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Crasworthiness research at NLR (1990 - 2003)

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ABSTRACT

In the past decade, NLR has carried out research and development activities in several areas to improve the crashworthiness of future helicopters and fixed-wing aircraft. The crashworthiness of composite helicopters has been studied, and components for the NH90 helicopter have been developed. In several international collaborations, NLR has been involved in the development of crashworthy composite and metal aircraft structures. The potential for further improvements is expected to incite continuing collaborative research and development.

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This report is based on a presentation held at the 4th International Krash Users Seminar, IKUS4, Amsterdam, 2 - 4 June 2003

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CRASHWORTHINESS RESEARCH AT NLR (1990-2003)

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Abstract

In the past decade, NLR has carried out research and development activities in several areas to improve the crashworthiness of future helicopters and fixed-wing aircraft. The crashworthiness of composite helicopters has been studied, and components for the NH90 helicopter have been developed. In several international collaborations, NLR has been involved in the development of crashworthy composite and metal aircraft structures. The potential for further improvements is expected to incite continuing collaborative research and development.

Crashworthiness

Crashworthiness can be defined as the capability of an aircraft to provide the occupants from serious injury and death in case of accidents that are potentially survivable. In the case of fixed-wing aircraft, such accidents are characterised by impacts with the surface at modest speeds and fairly horizontal flight paths. They mainly pertain to problematic take-off and landing situations, or of aircraft running out of fuel or losing engine power, that are attempting a controlled emergency landing or ditching. Such accidents form a significant percentage of all fixed-wing aircraft accidents. Helicopters often fly at low speeds and altitudes, and helicopter accidents are therefore more often potentially survivable.

Aircraft structures have inherent crashworthiness, because they are able to absorb energy by permanent deformation. In this respect, bigger aircraft structures can absorb more energy than smaller aircraft. In an accident, the survivability of the occupants is governed by several conditions, of which the most important are the fact that their speed must be decreased gradually to zero, that they must not be severely impacted by their surroundings, and that they can escape before a fire breaks out. Since the seventies, the aeronautic community, with the objective to reach improvements in all these conditions, has pursued dedicated design for crashworthiness. The authorities have defined specific design requirements, and new structural concepts and numerical simulation capabilities have been developed by the industry. Even airports are now required to install "frangible" approach light structures, which break, distort or yield upon impact, while absorbing minimal energy, so as to present a minimum hazard to aircraft.

Military helicopters

Design for crashworthiness was pioneered for military helicopters, where the potential for improvement was highest, since accidents often occur at low speeds, while the structure surrounding the occupants, that is available for energy absorption, is minimal. Therefore, the major threat to helicopter occupants in a crash is abrupt vertical deceleration, which may lead to fatal spine-injuries. As a result, design requirements were defined, such as the notorious MIL-STD 1290, and structural concepts to integrate energy-absorption mechanisms have been developed. These mechanisms primarily consist of specially designed energy-absorbing landing gears, crushing sub-floor structures and stroking seats (Fig.1).

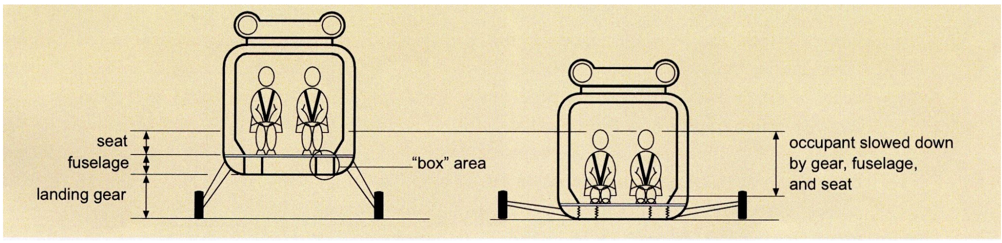

Fig.1 Mechanisms for energy absorption (courtesy Jim Cronkite/Bell)

The concepts have the objective to provide survivability for accidents with a vertical velocity of up to 11 m/s. The use of composite materials for fuselage structures was also pioneered for military helicopters, such as the NH-90 helicopter. The lack of plastic deformation of composites and their complicated failure modes have presented a big challenge to the designers, to provide the structure with sufficient crashworthiness. Another aspect that is currently under investigation, both in the US and in Europe, is the water impact scenario. Many helicopters operate over water, which means that it is not unlikely that accidents involve an impact with the water surface. Compared to designing crashworthy concepts for impacts on land, this requires new innovative structural solutions, and more complicated simulation techniques.

