Investigation of a helicopter harsh landing based on signals from installed sensors

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Abstract

Full scale testing of actual aircraft structures is one of the important methods of structural design experimental validation. Such testing is also used to support creation of future use strategy of ageing aircraft. Influence of hard landings on the structural integrity is one of the key issues in the process of helicopter service life extension for ageing aircraft, such as the Polish Air Force Mi-8/17 helicopters.
An experimental vertical drop test simulating a hard landing has been one of the tasks in the European Defense Agency's „ASTYANAX" research project. The aim of the test was to verify the extent of structural damage for landings occurring in the permitted velocity range (i.e. below 3,05 m/s).
A Mi-8 helicopter decommissioned from the Polish Air Force has been used for the test. Various measurement systems were used in the test: deformation measurements with strain gauges, Bragg gratings and PZT sensors as well accelerometer systems and landing gear cylinder displacement meters. In addition, after each drop test step, a visual NDI as well as comparative analysis of three-dimensional surface deformation (made with optical scanners) took place. A measurement of 3D coordinates of discrete control points has also been performed. Preliminary analysis of the experiment results is presented in the paper.

Keywords: drop experiment, harsh landing, helicopter dynamics, vertical drop.

Introduction

In the paper, a vertical drop test of a military transport helicopter is presented along with the results. The experiment was one of the tasks of the European Defense Agency's ASTYANAX research project. The main aim of the project is to further develop the methodologies researched in the preceding EDA project HECTOR which dealt with devising of a predictive expert system used for detection defects in the airframe (Ref. 1 and 2). One of the damage modes for which the predictive network has to be calibrated in the current project is the harsh landing event. The presented experiment was performed to provide data for this calibration.

Figure 1 – typical wrinkling in the tailboom region

The problem of harsh landings is an important issue for the Mi-8/17 helicopter fleet operated by the polish air force. Flight records show that harsh (high-velocity) landings are frequently encountered in service (especially in battlefield conditions).

The experiment described in the present article was one of the means of determination of impact of harsh landings on degradation of the structure, and also helped to establish the relationship between the landing velocity and the incremental loss of structural integrity. The test that was supposed to simulate a harsh landing has been conducted in the form of a series of vertical drops of a full-scale, fully equipped Mi-8 helicopter with installed landing gear. Drop velocities were kept below a guideline harsh landing limit of 3,05 m/s (Ref. 3).

Drop testing use in aircraft research

Crash and drop testing is an important part of aircraft airworthiness research, and greatest contributions were made in the course of crash analysis programs conducted at Impact Dynamics Research Facility (IDRF) at NASA Langley Research Center. The IDRF main testing rig is a 73 meter high gantry structure (Ref. 4).

Example experiments include the 1980 test (Ref. 5) in which four identical four-place, single-engine airplane specimens with nominal masses of 1043 kg each were crash tested under controlled free-flight conditions. These tests were conducted with nominal velocities of 25 m/sec along the flight path at various flight-path angles. In 2010 a test of a MD-500 helicopter (Hughes OH-6 derivative) with deployable energy absorbers (DEAs) (References 6 and 7) was performed - vertical velocity of 7.8 m/s and forward of 12 m/s was achieved. 160 channels of data were recorded, including accelerometers, strain gages and miniature video cameras. Another drop test of a helicopter was performed in 1999 (see References 8 and 9). This test was a part of the ACAP program, a proposed 82% composite replacement of the S-76 helicopter. The impact was performed at a velocity of 15,5 m/s (see Ref. 11). 90 sensor channels were recorded (62 accelerometers, 11 displacement transducers) at a 10 kHz sampling rate. Destruction of the structure occurred. Another recent test was performed in December 2006 (Ref. 12) as a Part of NASA’s Subsonic Rotary Wing Project (Ref. 13) - in the test a landing gear of a HX-2 WASP, a 1,000-lb kit-built two-seat helicopter was examined (8.4 fps drop was used). On the other hand, an example of a component drop-test is described in a 2001 paper (see Ref. 15). In that experiment, only the helicopter subfloor drop behavior was researched. The subfloor structure had a mass of 5 kg, and a ballast of 500 kg was attached to its upper surface. The article was dropped from a height of 4.5 m, resulting in an impact speed of 9.23 m/s. Based on the test results explicit numerical simulation of subfloor elements crushing was validated. Drop experiment was also used for model validation in another recent test from 2008 (Ref. 16) in which a helicopter underfloor made an impact with water to facilitate LS-DYNA numerical simulations. Impact velocity of 8 m/s was achieved.

