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Please note this document consists of a copy of the paper and the presentation slides from the conference.

# Multibody Systems Simulations of Helicopter Crash Scenarios

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## Abstract

The work described in this paper describes how the computer aided engineering software programmes, ADAMS and MADYMO, have been used at Coventry University to carry out computer simulations investigating civil helicopter occupant protection systems. The work was carried out as part of the European 6$^{th}$ Framework HeliSafe TA project which considered the potential improvements in occupant safety through, for example, the introduction of airbags and new improved harness concepts. Models were developed at the start of the project to demonstrate the capability to model different landing scenarios for a full helicopter representation, including the fuselage, landing gears and tyres. The methods described here focussed on modelling the cockpit and cabin areas with representative models of the crash test dummies, the seats, the harnesses and a pilot airbag. The main elements of the models were developed using a multibody systems approach with additional use of finite elements for the modelling of airbags and harnesses.

The simulations performed fed into a larger programme of work involving 12 European partners. The simulations performed supported, within the larger programme of work, a series of physical tests involving sled testing of cabin and cockpit mock-ups and full scale instrumented crash testing of helicopter structures including a pilot dummy a forward facing passenger dummy and a side seated passenger dummy.

KEYWORDS: HeliSafe TA, MADYMO, Occupant protection, Crash analysis, Computer Simulation.

*The results presented here contributed to the European funded HeliSafe TA project under the 6$^{th}$ Framework programme. The authors wish to record their appreciation to the European Commission and the help and support of the project partners Autoflug (D) (Coordinator), Eurocopter SAS (F), Eurocopter Deutschland (D), PZL Swidnik (PL), SIEMENS Restraint Systems (D), DLR (D), CIDAUT (E), CIRA (I), TNO (NL), Politecnico di Milano (I) and University Delft (NL).*

## Introduction

Throughout their existence helicopters have proved their importance, not only in military service but also in a variety of civil applications. Their design and range of operational capability means that on some occasions a helicopter is the only effective means of transport available. It may have to operate in bad weather conditions or undertake search and rescue operations close to the ground or over open water. Operations of this type are often not possible with fixed wing aircraft (1, 2).

Modern helicopters are designed to meet international safety standards and use advanced design and analysis methods to deliver structures with high levels of crashworthiness. Projects such as Helisafe TA are intended to supplement a holistic approach to safety through more detailed study of the cabin and cockpit systems that contribute to and enhance protection for the pilot and other occupants. The work in Helisafe TA involved a large programme of developing and testing prototypes of the harnesses and airbag and as such relied on supporting computer simulation to progress the work. The methods used at Coventry University relied on models developed using a multibody systems approach with additional use of finite elements for modelling airbags and harnesses.

Initial studies involved the use of models in MADYMO to analyse helicopters impacting with ground terrain and utilised data for a generic helicopter. Using the multibody systems approach a full helicopter model was generated including representations of the mass distribution in the helicopter body, the articulation of the nose and main landing gears, the asymmetric nonlinear characteristics of the dampers and the tyre and wheel rim ground contact forces. Using these models the evolution of a rollover event was demonstrated (3) with simulations considering different approach angles and velocities and uneven representations of the ground surface. Further descriptions are provided here of a subsystem cockpit and cabin model of an actual helicopter subjected to a full scale crash test using a Bell UH-1D structure at the Italian research centre, CIRA in Capua.

The subsystem model was developed in MADYMO and replicates the test setup including a pilot dummy, a forward facing passenger dummy and side seated passenger dummy. Simulations were performed to recreate the inputs generated in the crash test and predict occupant injury levels. The paper concludes by describing how the model was used to investigate new occupant protection concepts involving the deployment of an airbag and new harness design concepts.