Large Aeroplanes

For large commercial aeroplanes, the vertical velocity in a survivable accident situation is a smaller problem than for helicopters, because the sub-floor structure is significantly more substantial. Made from aluminium, a material with a large capacity for plastic deformation and energy absorption, this structure has enough inherent crashworthiness. The major threat to such aircraft results from the large forward velocity that must be decreased, and the significant potential for post-crash fires. Since the eighties, the attention has focused on the definition of more stringent requirements for seats and their attachments to the floor, and studies aimed at the prevention or delay of the outbreak of fires were performed. In this respect it should be noted, that GLARE, a fiber-metal laminate used as a fuselage skin material on the Airbus A380, has a significantly longer burn-through time than aluminium, hence will provide the passengers with more time to escape.

Shell structures

Typically, aircraft structures are shell structures, made of lightweight materials. The structural concept of a shell structure is such, that its operational loads are carried "in-plane", for which it is most efficient. However, accidents impose loads transversely to the shell surface, which easily leads to penetration. Hence, energy absorption is achieved mainly by deformation of the sub-structure, such as frames, ribs, bulkheads and spars. This is also the case for other accidental impacts, which have to be considered in the design of aircraft: bird strikes, and impacts by runway debris, tire fragments and engine components. Although these are not considered to be scenarios pertaining to the concept of crashworthiness of an aircraft, they do affect flight safety as well.

Design of NH90

During the past decade, NLR has been contributing to the development of technology to design crashworthy aircraft structures. Because the aerospace industry in the Netherlands took part in the development of a helicopter, the NH-90 (Fig.2), and because the Royal Netherlands Air Force was going to operate helicopters on a much larger scale than before, a combined study was undertaken by Fokker and NLR under contract with the Ministry of Defence, during the years 1990-1992.

The objective of this study was to become acquainted with typical crashworthiness aspects of helicopters, in particular with structures made of composite materials.

Fig. 2 NH90 helicopter

The failure behaviour of composite materials was studied, and a design, fabrication and test cycle was carried out for one of the most promising structural components for energy-absorbing helicopter sub-floor structures, the sine-wave beam (Fig.3). This project was followed by a project to develop a "crash tube" for the nose landing gear of the NH-90, which must absorb additional energy in crash situations. This project was carried out for SP aerospace & vehicle systems, the company that is responsible for the development of the landing gears of the NH-90 (Fig.4).

