Brite-Euram project CAST: Crashworthiness of Helicopter on Water: Design of Structures using Advanced Simulation Tools”, G4RD-CT-2000-0178, 2000-2003.
2. “Brite-Euram project CRASURV: Commercial Aircraft – Design for Crash Survivability”, CT96-0207, 1996-1999.
3. “Brite-Euram project CRAHVI: Crashworthiness of Aircraft for High Velocity Impact”, G4RD-CT2000-00395, 2001-2004.
4. “A tensor-skin concept for crashworthiness of helicopters in case of water impact”, by H.G.S.J. Thuis and J.F.M. Wiggenraad, NLR TP 94045 L, January 1994.
5. “CRASURV – D.4.1.2, Behaviour of shear panels” by L.C. Ubels, NLR TR 97534 L, October 1997.
6. “CRASURV – D.4.1.3, Results of dynamic tests of tensor skin panels” by D. Kohlgrüber and H. Weissinger, DLR-IB 435-97/31, October 1997.
7. :Development of a trigger mechanism to reduce peak forces in crash loaded composite sine-wave spars“, by W. Lestari, H.G.S.J. Thuis and J.F.M. Wiggenraad, NLR TP 94319 L, July 1994.
8. “CRASURV – D.4.2.2, Results of dynamic tests of composite sub-floor boxes – Final report” by D. Kohlgrüber and H. Weissinger, DLR-IB 435-98/22, June 1998.
9. “Development of a crashworthy composite fuselage structure for a computer aircraft”, by J.F.M. Wiggenraad, A.L.P.J. Michielsen, D. Santoro (Alenia), F. Lepage (CEAT), C. Kindervater (DLR) and F. Beltran (Principa), NLR TP 99532 L, December 1999.