In the above experiments multiple sensor signal channels were utilized. Most channels are typically devoted to accelerometer data. Strain gages are used to evaluate structural response of the airframe as well as occupants, and fast camera systems are used to facilitate kinematics examination. Data reduction of recorded acceleration signals was essential – for that, low-pass filtering was used. Compared to the earlier tests, in the presented research a greater emphasis was put on an extensive strain gauge network for structural behavior assessment. Also, while most of the mentioned full-scale tests ended in destruction of the airframe, the aim of the presented experiment is not the complete destruction of the test article. Thanks to this fact, multiple drops of a single test article could be performed, which is a novel feature of the described research.

Table 1 – drop levels used

level	Free fall velocity		
	Pre-calculated	Marker on wheel	Marker on fuselage
0,00	0,00	- - - -	- - - -
0,10	1,40	1,39	1,87
0,25	2,21	2,19	2,51
0,35	2,62	2,61	2,90
0,48	3,07	3,01	3,12
0,75	3,84	3,81	3,89

Test Preparation

Although most of the mentioned full-scale drop/crash tests utilized a dedicated test rig, in the present activity, because no forward velocity was needed, an existing gantry crane of the ArcellorMittal steel mill in Warsaw, Poland has been used. The crane was certified for a load of 50 tones, which was well in excess of the planned helicopter weight of 11 t. The crane had a maximum hook height of 8,5 m witch gave an operating range of 2 m for the test. The experiment was planned as a series of vertical drops. For each drop attempt the helicopter was successively raised to a higher level, to increase the touchdown velocity.

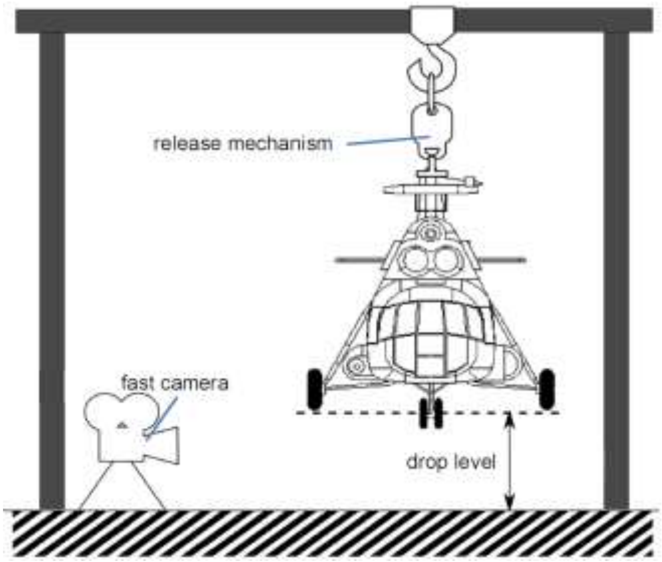

Figure 2 – test set-up

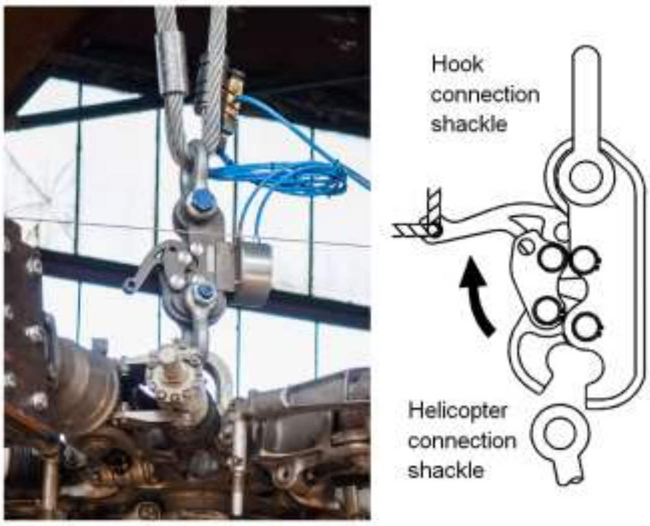

Figure 3 – release system operation

Obtaining of a suitable test article (helicopter) was a significant issue, as the full-scale helicopter had to be in a reasonable technical condition. A Mi-8 specimen that has been decommissioned from service in 2007 was acquired for this purpose. Several actual subcomponents (engines, gearboxes etc.) were installed on the test article. Additional weight simulating the helicopter freight has been distributed in the test article in the form of sandbags. The main and tail rotor blades were replaced with equivalent lumped masses. A special quick release mechanism was used for the release of the test article (Figure 3). Release occurs by opening of the system's grips, which is done with the use of pneumatics.

