Crashworthiness of rotorcraft on water, an experimental test campaign

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Abstract

The present paper describes the preparation and results of two water impact test performed at CIRA. The activities were included in the research project CAST, devoted to improve crashworthiness of rotorcraft on water. First test was executed on a Westland WG30 sub-floor section, the second was the water impact of a complete full scale WG30 fuselage. For both tests, impact velocity was 8 m/s with flat attitude. Test specimens were fitted with ballast masses to recreate realistic load conditions, and equipped with pressure transducers and accelerometers to obtain objective quantitative data representing the severity of the loading, to which the structure was exposed. Moreover tests results were needed to assess numerical simulations performed by other partners of the project.
Pre-test numerical simulation results produced by DLR together with advice from Westland led to the final test configuration of the component. This avoided unrealistic failure of the test specimen in question.
The test specification for the full scale test was provided by Westland

Introduction

As shown by CAA and FAA accident investigation reports, a relevant percentage of accidents involving helicopters occurs on water, despite the fact that regulation and crashworthiness design criterion make reference to rigid surface accidents only. The EU sponsored research project CAST, within which the activities described in this paper have been carried out, is targeted to investigate the dynamic behaviour of helicopter structures in water impact with the final aim of leading to the entry into service of water-crash-worthy rotorcraft. Data obtained in experimental tests have been used to improve the understanding of this specific dynamic environment and to compare with numerical simulation results in order to assess the modelling of the phenomena and highlight capabilities and limits of currently available simulation tools.

Component test

Test specimen description and test set-up

The component tested was a section of a WG30 under-floor structure. Specifically, it was the section included between Fuselage Station 1210A and 240A, as shown in Fig. 1. The overall dimensions of the section were 2170 mm width and 970 mm length. The test specimen also included floor panels.

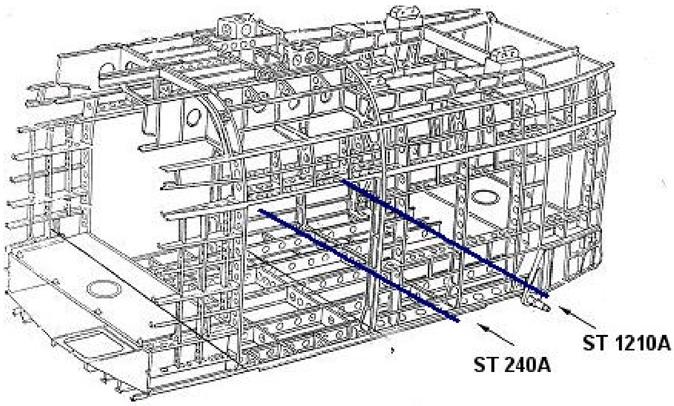

Fig. 1 Subfloor section

The structure, apart from the frames 240A and 1210A also included five longitudinal keel beams, on which the seat tracks were mounted.
Prescribed test conditions were 8 m/s impact velocity at flat attitude. To obtain this result a drop facility has been installed in the CIRA's ditching water pool. The facility consists of a tower that can guide a trolley to impact water at fixed attitude. The test specimen has been attached to the trolley by mean of a number of rods connected to the seat track. In a first proposed arrangement, there were only eight hosting points connecting the test specimen to the trolley. After the manufacturer's suggestions and the DLR pre-test simulation, arrangement was changed into an eighteen-point configuration.