For safety simulations, whether for an aircraft or automobile, there are generally two types of modelling approaches available. One approach is the use of hybrid code models combining multibody and finite element techniques. The other approach is based on full finite element models including the vehicle structure, passenger cell, seats and safety systems. The finite element approach offers challenges in the complexity of model generation and computer simulation time while the multibody approach offers efficiencies that can offset these. A further approach, used in aerospace, is the use of a specialised hybrid software DRI-KRASH applied successfully in Helsafe TA by project partners DLR. For the work at Coventry University presented here a modelling approach was adopted in which cockpit/cabin models were developed and then analysed using representative acceleration pulses applied at the appropriate cockpit/cabin floor locations. Figure 1 shows in schematic form the modelling and simulation approach used throughout Helisafe TA.

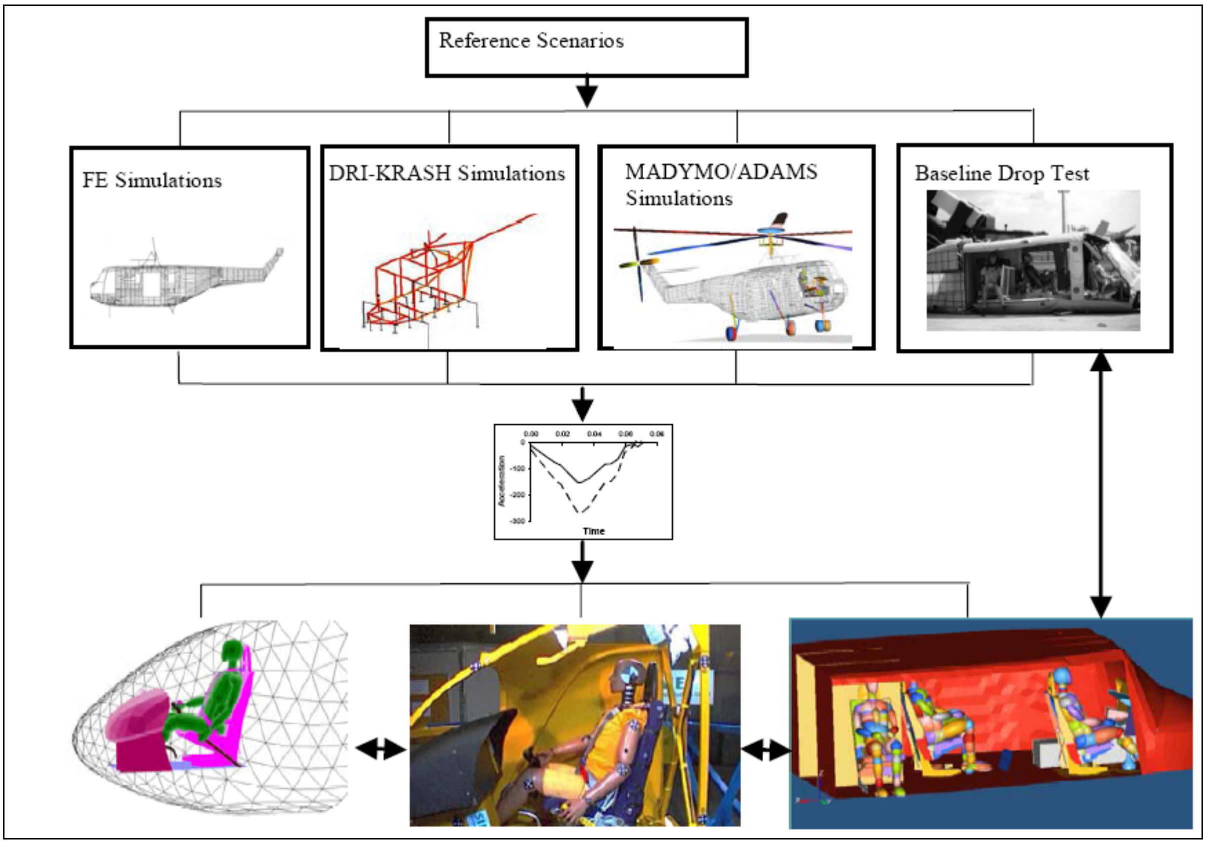


Figure 1 Safety modelling approach adopted in HeliSafe TA

## MADYMO Cabin/Cockpit Model Creation

In order to complete the study it was necessary to generate a MADYMO model of a Bell UH-1D cockpit and cabin interior allowing the incorporation of models of the seats, dummies and proposed safety concepts. An initial CAD model capturing the relevant areas of cabin geometry was developed using information from technical manuals and physical measurements of an actual helicopter. Surveys of the helicopter interior were carried out on a similar Bell UH-1H helicopter, which has the same body structure as a Bell UH-1D helicopter but a different engine.

