Improved Occupant Crash Safety in Helicopters

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Abstract

The objective of the European project 'HeliSafe TA' was to improve the survivability of occupants in helicopter crashes and to minimise the risk of injuries. This was achieved by an advanced safety system concept based on interacting safety features such as enhanced safety seats, improved harness systems and deployment of airbags.

A key feature of 'HeliSafe TA' was the application of numerical simulation tools to predict cabin and occupant response to crash loads in order to optimise the layout of the safety system. For the verification of the simulation models and in order to generate a broad load data base, three fully instrumented drop tests were carried out in Europe's most extensive helicopter crash test programme to date. Furthermore, numerous sled tests with two generic helicopter mock-ups were conducted.

The paper gives a brief overview on HeliSafe TA with emphasis on DLR's contribution to the project. DLR was responsible for the crash simulation of the full-scale helicopter drop tests and the definition of acceleration pulses in the sled test programme. Detailed simulation models of the cockpit mock-up were developed which included the pilot dummy and safety features such as the energy absorbing seat and the belts. With the verified models, DLR carried out different parametric studies in order to optimise the properties of the energy absorbers used in the cockpit seats and to propose a concept which leads to the lowest possible injury rates for occupants of different weights and sizes. Optimised adaptive and non-adaptive attenuator systems were then proposed.

Contents

1 Introduction

The risk of a helicopter crash is about ten times higher in comparison to that for fixed wing civil transport aircraft, mainly due to inherently risky operations close to ground and water. Over the last decades, the design of helicopters with regard to crashworthiness was considerably improved. Energy absorbing landing gears and subfloor structures were introduced and energy absorbing seats developed – even if these are not yet used in all helicopter models.

Within the earlier European research project 'HeliSafe' (2000-2003, coordinator: Autoflug), studies were carried out in order to enhance the safety equipment inside the helicopter [3]. Cockpit and cabin mock-ups were produced in which energy absorbing seats and an airbag could be installed. With these mock-ups, sled tests were conducted using a FAA Hybrid III 50th percentile dummy and the standard triangular acceleration pulses defined in the respective regulations (FAR/CS 27 & 29).

In the subsequent EU project 'HeliSafe TA' (Helicopter Occupant Safety – Technology Application, 2004 – 2007 [1]), helicopter cabin safety technology was being developed for more severe crash scenarios and for more realistic cabin and seat configurations than those considered in the earlier 'HeliSafe' project. A major step forward was the execution of three fully instrumented drop tests with Bell UH-1D helicopters at the test site of the Italian project partner CIRA. Each helicopter was equipped with three energy absorbing seats and occupant dummies. In the final drop test, a pilot airbag was deployed.

Additionally, 15 sled tests with the two generic helicopter mock-ups were conducted. All sled tests for the cockpit mock-up containing the pilot dummy and airbag were carried out by Siemens Restraint Systems in Germany. The sled tests for the cabin mock-up containing the passenger dummies were conducted by CIDAUT in Spain. In most of these tests, the acceleration pulses derived from the full-scale drop-tests were used instead of the standard triangular pulses in the earlier project. The mock-ups were improved with devices that allow the emulation of a possible floor deformation. With the use of a FAA Hybrid III 95th percentile dummy, the influence of different occupant sizes and weights could also be studied.

Besides the extensive test programme, a further objective of HeliSafe TA was concerned with the generation and improvement of crash simulation models. Different project partners used different computer programs for the crash simulation of helicopters and their occupants. In fact, the codes that were applied in the project represent the complete range of currently available types of crash simulation tools. Eurocopter used the finite element crash code RADIOSS for the simulation of the modern helicopter EC120 and the safety equipment developed in HeliSafe TA. Politecnico di Milano applied the programs HKS/ABAQUS and VEDYAC for the simulation of different seat/occupant configurations. DLR generated a model of the Bell UH-1D helicopter used in a range of simulation runs with the hybrid crash simulation program DRI-KRASH [6]. Various project partners applied the program MADYMO [12] for the detailed simulation of the interaction between occupant dummies, seats and safety equipment.

In the past, the quality of the achievable crash simulation results in the aerospace field was not on the same level as in the automotive industry, simply because of a lack of crash test results which are needed for the verification of the simulation models. The number of tests – especially full-scale crash tests – which is carried out is extremely small in comparison to the automotive sector where a car can be crashed at relatively low costs. The same is true for the dummy model development. The relatively small number of tests and the additional needs of aviation dummies such as the 'vertical' measurements (e.g. lumbar spine loads) require additional effort to be put into the respective dummy software models. The broad test data base generated within the project 'HeliSafe TA' helped to improve the quality of crash simulation in the aeronautical field.

This introduction gives a brief overview on some of the activities carried out within the EU funded project 'HeliSafe TA'. Many other activities such as the development of new harness systems by Autoflug are not described in detail in this paper.

2 Full-scale Drop Tests in HeliSafe TA

Fig. 1: First HeliSafe TA drop test at CIRA.

Three drop tests were carried out within 'HeliSafe TA' at CIRA's test facility LISA with helicopters of the type Bell UH-1D (also named Bell Model 205 or Huey). They were equipped with 3 Martin-Baker safety seats and 3 dummies (pilot, forward and side facing passengers). Missing parts of the helicopter like the engine or the gear box were replaced with adequate metal parts in order to have the correct mass distribution [4].

The helicopters were equipped with on board data acquisition units from CIRA and SRS (Siemens Restraint Systems). In total, 128 channels were used to measure the accelerations on the structure, the seats and dummies as well as the loads on the dummies and the displacements of the cabin and the seats. Apart from several normal cameras, four digital high speed video cameras were used for the documentation of the tests.

In the test, the helicopter was accelerated along the LISA truss and then released in a predefined height above the ground in order to impact with the planned velocities.

Impact conditions:

The initial pitch Euler angle Theta in the 3 tests was between 8.5° and 8.8° nose up.

The impact forward velocities Vx were 11.1 m/s in the first test and 12.3–12.6 m/s in the other tests.

The impact downward velocities Vz were 9.3 m/s in the first test and 7.7–7.8 m/s in the other tests.

These values are given in the global coordinate system (ground axes).

In the local coordinate system – parallel to the helicopter floor – this corresponds e.g. in the first drop test to 9.5 m/s in x-direction and 10.9 m/s in z-direction (see Figure 2).

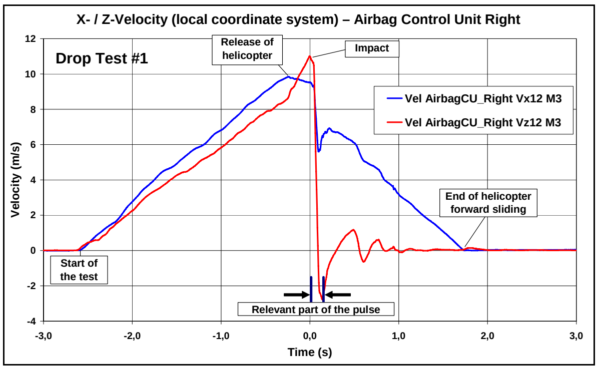

Fig. 2: Velocity time histories in first drop test.

Fig. 3: Bell UH-1D (before drop test #3).

Fig. 4: Bell UH-1D after drop test #1.

3 KRASH Simulation of the UH-1D Drop Tests

DLR was responsible for the simulation of the full-scale helicopter drop tests in 'HeliSafe TA'. For this purpose, a DRI-KRASH model of the Bell UH-1D helicopter was generated which also included a simplified representation of the 3 energy absorbing seats and the occupants [5].

Figures 5 and 6 show two different views of the UH-1D KRASH model which has a total mass of 3850 kg.

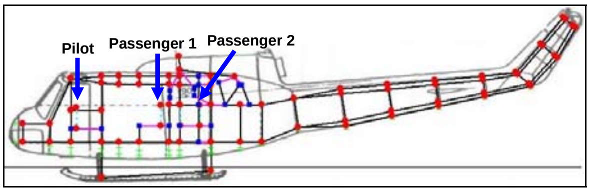

Fig. 5: Overlay of KRASH model and UH-1D drawing

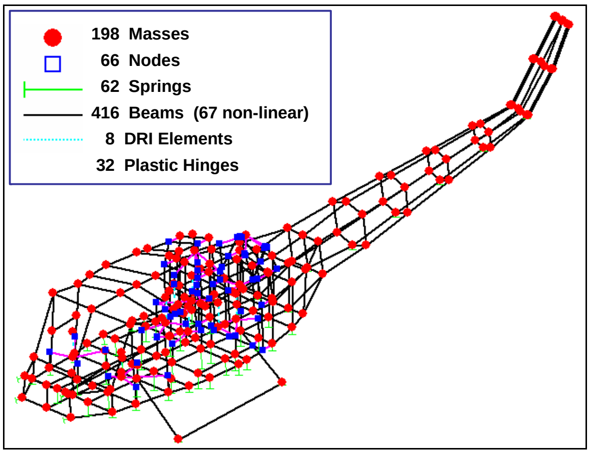

Fig. 6: Perspective view of UH-1D KRASH model.