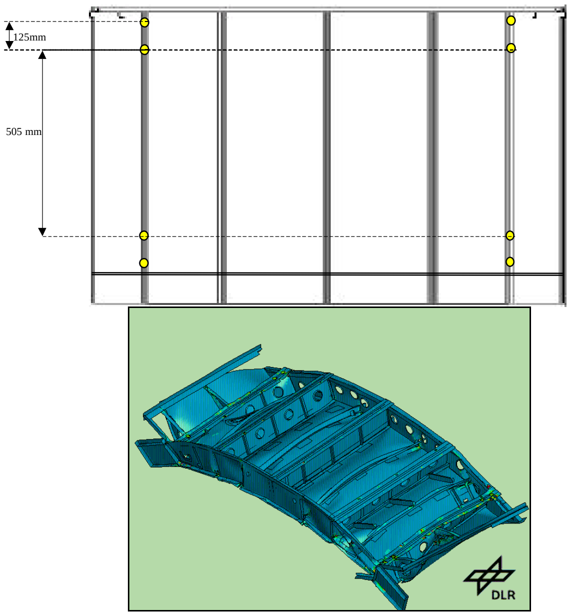

Fig. 2 Eight hosting point lay-out and simulation results

As shown in Fig. 2, the eight point arrangement would have caused an unrealistic bending failure of the structure. The pre-test simulation on the new configuration led to the final test set-up. Fig. 3 shows the simulation result with the eighteen-point configuration.

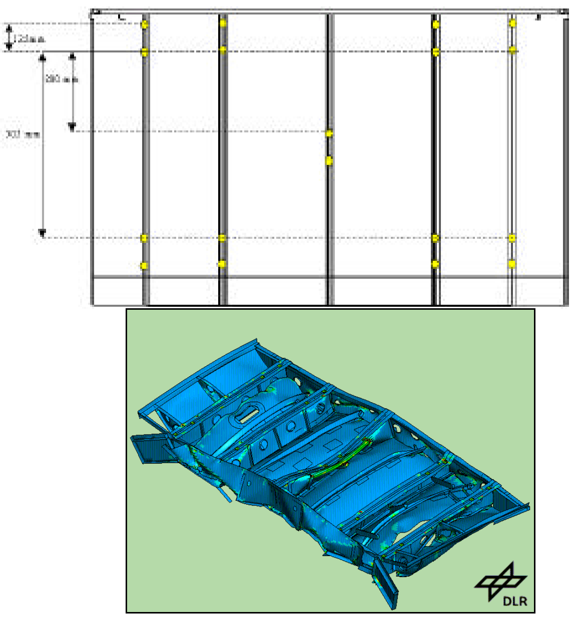

Fig. 3 Eighteen hosting point lay-out and simulation results

Ballast was added to the impact trolley to recreate meaningful loading conditions. The test specimen weight was 607 Kg. The following picture shows the final test set up.

Fig. 4 Final test set-up

Test instrumentation

The test specimen was instrumented with 14 pressure transducers on the belly skin in order to measure the pressure of water at impact. Strain gauges were also installed on the inner side. The following picture shows the transducers' location.

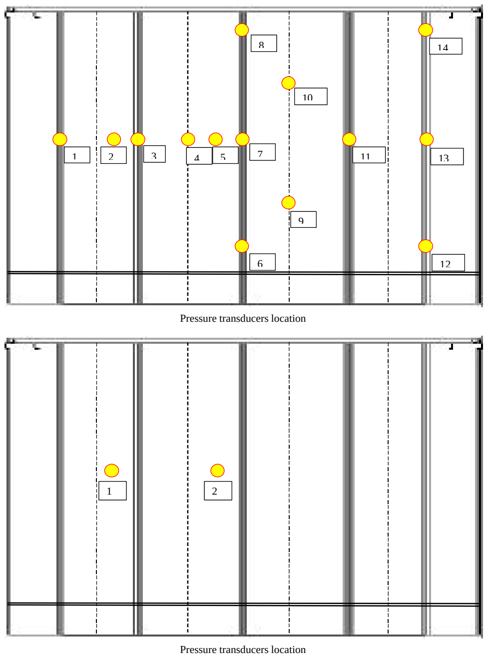

Fig. 5 Pressure transducers and strain gages location

Transducers were connected to the acquisition system via an umbilical cable, sampling frequency was 10 kHz. Also two high speed cameras were installed to capture the impact sequence. The impact velocity was measured by a photocell based system.

Test results

Measured impact velocity was 7.85 m/s. In the following picture the impact sequence as collected by one of the high speed cameras is shown.

Fig. 6 Impact sequence

Higher pressure values were reached at stiffer locations, which also corresponded to shorter pulse duration. In the following figure, time histories of transducer p6, which was mounted at a reinforced location corresponding to the sub-floor central keel beam, and p5, which was mounted on the panel's centre, are compared.