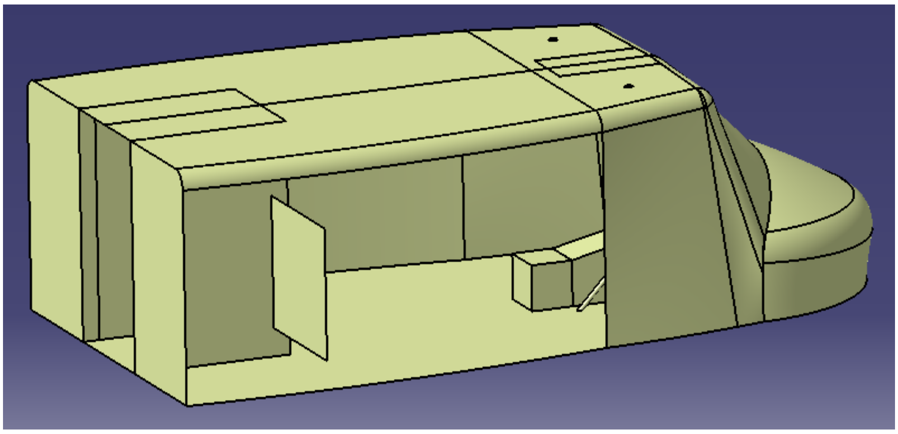

Figure 2 CAD geometry model of the cabin/cockpit for the Bell UH-1D helicopter

The measurements obtained were used to create CAD geometry files of the helicopter interior as shown in Figure 2. The interior details included the pedals, control sticks, the instrument panel and the surrounding cabin interior. The developed CAD model was saved in the IGES format and then imported into Hypermesh to mesh the surfaces. Once the surfaces were meshed the nodes and the elements of the cabin/cockpit model were transferred to MADYMO in different surface groups. All of these meshed surfaces of the cabin/cockpit interior were defined as facetted ones in the MADYMO simulations presented in this paper.

Figure 3 shows the layout used in the full-scale drop test at CIRA. A total number of three occupants were chosen: one pilot, one forward-facing passenger in the third row and one side-facing passenger in the fourth row. Three state-of-the-art BK117 crashworthiness seats were adopted for the occupants to replace the original seats. All the other seats were removed from the helicopter and simulated by masses (metal plates) attached to the floor. The BK117 seats have been adopted in both of the previous HeliSafe and the ongoing HeliSafe TA projects. This made it possible to compare the later improvements with the existing HeliSafe test results. A 50th%-ile HeliSafe Hybrid III dummy provided by TNO, a 50th%-ile FAA Hybrid III dummy provided by CIRA, and a EuroSID dummy provided by Siemens Restraint Systems were used for the pilot, forward-faced passenger and side-faced passenger, respectively.