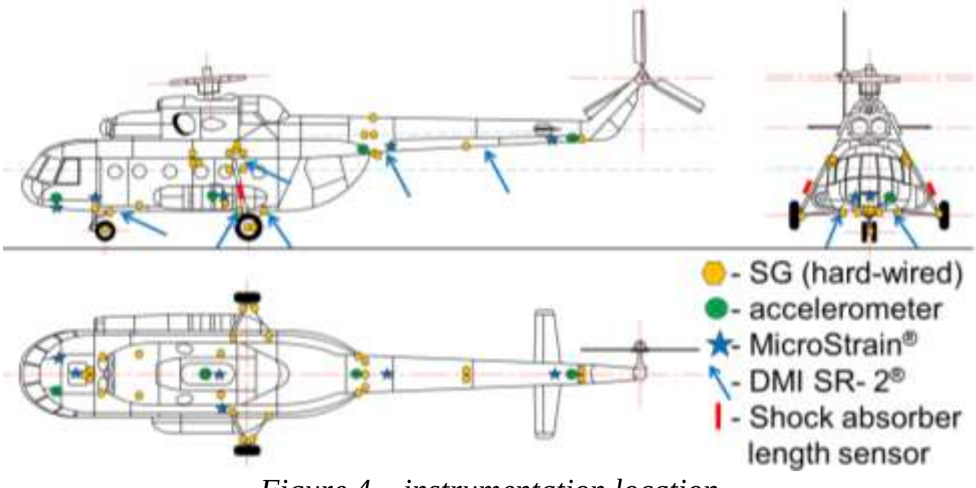

Figure 4 – instrumentation location

Instrumentation

Helicopter was instrumented with an elaborate sensor suite to capture the movement, rotation as well as structural response of the airframe. The ACRA® KAM-500 system has been used for recording of the sensor signals. The measurement was performed with a 15 kHz sampling rate. The sensors used included 54 strain gage channels in various bridge configurations, 4 accelerometers, 4 laser distance meters, 2 shock absorber extension sensors, 25 wireless polymer strain gages, 6 MicroStrain® nodes (strain gages and MEMS accelerometers), 4 lines of 190 FBG sensors, as well as 12 PZT sensors in 3 network groups. A fast camera system (1000 fps) has also been utilized. Location of the sensors is presented in Figure 4.

Two acceleration sensor types were used in the experiment – the piezoelectric, triaxial ENDEVCO 65R-10 accelerometers, as well as the classic, soviet produced, uniaxial MP-95 spring-mass g-meter. The soviet MP-95 is the same type of sensor that is used in routine service of the Mi-8/17s – this enables a comparison of flight test data and the drop experiment signals. The accelerometers were placed in various airframe locations, including the center of mass.