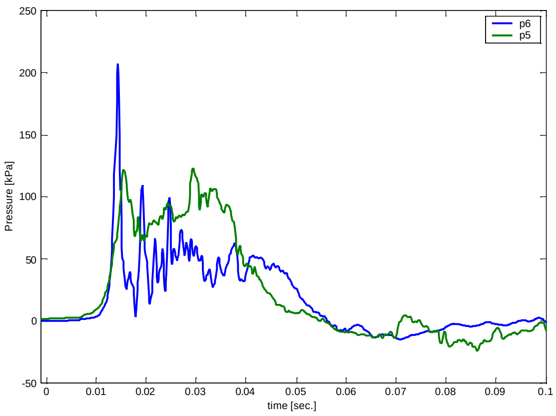

Fig. 7 Pressure time histories at location 6 and 5

After testing, the specimen preserved its structural integrity. Relevant deformations were observed on the skin panel, which bent under the pressure of water.
Frame 240A also reported large deformation as shown in Fig. 8. Ruptures were observed on panels close to frame 1210A, which was considerably stiffer and did not allow panel deformation. Main damages are reported in Fig. 9.

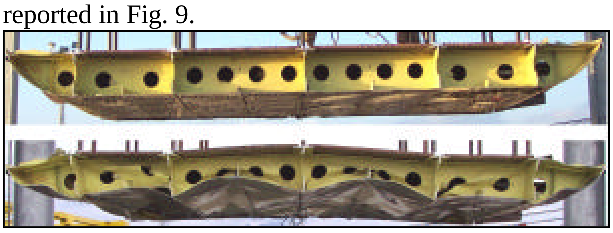

Fig. 8 Frame 240A pre- and post-test

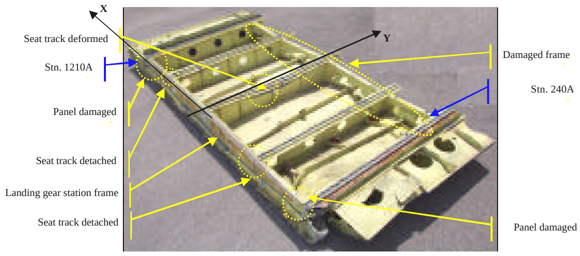

Fig. 9 Main damages location

Full scale test

Test specimen description

The test specimen was a Westland WG30 helicopter. It is a 16-seat, maximum AUW 5600 Kg aircraft, that was built in 1980. The airframe to be tested was fitted with seats, engines, transmissions and main/tail rotor hubs. The following mass items were added in order to recreate loading conditions representative of typical operational circumstances.

Item	*Mass*
10 passengers	10 x 75 Kg sand bags
pilot	Hybrid II Anthropomorphic Test Dummy
co-pilot	75 Kg sand bags
fuel in the fore and rear tanks	2 x 150 Litres of water
nose avionics	40 Kg lead plates
cockpit instrumentation	30 Kg sand bags
Inter-seat console instrumentation	20 Kg sand bags
instrumentation in the rear electrical bay	40 Kg sand bags

Table 1 Dummy masses mounted aboard test specimen

The test specimen was painted in grey and a black grid was drawn upon it in order to highlight motions in high speed cameras analysis.

Test instrumentation

The test specimen was instrumented with 21 accelerometers and 12 pressure transducers. Also an Hybrid II Anthropomorphic Test Dummy equipped with head accelerometers and pelvic load cell was installed at the pilot seat location. The following picture summarises the transducers' location.