For the representation of the different energy absorption processes, the correct definition of non-linear beams, plastic hinges and spring elements is of utmost importance.

The DRI elements are used for the calculation of the passenger's Dynamic Response Index – which can be correlated with the individual injury risk.

The DRI-KRASH model was initially used in pre-test simulations for the definition of the impact conditions in the drop tests. After the first UH-1D drop test, DLR carried out an extensive evaluation of the test results. By comparison of the simulation and test results, the KRASH model could be verified and in an iterative process further improved. As a typical 500 ms simulation run with the UH-1D DRI-KRASH model only took about 10 minutes on a PC, numerous model variations could easily be simulated.

The required modifications to the DRI-KRASH model included, for example, changes in the mass distribution, in characteristics of plastic hinges, in beam failure loads and in friction coefficients. In order to represent the behaviour of the landing gear correctly, plastic hinges as well as maximum deflections/rotations were defined for the respective beam elements in the KRASH model.

Figure 7 shows an example, where the correct choice of input parameters is of decisive influence for the overall behaviour of the helicopter model: In the area where the tail boom is attached to the helicopter cell, the occurring crushing and plastic deformation is represented with a combination of non-linear beam elements and plastic hinges.

The hybrid code DRI-KRASH [6]

The crash simulation program KRASH predicts the response of vehicles to multi-directional crash environments. KRASH provides the interaction between rigid bodies through interconnecting structural elements (beams), which are appropriately attached (pinned, clamped). These elements represent the stiffness characteristics of the structure between the masses. The equations of motion are explicitly integrated to obtain the velocities, displacements and rotations of the lumped masses under the influence of external and internal forces.

In the hybrid modelling technique, large regions of structure are approximated in a simplified manner. Non-linear behaviour (e.g. force-deflection curves) of substructures, which is already known from tests or other analyses can be introduced into the model by use of macro elements like springs, non-linear beams or plastic hinges. The fact that a KRASH model requires only a small number of elements (compared to models for use with FE-crash simulation codes) results in extremely short CPU times. Changes in the KRASH model and parametric studies can quickly be performed.

KRASH has a history of more than 35 years. Originally developed under U.S. Army sponsorship for application to rotorcraft, the following development, sponsored by the FAA, extended the capabilities of KRASH for application to general aviation and transport airplanes. During the last 18 years KRASH was significantly improved by Dynamic Response Inc., California. Many new features have been added to the code, important especially for aircraft crash simulation. DRI-KRASH now includes additional injury criteria, e.g. HIC and SI calculations, an expanded oleo-pneumatic landing gear module, a soft soil module as well as a water impact module.

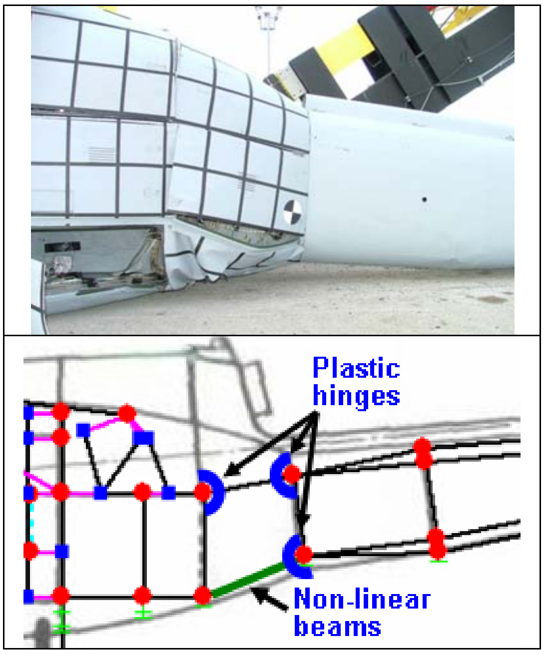

Fig. 7: Modelling of the 'crushing zone' between helicopter cell and tail boom.

Further non-linear beams are used for the representation of vertical beams connecting the floor and the deck (like the transmission tunnel beams or the engine deck beams) – part of the kinetic energy of the large upper masses can thus be absorbed by deformation of these vertical connections.

Verification of the UH-1D DRI-KRASH model

Figure 8 shows the deformation and the loading of the KRASH model during the first 200 ms after the impact. The sequence of the KRASH simulation is visualized with the KRASH Animation Program KAP 3.0 [7]. The different colours of the KRASH beam elements represent their loading (X-Force = Force in beam direction).

Figure 9 shows a sequence of the KRASH simulation in comparison with single frames taken from a high-speed drop test video. It can be observed that up to a time of 150 – 200 ms most of the major effects are represented quite well in the KRASH simulation. Some of these effects are the failure of the landing gear, the tail boom behaviour (rebound etc.), the downward movement of the seats and the formation of plastic hinges in the helicopter floor.

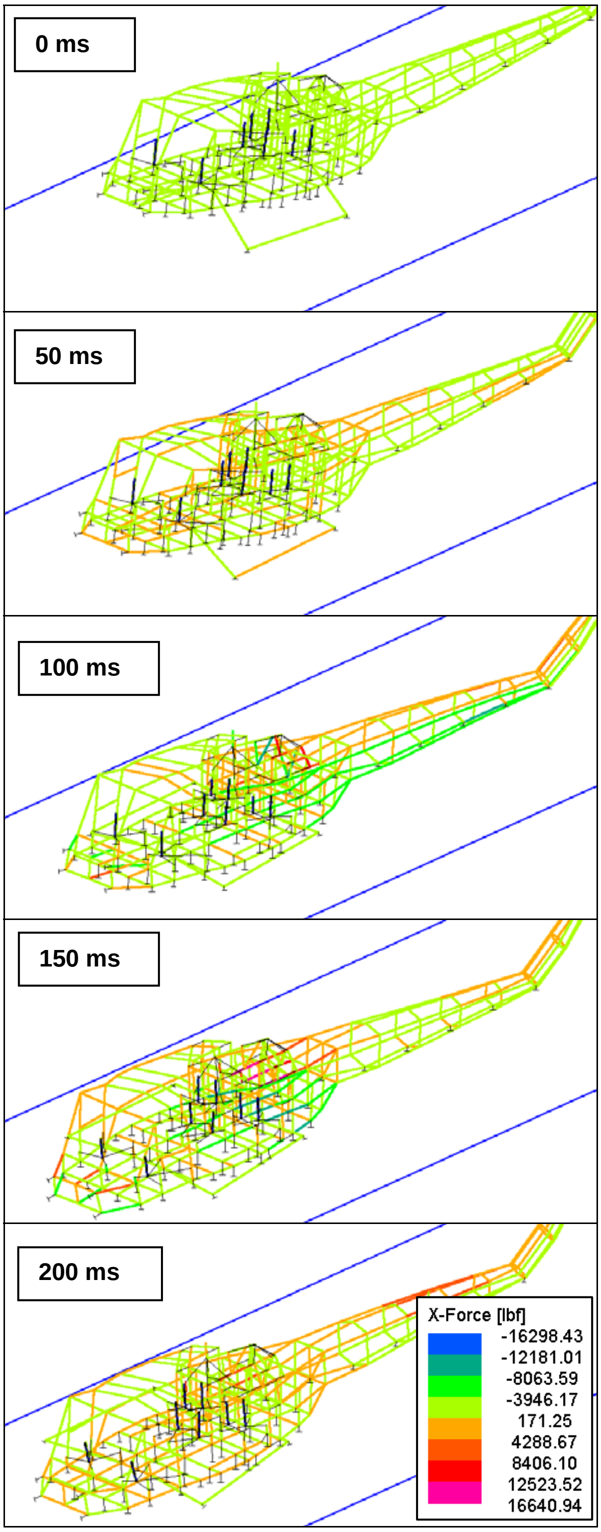

Fig. 8: KRASH simulation sequence (drop test #1 conditions).