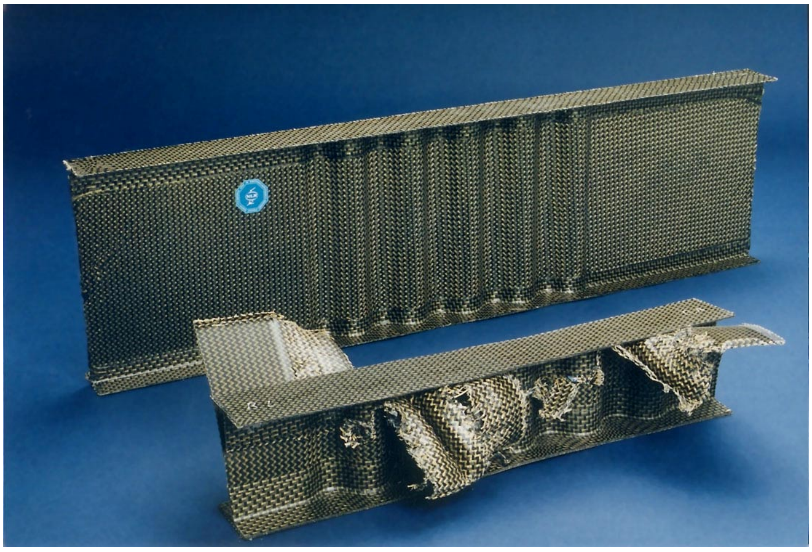

Fig. 3 Sine-wave beam concept for energy absorption

Fig. 4 Crash tube for NH90 nose landing gear and fabrication tooling

European Projects

Within Framework Programme III of the EU, NLR and Fokker participated in a project entitled "Crashworthiness for Commercial Aircraft", focused on aluminium fuselage structures. NLR's contribution consisted of the definition of three "potentially survivable" crash scenarios, based on accident statistics, to become a frame of reference for numerical analyses. In this project, NLR also used the "KRASH" finite element code to study the effect of local floor design, as generated by Fokker, on the acceleration pulse imposed on the passengers. KRASH is a relatively simple code, which was developed in the U.S. for the FAA and the US Army to evaluate and improve the crashworthiness of general aviation aircraft and military helicopters. The introduction of large troop carrying helicopters in the RNLAF, such as the Chinook and Cougar, raised the issue of the potential survivability of personnel seated on troop seats. Based on design specifications from the Italian helicopter manufacturer Agusta and in co-operation with students of HTS Haarlem, a crashworthy troop seat was developed [Fig. 5]. It was tested in the drop tower of Twente University.

Fig. 5 Troop seat with energy absorbing capability

Also, a structural concept was developed for the bottom skin panels of a helicopter fuselage, that would be able to withstand the pressure of an impact on water [Fig.6]. Regular composite skin panels would fracture easily, resulting in a reduced capability of the sub-structure to absorb impact energy, and in immediate water ingress. This concept is currently being evaluated in EU project "CAST", a project with Westland and Agusta, dedicated specifically to water impact of helicopters.

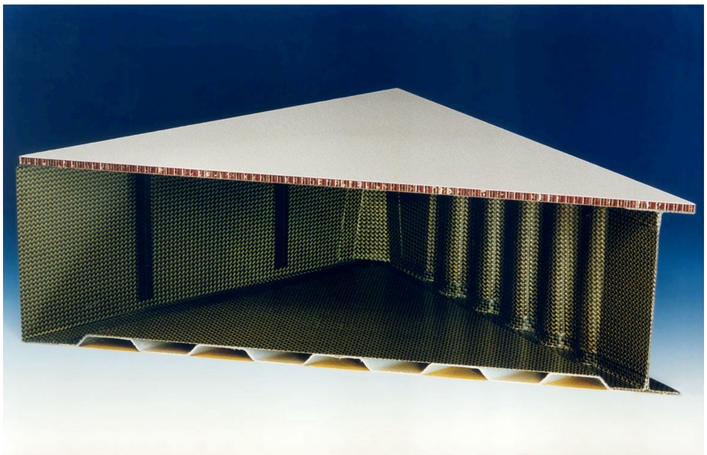

Fig. 6 Generic helicopter sub-floor structure with tensor skin

Within Framework IV of the EU, NLR participated in a project entitled CRASURV, on the crash survivability of composite aircraft structures. NLR's contribution consisted of the design and fabrication of composite "boxes" made of sine-wave beams [Fig.7], which represented generic helicopter sub-floor structures.

In collaboration with Alenia, a composite fuselage sub-floor structure was developed, based on the ATR commuter [Fig.8]. These structures were fabricated and tested in a vertical scenario, at DLR and CEAT, respectively. The test results were used to validate new numerical simulation capabilities, developed in the same project. In parallel, new material models for crushing composites, impacted at high speed, were developed in EU Project HICAS, for which NLR used the B2000 finite element code. At present, NLR participates in EU project CRAHVI, on crashworthiness for high velocity impacts. In this project, NLR focuses on the modelling of bird strikes on a composite horizontal stabiliser, and new design concepts for the leading edges. For many years, NLR has advised the Netherlands Department of Civil Aviation (IVW) with respect to the development of design requirements, guidelines and test methods