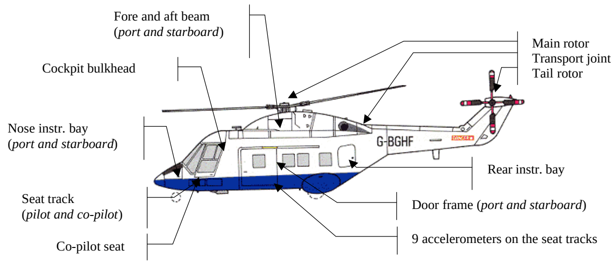

Fig. 10 Accelerometers' location on the test specimen

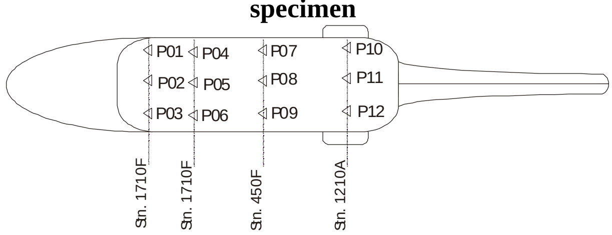

Fig. 11 Pressure transducers' location

Sensors were connected to the data acquisition system via an umbilical cable. Four high speed and two slow speed cameras were installed on the side of the pool. A retaining strip, connecting the hook of the crane and rotorcraft main rotor, was installed, in order to prevent the test specimen to completely roll to the upside-down position or drown and receive further damages by hitting the bottom of the pool. The length of the strip was set to come into tension when the rotor reached the water level. The test specimen was suspended on the water surface by means of a crane. In the following picture, the specimen ready for testing is shown.

Fig. 12 Test specimen ready for testing

Test results

The measured impact velocity was 7.95 m/s. At impact with water the fuselage assumed a positive pitch attitude which can be considered to be caused by the tail rotor mass. The following picture depicts the time history of the pitch angle as evaluated from the high speed camera.

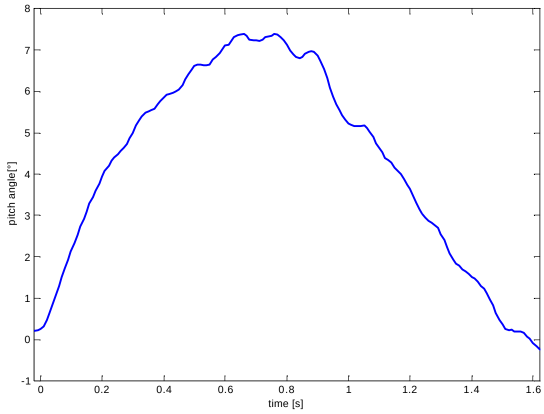

Fig. 13 Pitch angle time history

Two seconds after first impact, the test specimen rolled on the side because of the high upstanding engine and transmission masses. In the following picture, the impact sequence is shown as recorded by a slow speed camera.

Fig. 14 Impact sequence

The pressures on the belly skin were in the range from 50 to 130 kPa as it can be noticed from time histories of transducers located on the longitudinal centreline of the belly skin.The highest values were collected by transducer p02, which is located at F.S. 2457 F on a very stiff location between the front fuel tank and cabin. The lowest values on the contrary were reached at F.S. 450 F, which is located at the door frame on the same station the highest deformations were observed.

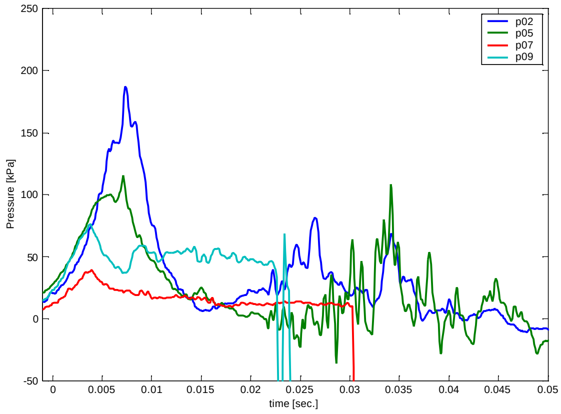

Fig. 15 Pressure time histories

The acceleration data presented in this paper have been obtained by filtering raw data through a SAE CFC180 filter. Even if SAE J211 suggests to use a CFC60 filter for analysing structural data, in this case a wider band filter has been chosen for the reason that a CFC60 would have resulted in a significant under-estimation of the loading magnitude. In Fig. 16, the acceleration time history acc13 located on the seat track on the central keel beam FS 450F is shown unfiltered and filtered with a CFC60 and a CFC180 filter.