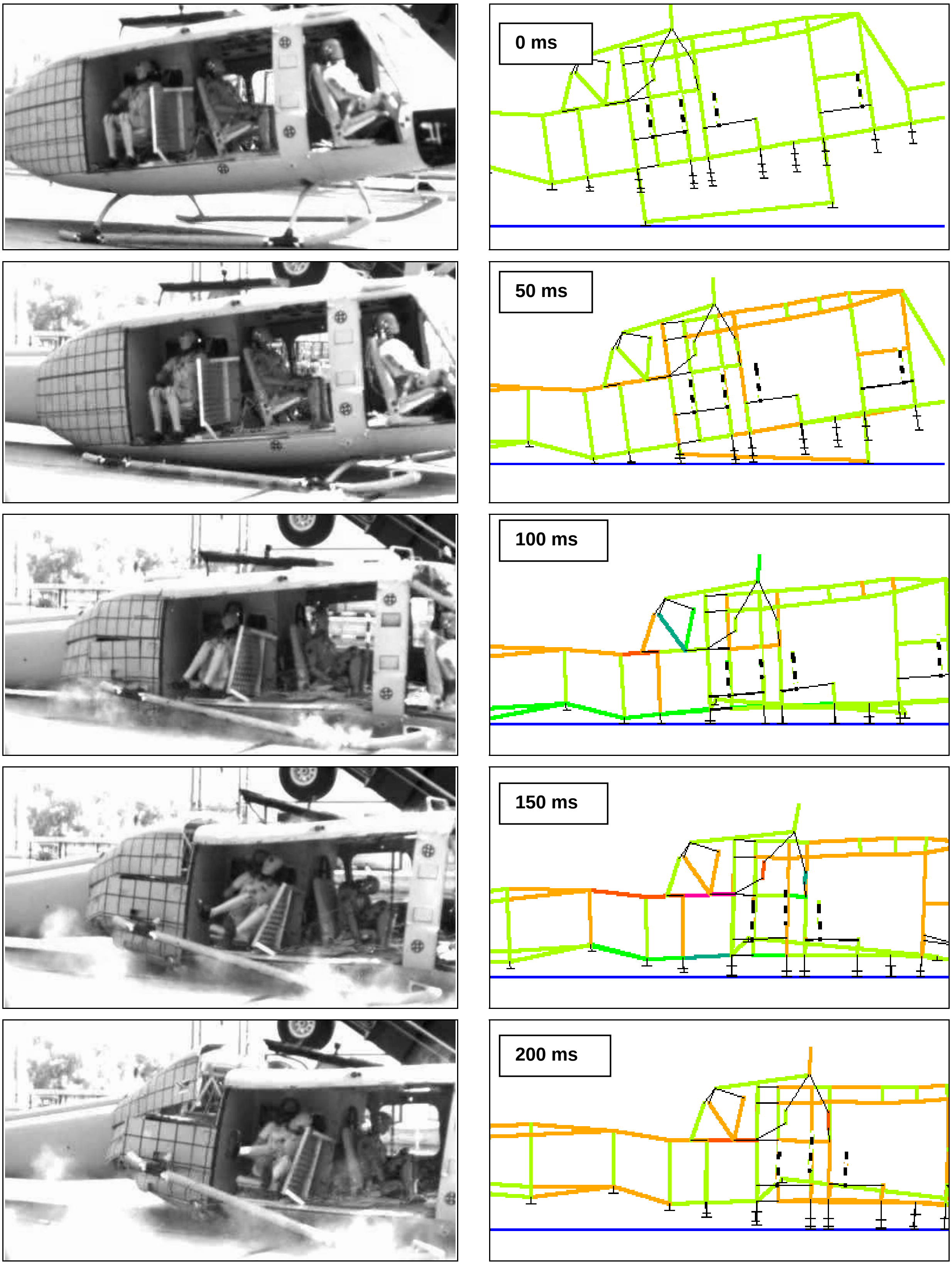

Fig. 9: Comparison of test video (source: CIRA) and KRASH simulation sequence.

In Figures 10 and 11, the x- and z-velocities of the 'Airbag Control Unit Right' accelerometer (SRS) are compared with the respective KRASH simulation results.

For the time after 0.6 s, the reduction of the forward velocity is mainly dependent on the friction coefficient. The sliding of the helicopter ends after 1.74 s resulting in a friction coefficient of about 0.47 in the first drop test.

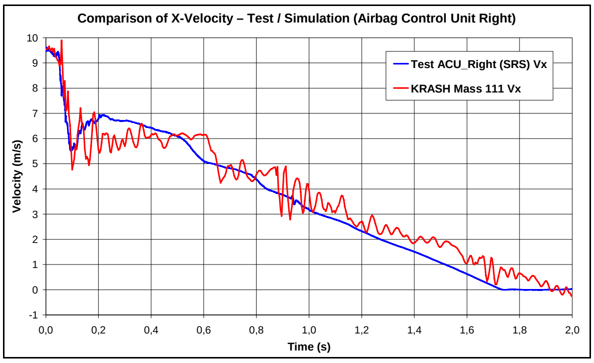

Fig. 10: Comparison of x-velocities – Drop test and KRASH results.

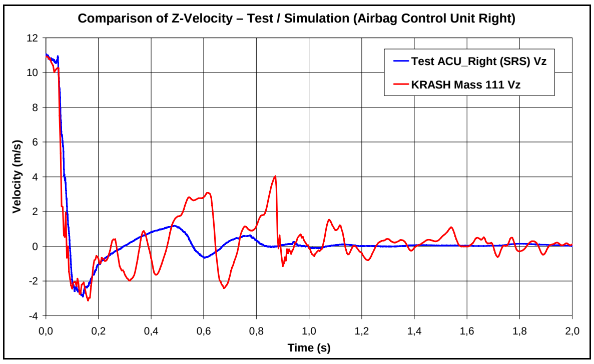

Fig. 11: Comparison of z-velocities – Drop test and KRASH results

For the vertical direction, a very good correlation between test results and KRASH simulation can be found up to 300 ms after the impact. Even the maximum rebound velocity of about -3 m/s is nearly identical. Between 300 ms and 900 ms, the simulated velocity curve oscillates with larger amplitudes than the measured curve. With regard to the loading of the helicopter occupants and the determination of their injury risk, however, only the first 200 ms after the impact are really relevant.

4 Procedure for the Definition of a Representative Floor Pulse

For the 'HeliSafe TA' sled test programme it was necessary to define sled test pulses which represent the 'real world' conditions in the drop tests in the best possible way.

In the project 'HeliSafe' which preceded 'HeliSafe TA', the **HOSS concept** (Helicopter Occupant Simulation Software) was developed': "*The basic HOSS concept is to decouple the helicopter structural crash response from the cockpit/cabin response in the crash, and to use existing software codes for modelling both the structural crash and cabin interior responses. The helicopter crash structure response is determined from simulations with established aircraft crash codes – either hybrid type (e.g. DRI-KRASH) or FE type (e.g. RADIOSS). The output from the crash codes is defined as floor deceleration pulses for particular crash scenarios, which became the input data for the cockpit/cabin safety studies.*"

In the earlier European project 'HeliSafe' only the standard triangular acceleration pulses were considered which are defined in the respective FAA regulations.

In a real crash, accelerations develop independently from each other in all 3 directions. In contrast, a (one-dimensional) sled test only allows the representation of acceleration components which are coupled with each other depending on the orientation of the test article.

As a further boundary condition, it is not possible to have alternating acceleration and deceleration phases in a sled test pulse. The accelerations measured in a drop test or resulting from the respective simulations are normally highly oscillating curves which cannot directly be used in a sled test application.

DLR developed a procedure for the generation of a pulse which has a suitable shape (without oscillations) but still represents the original drop test acceleration in the best possible way. This procedure was applied for the 3 different seat/dummy positions in the helicopter (one pilot, two passengers) – generating different representative floor pulses for all locations.

Basic input for the generation of the sled test acceleration pulses were the floor accelerations which were simulated at the 4 respective seat attachment points with the DRI-KRASH model of the UH-1D helicopter. (Remark: As not all required measurements were available from the first drop test, it was decided to rely on the validated simulation model.)

From the floor accelerations the velocity time histories are calculated for the four seat attachment points. Then the 4 curves are averaged to have one velocity time history curve for each seat.