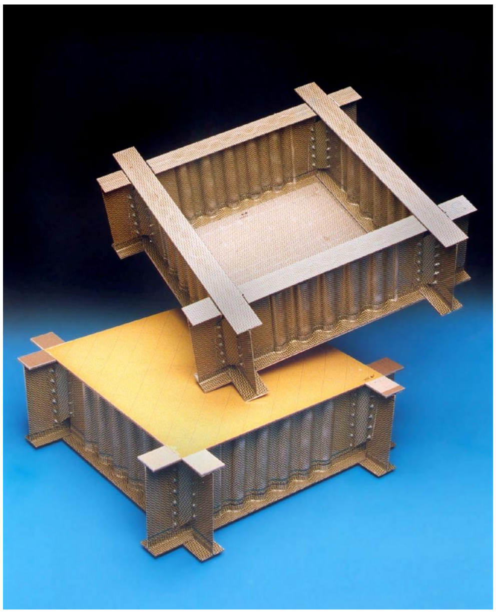

Fig. 7 Generic helicopter sub-floor structure

for frangible approach light masts. Subsequently, a capability for computer simulation, using KRASH, of the impact of the wing of a light aircraft against a frangible approach light structure has been developed [Fig.9], in co-operation with Twente University.

Fig. 8 Composite energy-absorbing sub-floor structure for a commuter aircraft

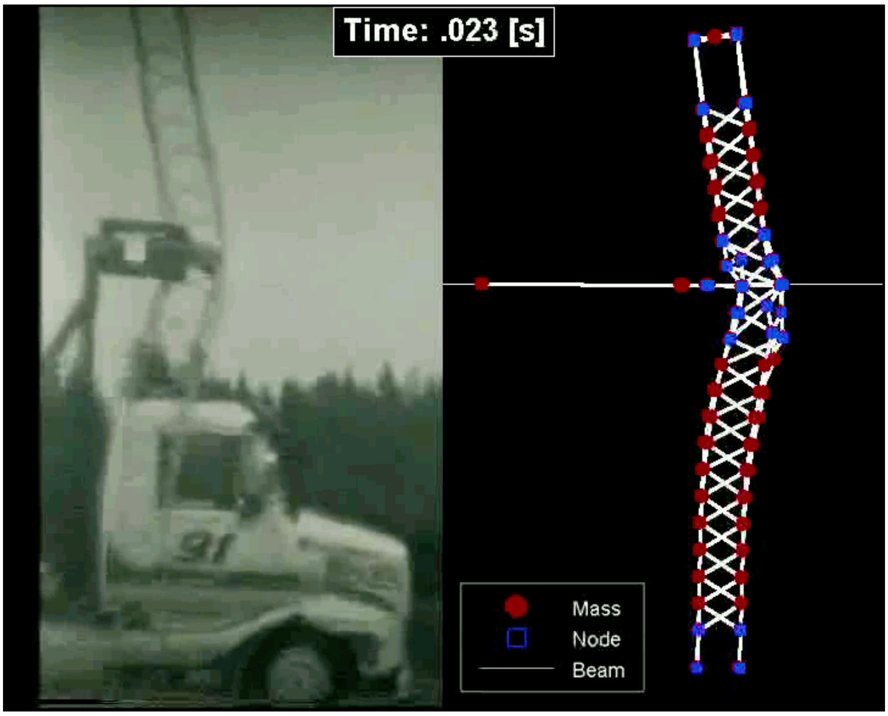

Fig. 9 *Impact test and KRASH simulation on a frangible approach light mast (courtesy Exel Oy/NLR)*

Numerical analysis

The subject of crashworthiness will be a challenging issue for a number of years to come, because the potential for improvements is still significant. Major improvements can be made only if a crash event can be simulated accurately by numerical analysis [Fig. 10].

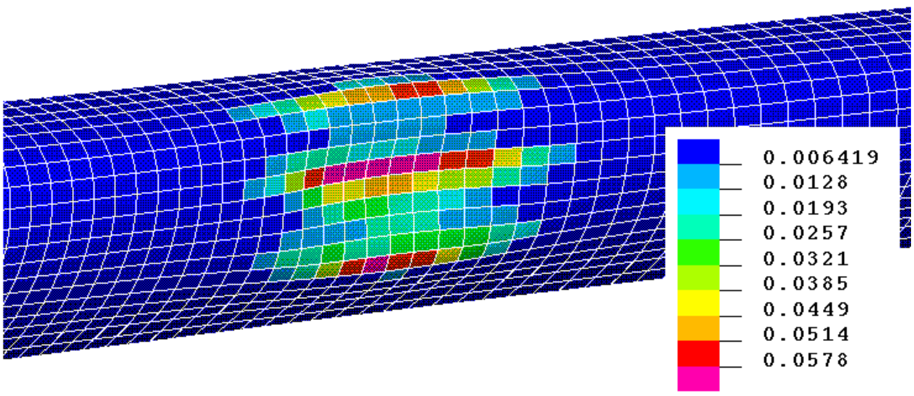

Fig. 10 *Strain distribution in a leading edge during a bird strike*

Predicting the sequence of events and the deformation process during a crash is difficult, and its success depends on the development of solution techniques and of models, that represents material behaviour beyond initial failure, especially for composite materials.