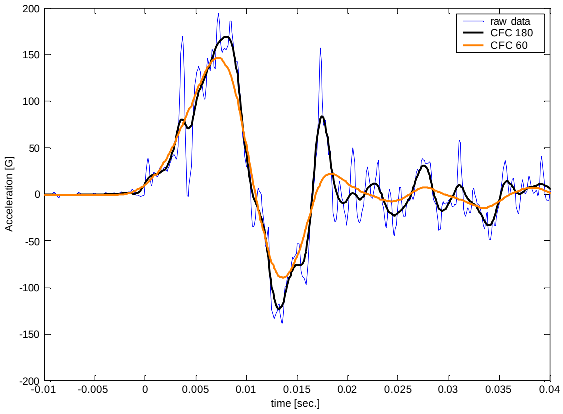

Fig. 16 Seat track acceleration time history at different filtering conditions

As it can be noticed, the use a CFC60 filter causes an underestimation of 30G in the main pulse, about 50G in the rebound, while solicitations subsequent to 15ms are nearly neglected.

The accelerations measured on the seat track were in the range between 50G and 160G. The highest values were reached at FS 450F, where the largest deformations were observed. In the following figure, three accelerometer time histories taken from the seat tracks are shown.

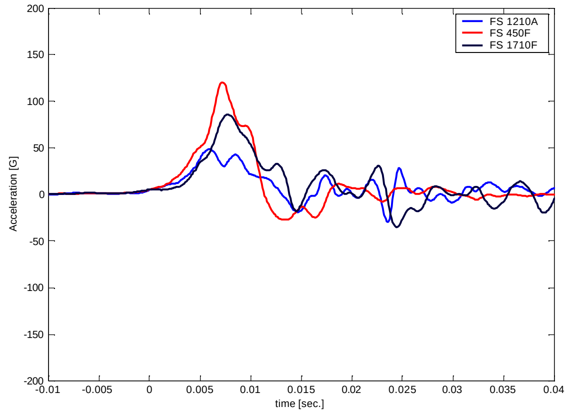

Fig. 17 Seat track acceleration time histories

Comparing these values to the accelerations measured on the rotors and tail cone, shown in Fig. 18, it can be noticed that in the second case the acceleration level is considerably lower. This is explained by the fact that the seat track accelerometers were mounted very close to the impact location. In this zone, no mechanism was available in the structure to reduce the load transmitted to the occupants. The upper parts of the structure, on the contrary, could benefit from deformation of side frames and for this reason experienced a lower loading level. In Fig. 19, the compressive load measured by the load cell mounted on the ATD's pelvis is shown. The maximum load exceeded the 6670 N limit prescribed by regulation, confirming that the deceleration environment, to which the occupant was exposed, was significantly high and could cause serious injuries. It must be stressed that the WG30 helicopter is not operative anymore and, being an old design, did not include any energy absorption feature. In addition, no benefit was provided by the landing gears as it would have been the case in an impact on rigid soil.