Orientation of mock-up in sled test

In a full-scale drop test or the respective crash simulation, the x- and z-velocity components change independently from each other after the impact and therefore the angle of the resultant velocity vector changes during the impact phase. A drop test cannot exactly be represented in a sled test, as the relation between the x- and z-velocity components is fixed and one or both velocity components can only be approximated.

Figure 12 shows the orientation of the velocity vector for the 3 dummy locations for the first 180 ms after the impact. The calculation is based on the relation of the z- and x-velocity components. For each of the 3 positions, a constant angle (dashed line) is drawn which could be used in a sled test to have the best representation of the drop test situation (see also Figure 13 for the definition of angles).

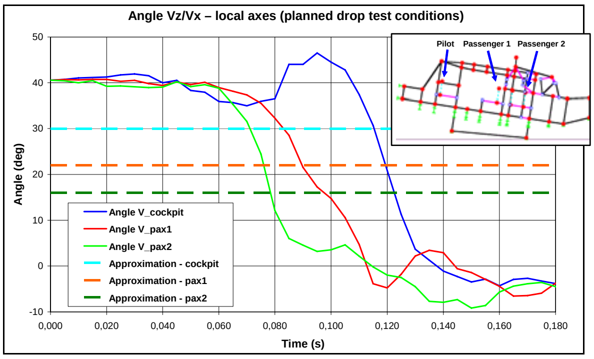

Fig. 12: Orientation of velocity vector for 3 different dummy locations.

Location	**Angle (°)**	Angle (°) between mock-up floor and ground: BETA
Cockpit (Pilot)	30	60
Passenger 1	22	68
Passenger 2	16	74

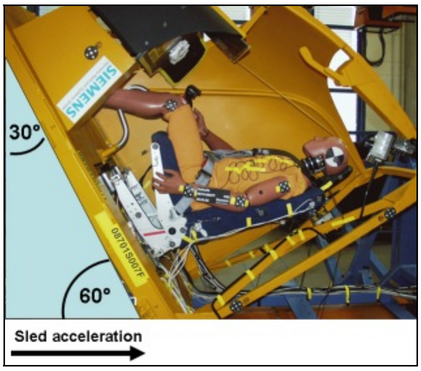

Fig. 13: Proposed sled test mock-up orientation.

Calculation of acceleration pulses

In the next step, the velocities are differentiated for the calculation of the acceleration curves. Here, only every fifth data point of the new velocity time histories is used (time step 5 ms instead of 1 ms) in order to obtain 'smoother' acceleration curves.

As the chosen scenario is dominated by this vertical component, it makes sense to fix the z-component so that it corresponds 'exactly' to the z-acceleration in the drop test. The less important x-component is then approximated by multiplication of the z-component with a constant factor which depends on the angle between the mock-up floor and the ground. This factor should give the best possible representation of the drop test situation over the relevant part of the pulse.

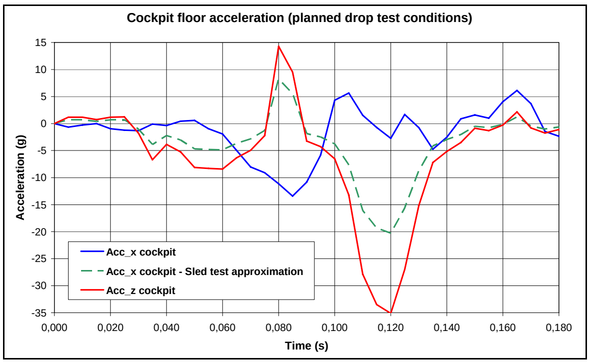

Fig. 14: Cockpit floor acceleration / sled test approximation.

In order to judge the quality of the approximated x-acceleration curve, the resulting x-velocity and x-displacement are also compared with the original data. Figure 15 shows the time histories of the two velocity components for the cockpit floor. For the z-component, the change in velocity corresponds more or less exactly to the drop test situation. For the x-velocity curve, there are of course discrepancies between the drop test conditions and the sled test approximation (dashed line).

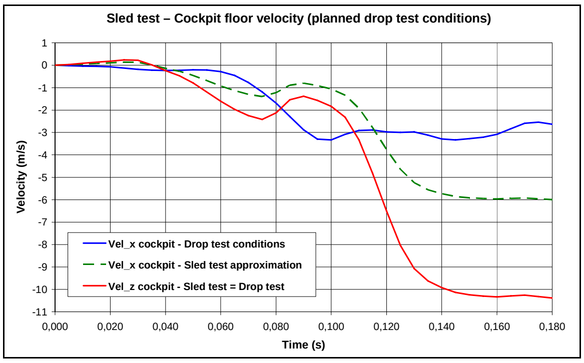

Fig. 15: Cockpit floor velocity / sled test approximation.

In the following diagram, the z-acceleration pulse of the cockpit is compared to the pulses of the two passenger positions. 'Passenger 2' is exposed to the severest acceleration pulse.

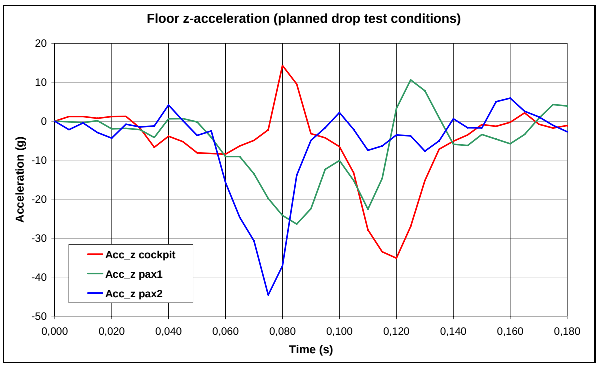

Fig. 16: Comparison of floor z-acceleration pulses / sled test approximation.

For the pilot, the maximum acceleration as well as its onset rate are higher than in the definition of the standard triangular FAA pulses. This pulse shape does not account for the first phase after a 'real world' impact when only the landing gear is in contact with the ground.

It can be seen for passenger 1, that the maximum accelerations are similar to the 'standard' values but that the triangular shape of the FAA pulse is quite different to the 'real world' pulse shape with the two major peaks at 85 and 110 ms. Here, a trapezoidal acceleration pulse shape would give a much better representation of the 'real world' situation than the standard triangular pulses.

Resultant sled test acceleration

Finally, the resultant sled test acceleration (parallel to the ground) is calculated by dividing the z-acceleration component with the sine of the angle between the mock-up floor and the ground (see Figure 17).

Only the relevant part of the pulse (25 - 155 ms in case of the cockpit) is considered: Time 0 corresponds to 25 ms in the original time scale, 130 corresponds to 155 ms in the original time scale. As a result, the red dashed curve (Acc_resultant orig.) is generated.

It is not possible to have alternating acceleration and deceleration in a sled test. The positive accelerations during the interval 55 – 60 ms can therefore not be realised in a sled test. This part of the curve has to be modified (=> blue curve).

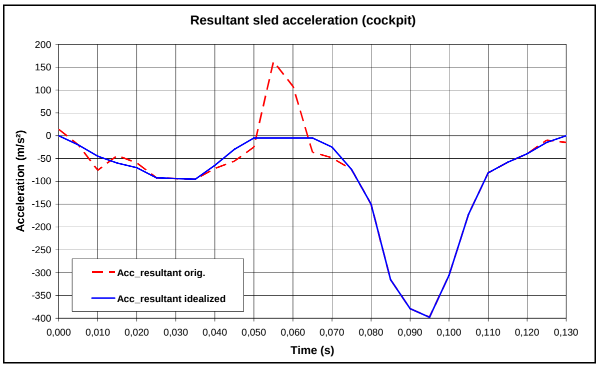

Fig. 17: Resultant sled test pulse for the cockpit mock-up.

5 Sled Test Programme

An extensive sled test programme was carried out in HeliSafe TA at the facilities of SRS (Siemens Restraint Systems) [8] in Germany and CIDAUT [9] in Spain. Figure 19 shows the helicopter cockpit and cabin mock-ups which were used in the sled tests. For both mock-ups 3 different test configurations are shown.

Besides those sled tests which were carried out with a standard triangular acceleration pulse in the horizontal direction (18,4 g peak at 71 ms), the sled tests should represent the mainly vertical loading conditions in the UH-1D drop tests as well as possible. In Figure 18 the theoretical acceleration pulse calculated by DLR is compared to the actual achieved pulse in the cockpit sled tests at SRS.