European collaboration

Most of the work is carried out within the framework of European projects, in which the Structures Technology Department of NLR co-operates closely with the Structural Integrity Department of DLR in Stuttgart, the Structure and Damage Mechanics Department of ONERA, the Crashworthiness Group of CIRA and the large scale crash test facilities at CEAT. This close collaboration with our European colleagues on safety issues began in 1992 and has been continued in five projects funded by the European Union. It might be speculated that these joint activities may one day lead to the establishment of a European 'Centre for aircraft structural safety', in order to better serve the European aircraft industry and support the safety authorities.

Conclusions

Within a period of just over a decade, NLR has developed expertise in the research area “design for crashworthiness and impact”. The scope of this expertise pertains to the development of design concepts, the development of models and application of computer codes for numerical analysis, and the development of design guidelines and assessment methods for frangible equipment at airports. This expertise was acquired within the framework of several projects for the Ministry of Defence, the Netherlands Department of Civil Aviation (IVW), landing gear manufacturer SPa&v, and the European Union, as well as in several independent projects. The expertise was partly developed in co-operation with the Dutch universities, with EREA-partners, and with code developers DRI (KRASH) and SMR (B2000). NLR aims to exploit its expertise for Fokker (design for bird strike [Fig. 11]), SP aerospace & vehicle systems (landing gears for helicopters [Fig. 12]), the Ministry of Defence (survivability of occupants in helicopters), ICAO (design guidelines and requirements for frangible equipment at airports [Fig. 13]), and airports and airport equipment suppliers (consultation with respect to frangibility [Fig. 14]).