Figure 5 – helicopter before release and at maximum strut compression

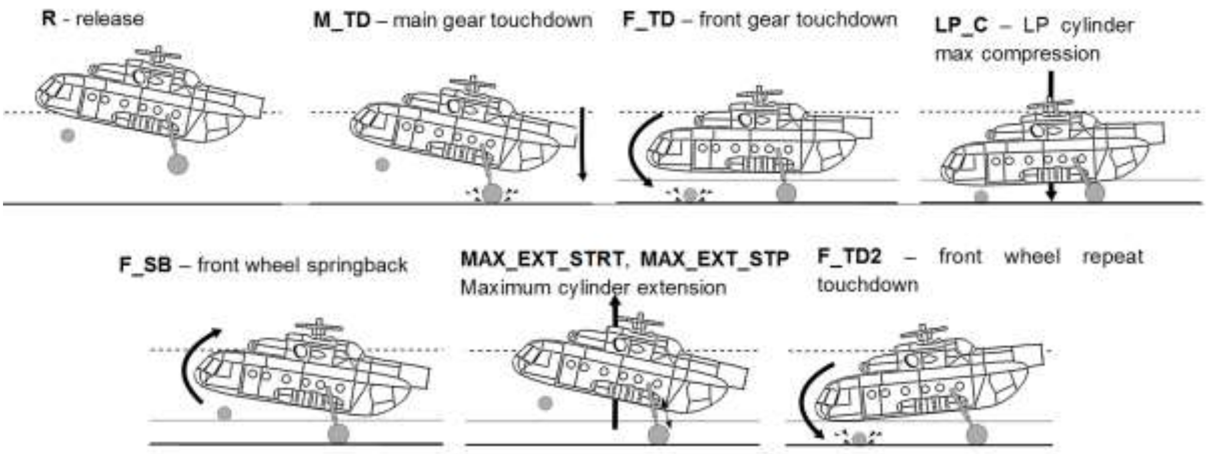

Figure 6 –sequence of events during drop, event marker names

Test drop levels that result in touchdown velocities below 3,05 m/s (Ref. 3) were chosen for the experiment. Table 1 presents the drop heights that were actually used (based on the fast camera measurement results). Because of the low structural impact of the 48 cm drop, additional drop height of 75 cm has been employed. The 0 cm level is defined as the height at which the main gear wheels barely touch the ground (see Figure 2).

Test Result Discussion

A series of events and interactions take place in the course of a single vertical drop. Firstly, after the quick release system is opened, a characteristic free-body structural response (Figure 8) is observed during the free-fall phase. After the free-fall phase, the landing gear touchdown occurs. After touchdown, the process of shock absorber contraction starts in the main gear. In this phase, the deceleration of the helicopter reaches the highest amplitude, and the highest strain gauge signals are recorded. Action of the absorbers results in decaying oscillation of the helicopter pitch angle as well as of the vertical position of c.m. These oscillations result in rebounds of the front gear. Graphical illustration of the events in the sequence is shown in Figure 6. Typical time-histories are presented in Figure 9 and Figure 10. The corresponding event marker examples are shown as vertical lines on these figures. Example of the influence of drop height on strain increase is shown in Figure 7. Filtering of the piezoelectric accelerometer signals was performed with the use of a SAE/J211 compliant CFC30 digital low pass filter (low-pass, 30 Hz cut-off) (consult Ref. 14).

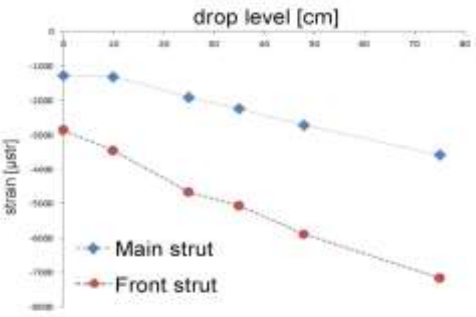

Figure 7 – comparison of maximum strut strains

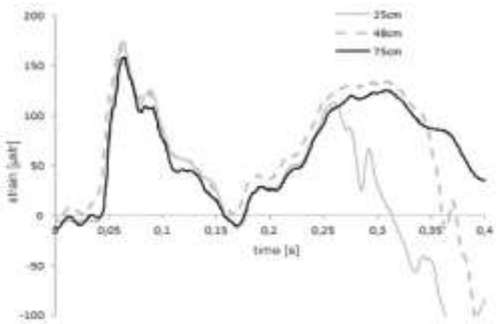

Figure 8 – release response (frame 10 near stringer 10)