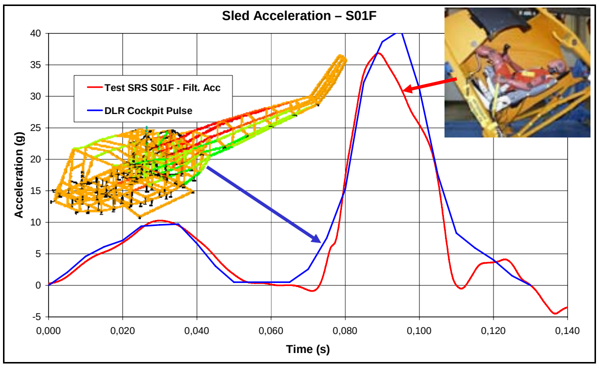

Fig. 18: Comparison of DLR cockpit pulse and SRS sled test pulse.

The cockpit and cabin mock-ups were equipped with safety seats from Martin-Baker who were a partner in the first HeliSafe project. These seats have two energy absorbing devices and are e.g. used in the BK117 helicopter.
Special modules were added to the floors of the two mock-ups at the seat attachment points which allowed to preload and misalign the seats around two axes (10° roll / 10° pitch) – thus representing a possible floor deformation during the impact.

Most sled tests were conducted with the FAA Hybrid III 50th percentile dummy which has enhanced bio fidelity and the ability to measure and assess relevant injuries in helicopter crashes.

Besides the tests with the 50th percentile dummies, some sled tests were also carried out with a 95th percentile dummy in order to study the influence of different occupant sizes and weights.

An EuroSID-2 dummy was used in the side-facing sled test configurations.

The sled tests included the evaluation of different harness types and the variation of pretensioner loads and firing times. In case of the cockpit, SRS also developed an airbag which was tested in sled tests as well as in the final drop test.

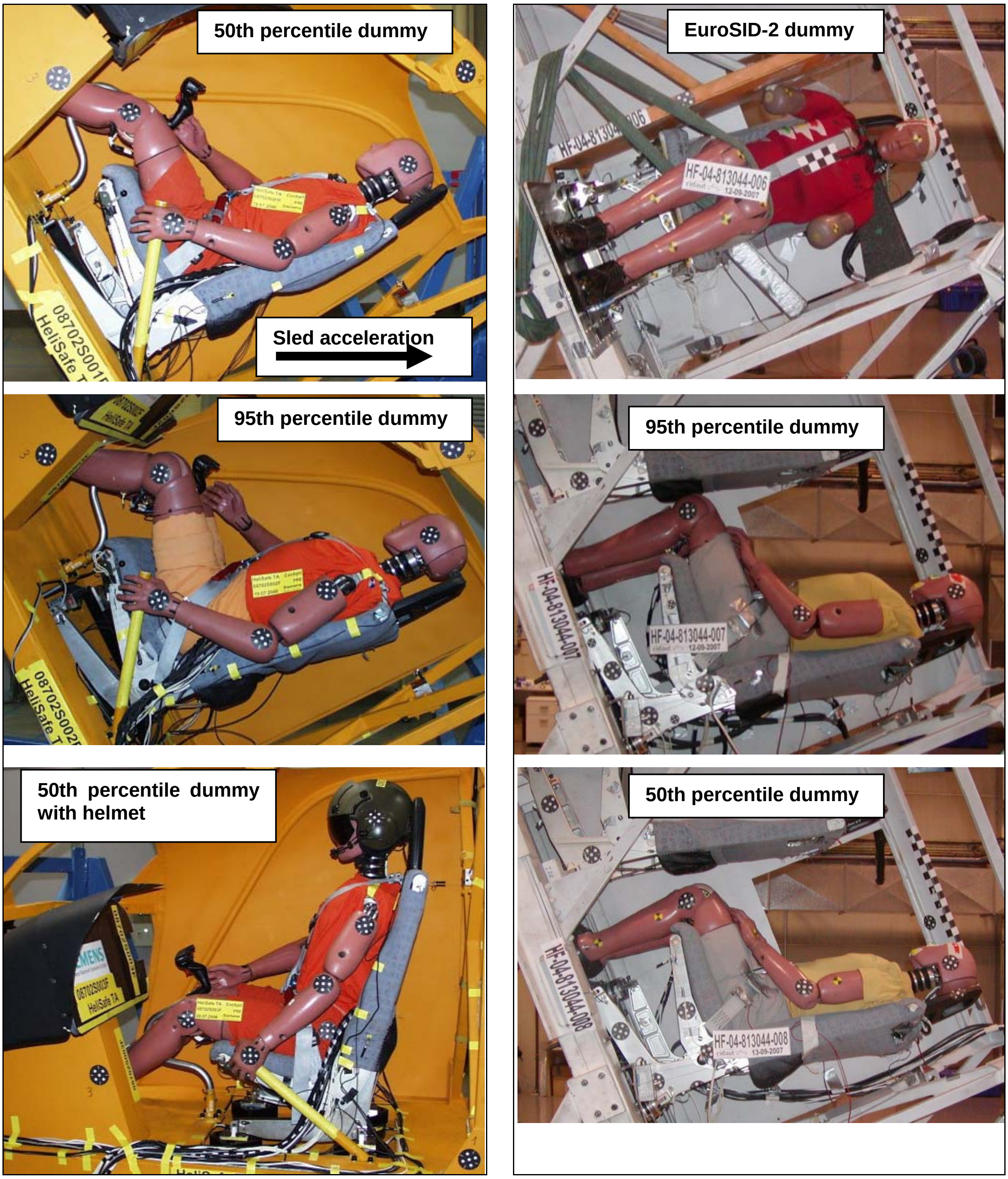

Fig. 19: Sled test configurations in HeliSafe TA (Cockpit – SRS, Cabin – CIDAUT).

6 Cockpit Simulation Studies

Different project partners used the program MADYMO in 'HeliSafe TA' for the detailed simulation of the helicopter dummies and seats together with the restraint system (belts, airbag). The MADYMO models also included a representation of the surrounding structure in the cockpit and cabin mock-ups.

First, the baseline sled tests were used for the verification of the models. Subsequently, improved safety equipment (e.g. harness system, airbag) was developed in parametric simulation studies. After the final sled tests with the improved equipment the simulation results could once again be verified.

DLR and SRS carried out the simulations with the MADYMO models of the cockpit mock-up. SRS performed the simulations of the horizontal load case and DLR carried out the studies with the mainly vertical loading of the pilot dummy [10, 11].

Figure 20 shows a sequence of the sled test video compared to the MADYMO simulation with the 95th percentile dummy.

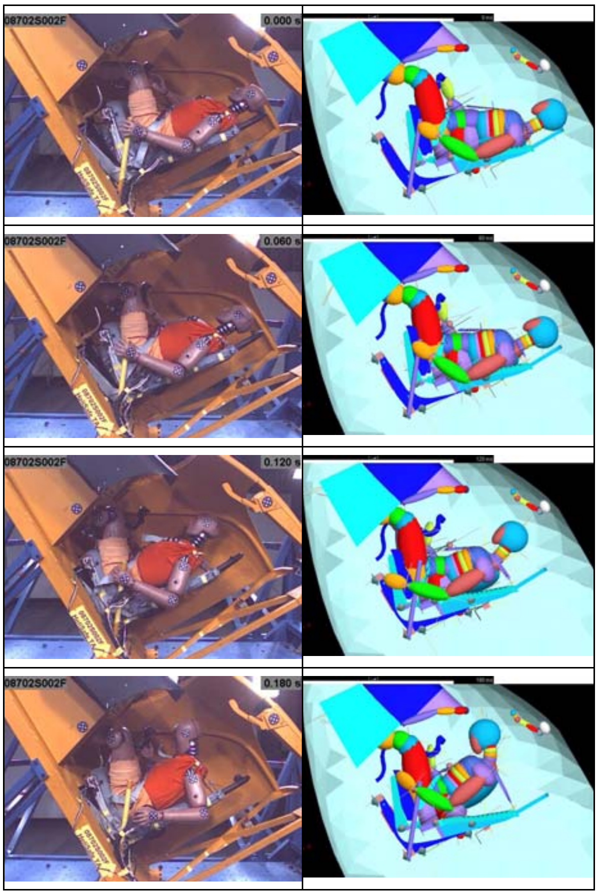

Fig. 20: Comparison of cockpit sled test S2 (SRS) and MADYMO simulation (0 / 60 / 120 / 180 ms).