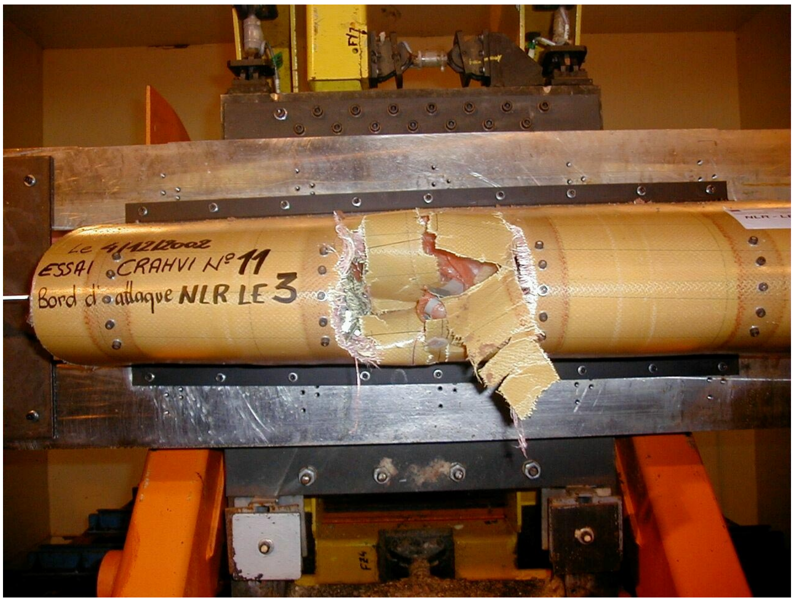

Fig. 11 *Composite bird-strike resistant leading edge*

Fig. 12 *Composite trailing arm NH90 helicopter (courtesy SP)*

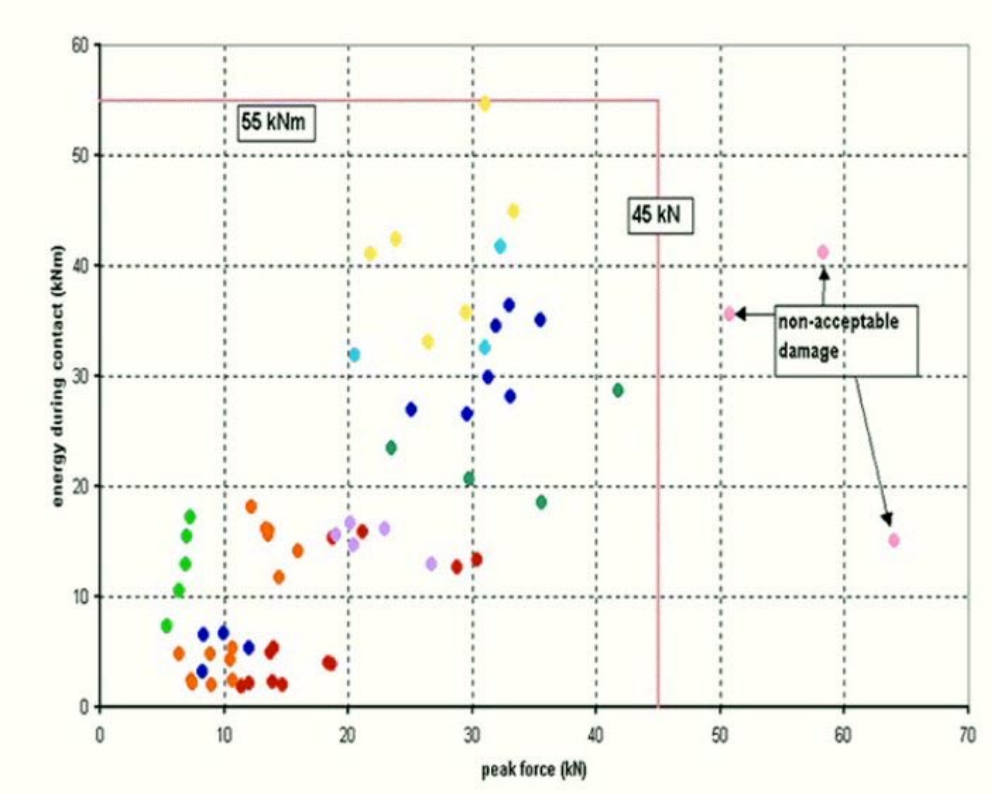

Fig. 13 *Test data of several frangibility tests on approach light masts*

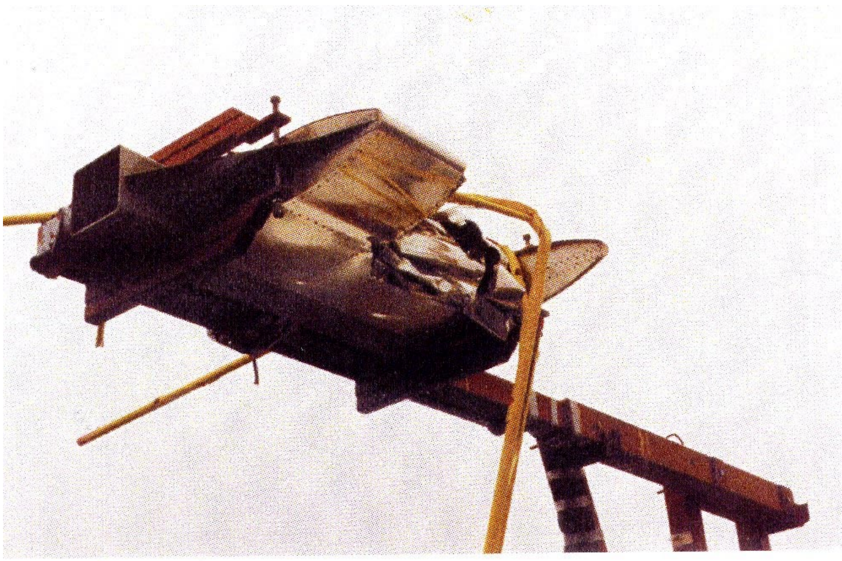

Fig. 14 *Impact test of a light aircraft wing section against a frangible approach light mast (courtesy Exel Oy)*