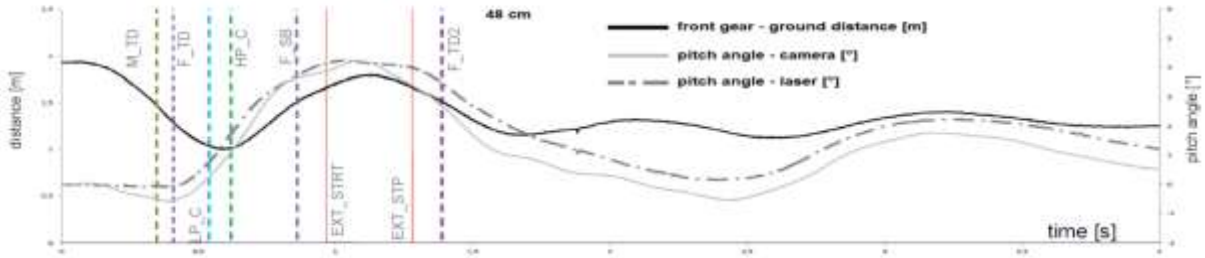

Figure 9 – pitch angle and front gear kinematics overview

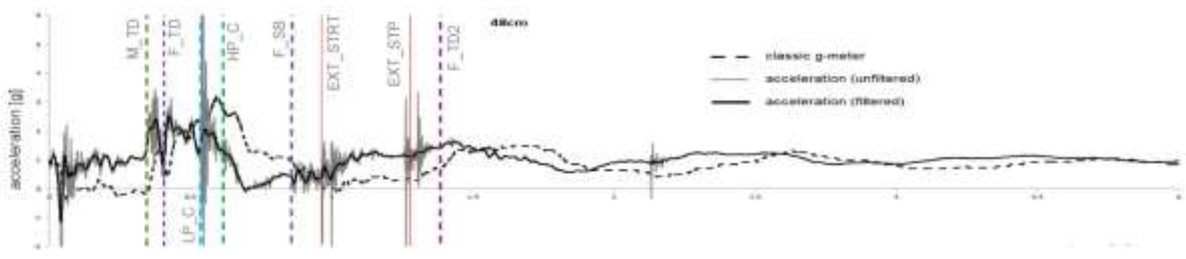

Figure 10 – overview of recorded accelerations

The main frames are the most important structural elements of the helicopter. Both the initial hanging attachment forces, as well as the gear impact forces are distributed through these frames. This is showcased by high amplitude response of the frame strain gauges for all of the discrete drop events, and is confirmed by analysis of the recorded signals. Strain histories on main frame 10 (to which landing gear is attached) show a good correlation with the strain in the corresponding gear fitting region. Strain in main frame 10 is directly dependent on the vertical acceleration of the helicopter. Front gear strains are a result of the touchdowns and rebounds of the front tire (which is a result of fuselage rotation, and absorber action). It can be concluded that the structural impact of the drop is mostly localized to the landing gear struts and regions near landing gear-fuselage attachments.

Structural Impact of the drop

For most of regions of the airframe, the strain values recorded by the sensors were considerably lower than the material yield limit. The highest signal amplitudes were recorded in the landing gear struts – with strain especially high in the front gear strut, which is a result of strut compression on first touchdown. As a means of structural deformation assessment, a geometry inspection has been performed after each drop attempt. The assessment was made with the inspection methods used in the day-to-day service of the aircraft. A discrete point geometry check was done with the use of a Leica TDRA6000 laser measurement station. A baseline measurement was performed before the drop test and subsequent post-drop measurements were compared with it. The findings suggest that the increasing drop heights contribute to leftward rotation of the tail fin (in the order of 14 arc minutes). In addition, an optical scanning of selected skin regions was performed with the GOM ATOS III system. Again, a comparison with baseline was performed after each drop. The results suggest that only after the 75cm drop did any significant structural deformations occur. The deformation near the main gear attachment observed in the drop has a form similar (but not identical) to the deformation that is encountered during routine inspection (Figure 14).

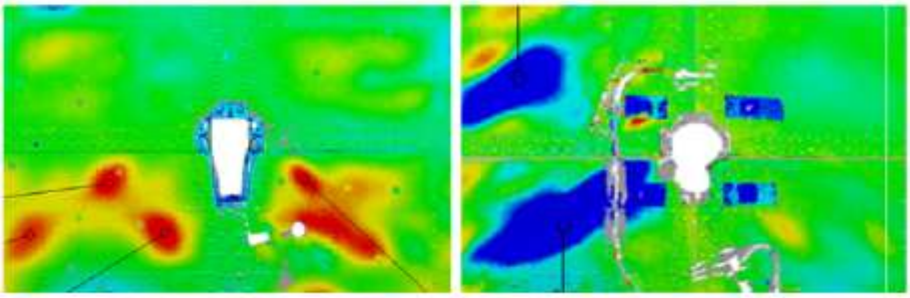

Figure 11 – comparison of drop deformation (right) and typical in-service deformation (left)

Conclusion

The experiment provided an extensive amount of data and this enables a detailed insight into the dynamics of a harsh landing event. Analysis of the recorded data (strain gage readings in particular) suggests that the Mi-8 airframe is resistant to ground impacts for impact velocities below 3,05 m/s – i.e. the assumed harsh landing threshold. For the highest drop level only an onset of plastic deformation is observable. The geometry measurement methods used routinely in Mi-8/17 helicopter geometry assessment did not record any significant deformation. This finding is confirmed by the strain gauge readings – the highest recorded strains were below the yield limits of the material.
Findings from the drop experiment, including the recorded data, will be used to establish, by extrapolation, the safe flight parameter thresholds for landing. In addition the data will be used for validation of a Finite Element model created as a part of the "ASTYANAX" project.