MADYMO is a software program from the Dutch company TASS (TNO Automotive Safety Solutions). It is widely used in the automotive industry, primarily for occupant safety analysis. MADYMO features generic multi-body and finite element capability, a full range of dummy models as well as tools supporting the restraint optimisation process [12].

The visual comparison of the test video from SRS and the simulation shows a relatively good agreement with regard to the movement of the upper part of the body and the head. The behaviour of the left arm does not correspond to the test from about 90 ms onwards. In the model the complete hand is represented with one ellipsoid (without fingers). Therefore, the contact between the hand and the stick is not well represented in the simulation.

It can clearly be seen in Figure 20 that the seat moves downwards between times 60 and 120 ms and thus absorbs energy during this period.

Figure 21 shows the lumbar spine loads in the test and different simulation runs, in which the characteristic of the seat energy absorbers was varied. It can be seen that the shape of the curves are similar but that the load level is higher in the simulations than in the test.

The second load increase after about 125 ms occurs when the available seat stroke of 120 mm is used up (bottoming out).

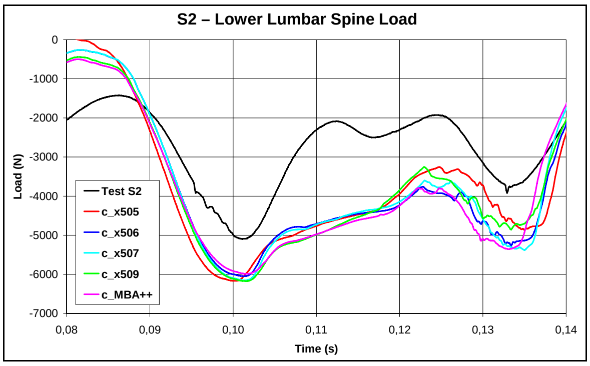

Fig. 21: Lumbar spine load in cockpit sled test S2 (SRS) and MADYMO simulation.

It must be mentioned that the accuracy of the simulation results was higher for the FAA Hybrid III 50th percentile dummy model than for the 95th percentile dummy model shown here. As the development of the latter started much later, it could not yet be verified to the same extent as the lighter 50th percentile dummy model.

Assessment of occupant safety

In order to judge the occupant safety in helicopter crashes, the injury severity index IRSIX was established in HeliSafe TA [13].

Instead of looking only at a single injury criterion like the HIC value (Head Injury Criteria), 15 different injury criteria are combined in one parameter, the injury severity index IRSIX. It includes e.g. femur forces, pelvis acceleration, chest deflection, neck extension, HIC and lumbar spine loads. Each criterion is weighted according to its importance for the respective crash scenario:

$$IrSIx = \sum_i (IrSIx)_i = \sum_i (weighting)_i \cdot \frac{(LoadValue)_i}{(LoadLimit)_i} \cdot 1000$$

In a mainly horizontal impact scenario, the most important criteria are the HIC with a weighting of 30%, the chest acceleration (20%) and the chest deflection (10%). In a mainly vertical load case, the lumbar spine load is weighted with 40%. HIC (20%) and chest acceleration (10%) are the next most important criteria.

The smallest possible IRSIX value represents the lowest injury risk and thus the best possible solution.

The different HeliSafe TA project partners conducted numerous parametric studies in order to define the optimum safety system for helicopters. Siemens Restraint Systems developed and optimised a pilot airbag (Figure 22). Here, parameters like inflator power, the size of the vent hole or the time to fire the airbag were considered.

Figure 23 shows MADYMO models of different harness systems which were analysed in the project (mainly by Autoflug and Coventry University). Besides the arrangement of the belts, parameters like belt elongation, pretensioner load, time to fire and load limiter were also investigated.

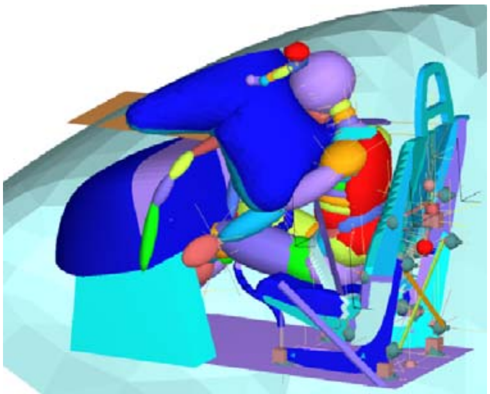

Fig. 22: Cockpit airbag developed by SRS.

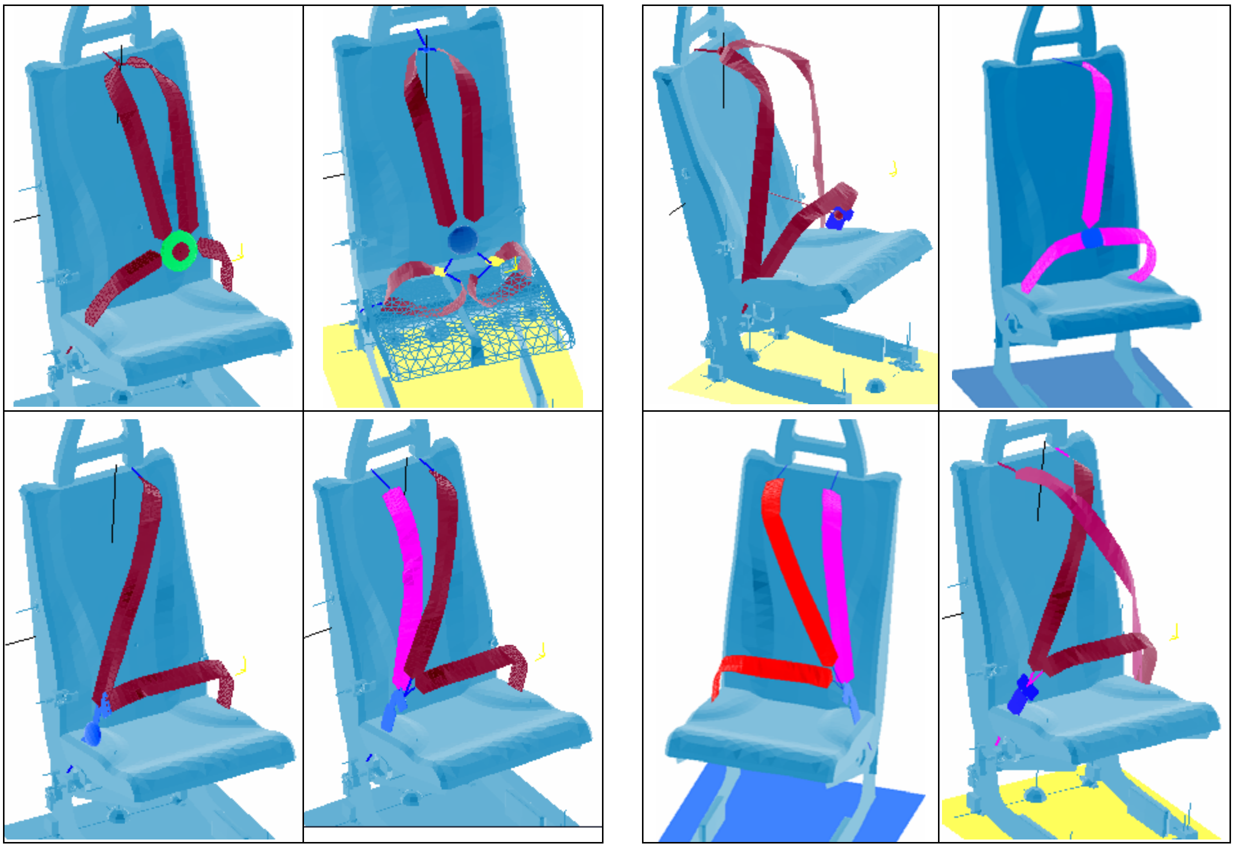

Fig. 23: Harness systems analysed in HeliSafe TA (Source: AUTOFLUG, Coventry University).

7 Optimised Energy Absorber Elements

DLR examined the mainly vertical load cases for the helicopter cockpit. Here, the injury severity index, IRSIX, is dominated by the lumbar spine load criterion. This means that – in most cases – the minimisation of the lumbar spine loads is equivalent to the optimisation of the overall IRSIX value.

The lumbar spine loads, in turn, primarily depend on the characteristic of the seat energy absorbers. DLR carried out an extensive parametric study in order to optimise the properties of the energy absorbers used in the cockpit seats and to propose a concept which leads to the lowest possible injury rates for occupants of different weights and sizes [14].