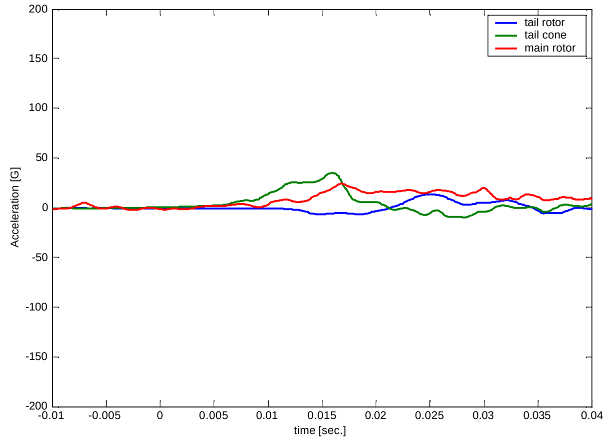

Fig. 18 Rotors and tail cone accelerations

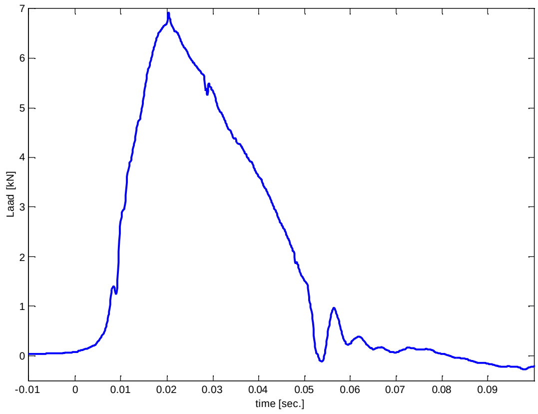

Fig. 19 Compressive load in ATD spine

The largest damages in the fuselage were observed on the belly skin and sub-floor structure. Some panels were ripped off, as shown in Fig. 20, and the sub-floor frames also exhibited evident deformations as can be noticed in Fig. 21 (picture taken after removal of seats and floor panels). The side frames underwent a plastic bending deformation as well because of the heavy rotor and transmission load, shown in Fig. 22.

Fig. 20 Belly skin damages

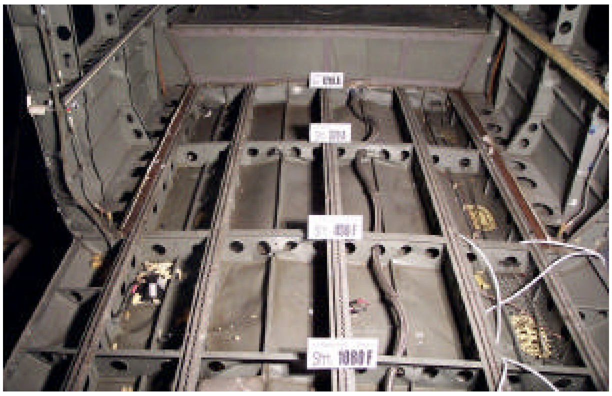

Fig. 21 Sub-floor inner deformations

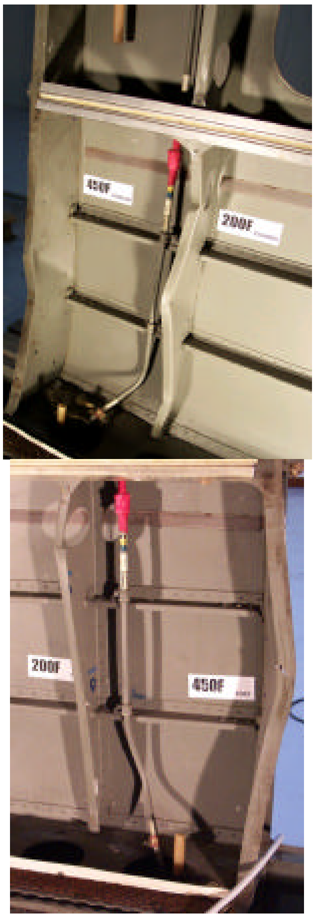

Fig. 22 Side frames deformations

As overall, the structure kept its structural integrity. No structural separation occurred. The cabins preserved the occupants and pilot. No injury came from the penetration of disconnected parts.

Conclusions

The tests conducted at CIRA were targeted both to provide experimental data, which were needed to assess numerical simulation performed by other partners in the research consortium, and to investigate the dynamic environment of a rotorcraft impacting on water focussing on possible causes of injuries for the occupants.

As highlighted by the test results, the skin panels underwent a large deformation and ruptured at some places because of high loads caused by the water pressure. In fact, during an impact on water no energy absorption and load reduction is provided by the landing gear. For this reason, occupants can be exposed to high deceleration loads, as demonstrated by the accelerations recorded on the seat tracks and by the high load in the ATD spine.
After impacting on water, the rotorcraft rolled on the side because of the high upstanding masses of rotors and transmission. This is a common feature of rotorcraft, as mentioned in numerous accident investigation reports, and is related to cabin evacuation issues. In fact, in a number of helicopter accidents involving water, fatalities were caused by the impossibility of escaping from the drowning fuselage.

Acknowledgements

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