Acknowledgments

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References

1. Giglio, M., Manes, A., Mariani, U., Molinaro, R., & Matta, W. (2009). Helicopter fuselage crack monitoring and prognosis through on-board sensor network.*Proc. of CM*
2. Vallone, G., Sbarufatti, C., Manes, A., & Giglio, M. (2013). Artificial Neural Networks for Structural Health Monitoring of Helicopter Harsh Landings. *Applied Mechanics and Materials*, *390*, 192-197.
3. Zimmerman, R. E., Warrick, J. C., Lane, A. D., Merritt, N. A., & Bolukbasi, A. O. (1989). *Aircraft Crash Survival Design Guide. Volume 3. Aircraft Structural Crash Resistance*. SIMULA INC PHOENIX AZ
4. Jackson, K. E., Boitnott, R. L., Fasanella, E. L., Jones, L. E., & Lyle, K. H. (2006). A Summary of DOD-Sponsored Research Performed at NASA Langley's Impact Dynamics Research Facility. *Journal of the American Helicopter Society*, *51*(1), 59-69
5. Vaughan, V. L., & Hayduk, R. J. (1980). “Crash tests of four identical high-wing single-engine airplanes”. *National Aeronautics and Space Administration, Scientific and Technical Information Branch*.
6. Kellas, S., Jackson, K. E., & Littell, J. D. (2010). Full-Scale Crash Test of a MD-500 Helicopter with Deployable Energy Absorbers
7. Littell, J. D., Jackson, K. E., & Kellas, S. (2010, September). Crash test of an MD-500 helicopter with a deployable energy absorber concept. In *International Crashworthiness Conference* (No. NF1676L-10355)
8. Fasanella, E. L., Jackson, K. E., & Lyle, K. H. (2002). Finite Element Simulation of a Full-Scale Crash Test of a Composite Helicopter. *Journal of the American Helicopter Society*, *47*(3), 156-168
9. Fasanella, E. L., Boitnott, R. L., Lyle, K. H., & Jackson, K. E. (2001). Full-scale crash test and simulation of a composite helicopter. *International journal of crashworthiness*, *6*(4), 485-498
10. A Jackson, K. E., Fasanella, E. L., Boitnott, R., McEntire, J., & Lewis, A. (2004). Occupant Responses in a Full-Scale Crash Test of the Sikorsky ACAP Helicopter. *Journal of the American Helicopter Society*, *49*(2), 127-139
11. (Perschbacher, J. P., Clarke, C., Furnes, K., & Carnell, B. (1996). *Advanced Composite Airframe Program (ACAP) Militarization Test and Evaluation (MT&E) Volume V-Airframe Drop Test*. USAATCOM TR 88-D-22E
12. Fuchs, Y. T., & Jackson, K. E. (2011). Vertical drop testing and analysis of the WASP helicopter skid gear. *Journal of the American Helicopter Society*, *56*(1), 12005-12005
13. Jackson, K. E., Fuchs, Y. T., & Kellas, S. (2009). Overview of the National Aeronautics and Space Administration Subsonic Rotary Wing Aeronautics Research Program in Rotorcraft Crashworthiness. *Journal of Aerospace Engineering*, *22*(3), 229-239
14. Society of Automotive Engineers (SAE) (1995) “Recommended Practice: Instrumentation for Impact Test – Part 1, Electronic Instrumentation, SAE J211/1”
15. McCarthy, M. A., & Wiggenraad, J. F. M. (2001). Numerical investigation of a crash test of a composite helicopter subfloor structure. *Composite structures*,*51*(4), 345-359

16. Hughes, K., Campbell, J., & Vignjevic, R. (2008). Application of the finite element method to predict the crashworthy response of a metallic helicopter under floor structure onto water. *International journal of impact engineering*,*35*(5), 347-362