It could be shown that for the cockpit vertical load cases the influence of the belt related parameters is relatively small compared to the large influence of the attenuator characteristics. Therefore, these parameters were kept constant in the seat absorber study (TTF pretensioner: 8 ms, pretensioner load: 2 kN, load limiter: 4 kN).

The earlier described DLR cockpit pulse (Figs 17, 18) was applied in all simulation results presented here.

Absorber characteristics

Three different absorber groups (Figures 24-26) were investigated. In the first group, the absorber characteristics show an increasing force level with increasing displacement. In the second group, the force level stays constant until the bottoming out phase is reached (at 120 mm). In the third group, the force decreases with increasing displacement.

For each of the three absorber groups, 21 different variations (Case 10 – Case 30) were simulated. Between two variations, the force level is increased about 100 N – with Case 10 having the lowest level and Case 30 having the highest forces. This corresponds to an additional energy absorption capability of approximately 11.8 J in each step.

Each case represents a similar energy absorption capability for each of the 3 groups. (Example: Energy of **i18** = Energy of **c18** = Energy of **d18**.)

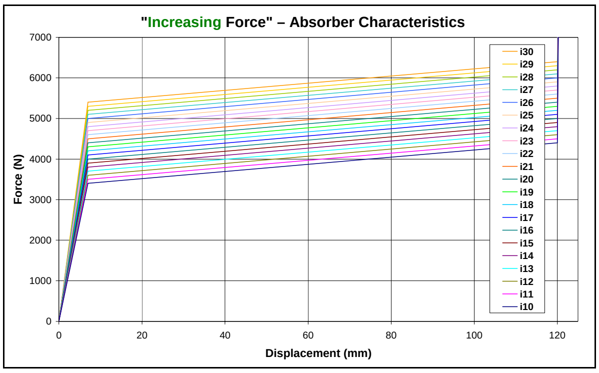

Fig. 24: Characteristics of the "increasing force" absorber group.

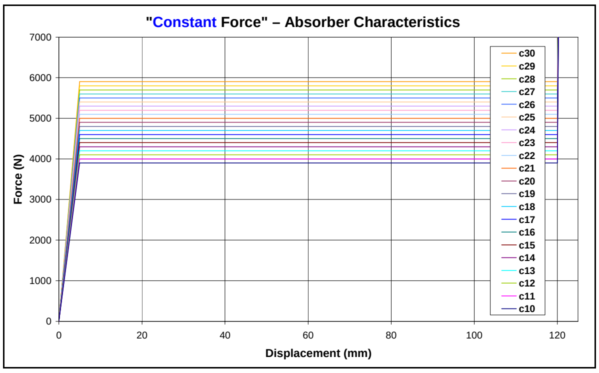

Fig. 25: Characteristics of the "constant force" absorber group.

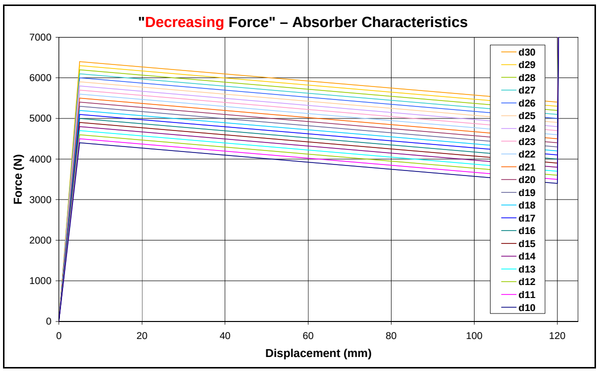

Fig. 26: Characteristics of the "decreasing force" absorber group.

Results for the 50th percentile dummy

Figure 27 shows the resulting IRSIX values dependent on the simulated absorber characteristics for configuration S1 (50th percentile dummy). For each of the three absorber groups, there is a clear optimum.

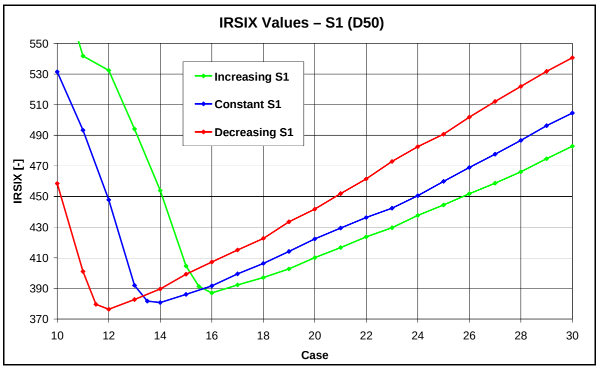

Fig. 27: IRSIX Values in configuration S1.

Figure 28 shows the maximum lumbar spine loads for each case. The comparison to the IRSIX diagram clearly shows the dependency of the IRSIX value on the lumbar spine load criterion.

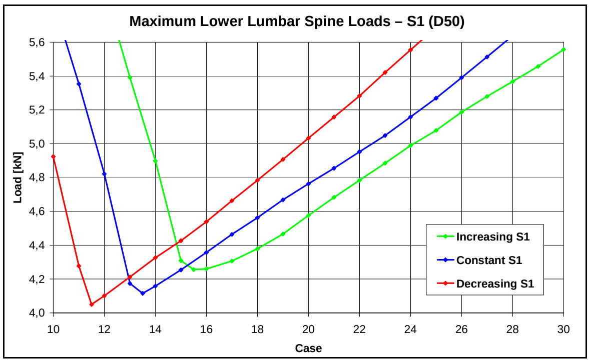

Fig. 28: Maximum lumbar spine loads in simulations with the 50th percentile dummy.

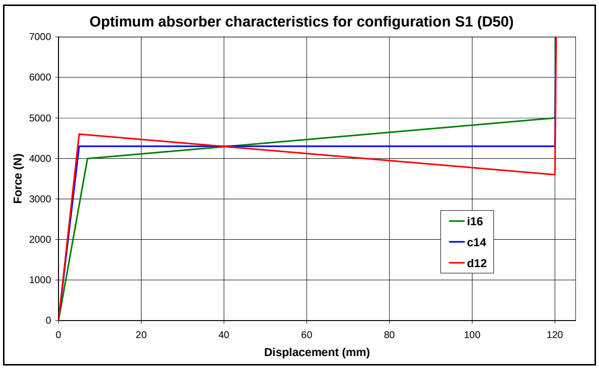

Fig. 29: Optimum absorber characteristics for configuration S1 (50th percentile dummy).

In Figure 29, the best absorber characteristics out of the 3 groups are shown. The lowest IRSIX value (376) is achieved for characteristic **d12**.

For characteristic **c14**, the IRSIX value is only slightly higher (381). As an absorber with a constant force level is easier to manufacture, it would be the recommended characteristic for configuration S1 (50th percentile dummy).

Results for the 95th percentile dummy

Figure 30 shows the maximum lumbar spine loads for the simulations with the 95th percentile dummy model (configuration S2). It can be clearly seen that the absorber force level has to be considerably higher than for the 50th percentile dummy in order to achieve acceptable lumbar spine loads. The absorbers which are best suited for the 50th percentile dummy (e.g. absorber **c14**) would generate a much too high spine load for the 95th percentile dummy (=> 8800 N / allowable Limit: 6670 N).

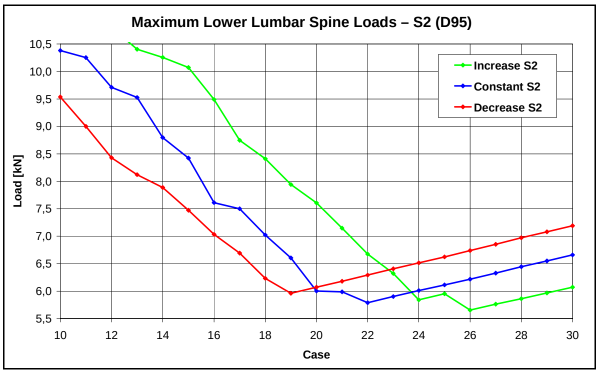

Fig. 30: Maximum lumbar spine loads in simulations with the 95th percentile dummy.

In Figure 31, the best absorber characteristics out of the 3 groups are shown for the 95th percentile dummy simulations. The lowest IRSIX values are achieved for characteristic **i26** (IRSIX=485) and for characteristic **c22** (IRSIX = 487).

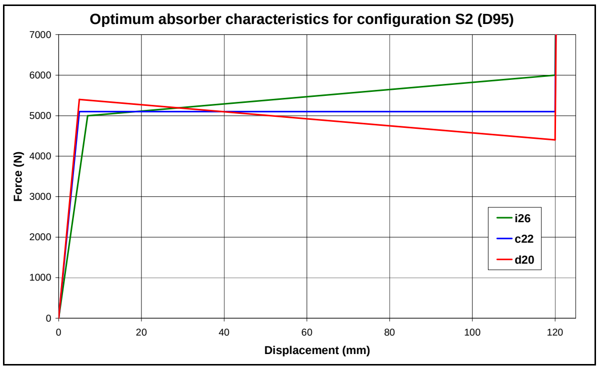

Fig. 31: Optimum absorber characteristics for configuration S2 (95th percentile dummy).

Best solution for different occupant sizes

Figure 32 shows the maximum lumbar spine loads of both configurations plotted in one diagram. The figure clearly shows that the optimal solutions for the two different occupant sizes (50th percentile / 95th percentile dummy) are not compatible with each other. The both dummy sizes require completely different absorber characteristics (and force levels) in order to achieve the lowest possible injury risk.

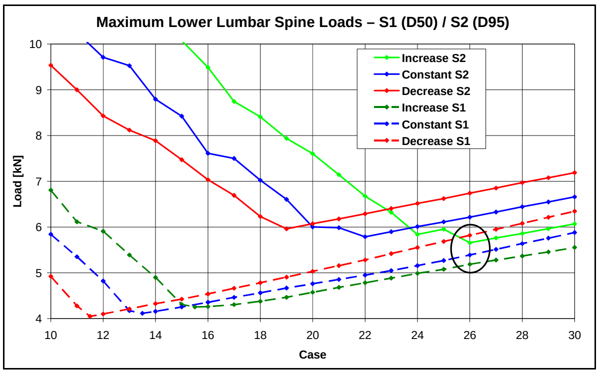

Fig. 32: Maximum lumbar spine loads in S1 and S2 simulations.

Variant 1 – Non-adaptive attenuator system

Figure 32 also shows the effects of the use of an absorber type which was not optimized for the respective occupant size (weight).

If, for example, the best absorber of the "increasing force" group for the 50th percentile dummy (**i16**) is used for the 95th percentile dummy, the lumbar spine loads are increased about 68% compared to the loads when the best absorber for the 95th percentile dummy (**i26)** is used. This would lead to lumbar spine loads at a level of 9500 N which is well beyond the allowable limit of 6670 N.

If, instead, the **i26** absorber would be used for the 50th percentile dummy, the increase of the spine loads is only 22%. With a maximum spine load of 5187 N, the limit is not exceeded.

The same behaviour can be seen for all 3 investigated absorber groups: The use of those absorbers which were optimised for the 50th percentile dummy, are not at all suitable for the 95th percentile dummy. On the other hand, in cases where the 95th percentile dummy optimised absorbers are used for a 50th percentile dummy, the increase of the spine loads is less critical.

In helicopter seat configurations in which occupants of different weight and size use the same seat and in which the absorber characteristics are non-adaptive (only one fixed absorber characteristic available for all occupant sizes), the best solution is to use the absorbers which were optimized for the heavier (95th percentile) dummy. Thus, the recommended absorber characteristic would be **i26** (see Figures 31, 32).

Variant 2 – Adaptive attenuator system

Figure 33 shows the recommended absorber characteristics for the two investigated dummy sizes. The curve **c14** which is recommended for the 50th percentile dummy results in an energy absorption of about 505 J. The curve **i26** which is recommended for the 95th percentile dummy gives an energy absorption of about 640 J.

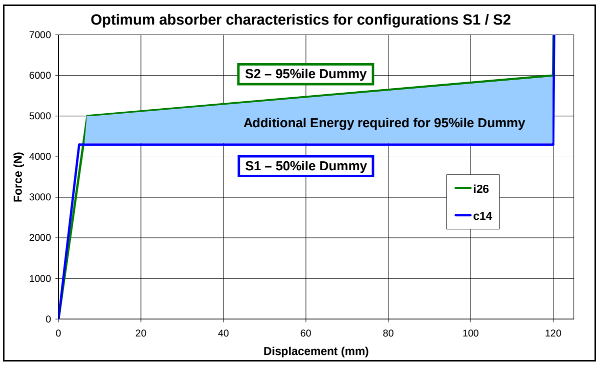

Fig. 33: Optimum absorber characteristics for configurations S1/S2.

In helicopter seat configurations with an adaptive attenuator system, it is recommended to supply two absorbers with the **c14** characteristic as standard. For heavier occupants, two additional absorbers with characteristic 'Add_95 (2X)' should be activated. Alternatively, depending on the seat design, only one optional add-on absorber with characteristic 'Add_95 (1X)' could be used. The best solution could be achieved with a system in which the force level of the additional absorbers is adapted according to the weight of the occupant.

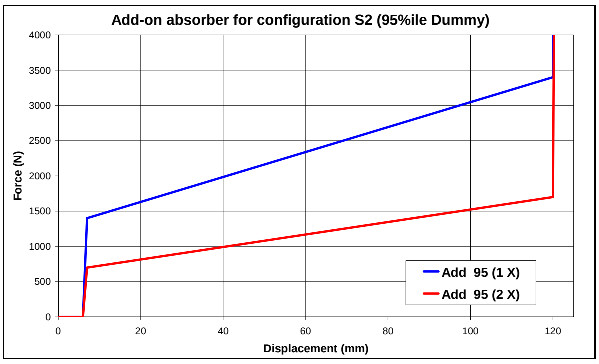

Fig. 34: Add-on absorber for configuration S2.

8 Conclusions

This paper has outlined some of the activities carried out within the EU research project 'HeliSafe TA', with a focus on the contribution of the German Aerospace Center (DLR). The overall aim of the project was the improvement of the occupant safety in helicopter crash landings.

- Safety devices such as energy absorbing seats, harness systems and airbags were improved or newly introduced.
- An injury severity index, IRSIX, was established in order to judge the injury probability and to compare different configurations (e.g. harness systems). It combines 15 different injury criteria in one parameter, including the HIC value, the lumbar spine loads, etc. – weighted according to their importance for the respective crash scenario.
- With three full-scale helicopter drop tests and 15 sled tests with cockpit and cabin mock-ups a wide load data base was developed. Thus, the different simulation models could be verified and optimised. In most cases, excellent agreement between test and simulation could be achieved. It was also shown that in single cases there is still room for improvements: The software model of the FAA Hybrid III 95th percentile dummy has to be further developed.
- DLR developed a DRI-KRASH simulation model of the UH-1D helicopter. As it proved to be very reliable, it was chosen to be used for the generation of the acceleration pulses in the sled test programme. The difficulties of representing a real crash (or drop test) in a sled test were explained. This paper described a procedure for the definition of a sled test pulse that can represent the conditions in a real crash in the best possible manner.
- It was shown that the standard triangular pulses defined in the regulations (FAR/CS 27 & 29) do not in any case correspond to the pulses measured and simulated within the project 'HeliSafe TA'. A trapezoidal pulse shape would probably give a better representation of the reality. It could also be seen that the pulses highly depend on the respective seat location within the helicopter.
- The equipment developed within 'HeliSafe TA' produced substantial improvements in occupant safety. With the cockpit airbag and the X-harness system, the injury severity index (IRSIX) could be reduced by 22% [15] in crash scenarios with high horizontal acceleration components. For the forward facing passenger, improvements of 13 – 20 % were achieved.
- Unfortunately, no improvements could be made for the side-facing passenger, as the intenseness of the contact with the bulkhead could not be reduced by the choice of different harness systems.
- In its cockpit simulation studies, DLR concentrated on crash scenarios with predominantly vertical acceleration components. It was shown that the IRSIX value is here mainly dependent on the respective maximum lumbar spine loads and thus on the energy absorption system in the seats. This paper described the results of a parametric study in which 3 different energy absorber groups were investigated for two different occupant dummy sizes.
- For each dummy size, an optimised absorber characteristic could clearly be identified. It was shown that a non-adaptive attenuator system can only be optimised for a specific occupant weight and size.
- If seats are used by occupants of different sizes and no adaptive system is available, it is recommended to apply absorbers which are optimised for the heavier occupant (95th percentile dummy).
- An adaptive attenuator system was proposed in which basic absorbers are supplied being optimised for a 50th percentile dummy. Additional energy absorbers should then be activated for heavier occupants.

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