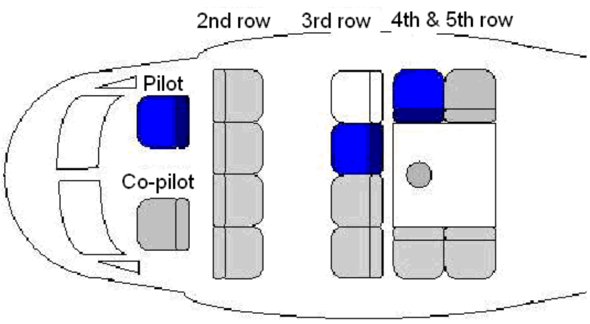


Figure 3 Layout of the Bell UH-1D helicopter for the full-scale drop test

The MADYMO cabin/cockpit model of the Bell UH-1D integrated the geometry models, seat models, occupant models, harness models, the models of proposed safety concepts and all other necessary elements. The layout of the MADYMO cabin/cockpit model is shown in Figure 4 and corresponds with the layout of the Bell UH-1D used for the full-scale drop test as described above.

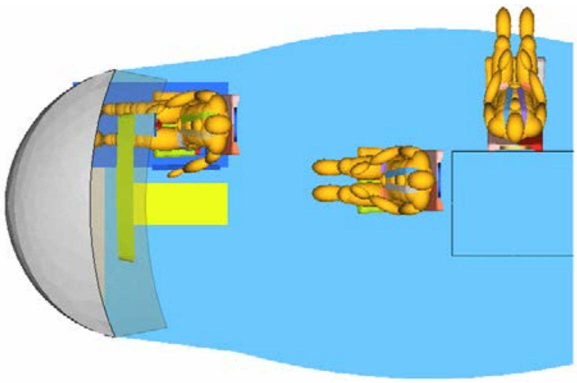

Figure 4 Layout of the MADYMO cabin/cockpit model of the Bell UH-1D helicopter

The three seats along with the HeliSafe dummies were positioned in the cabin/cockpit geometry according to the test set up. In the model the seats occupied with dummies included all surrounding parts that might be impacted by the dummies and the relevant safety devices. The precise location of the seat mountings, other relevant sensor locations and seat surroundings were needed to ensure fidelity in representing the test configuration. To facilitate the modelling process and also to meet the specific simulation requirements, three individual MADYMO models were first developed, which accommodated in isolation the pilot, forward-faced passenger and side-faced passenger, respectively. These individual models were then integrated into a final model with the three occupants included. Because there were no interactions between the individual dummy/seat systems, the individual models or the integral model with all three occupants could be used.

The main features of the MADYMO cabin/cockpit model of Bell UH-1D are as follows:

- Dummies and seats are positioned according to the actual full-scale drop test. The cabin/cockpit interior, including pedals, control sticks, the instrument panel and internal geometry are modelled as different parts with rigid facetted surfaces on the basis of CAD geometry data.
- The existing MADYMO BK117 seat model was adopted, which consists of 40 rigid bodies connected by joints.
- The harness modelled was a 4-point system with a Y-connection behind the neck, and a load limiter and pretensioner behind the seat. Switch elements were used to trigger and lock the pretensioner. Finite element belts with membrane elements were used to model the main belt parts.
- The modified 50th%-ile Hybrid III FAA dummy model provided by TNO for HeliSafe TA was used for all the occupants.
- The pilot, with and without an airbag was considered. The airbag model was translated from that used in the cockpit mock-up model of the first HeliSafe project for preliminary studies. No airbag was included for the forward and side facing passengers in the simulations described in this paper.
- The loading was applied on to the systems in the form of acceleration pulses.

**Simulations Performed using the Cabin/Cockpit Model**

To assist with the initial validation of the MADYMO cabin/cockpit model, two crash cases were considered, referred to as the HS1 and HS2 scenarios. The HS1 scenario is equivalent to a 12.8 m/s horizontal crash with $10^o$ yaw into a rigid obstacle. This is modelled by a triangular pulse (JAR 18.4 g) with duration 142 ms. The HS2 scenario is equivalent to a 9.2 m/s crash with the helicopter floor horizontal, but with the flight path at $60^o$ pitch angle to the ground. This is simulated by a triangular pulse (JAR 29.3) with duration 62 ms applied at $60^o$ to the helicopter floor [4]. The reason to choose these two cases was that sled test data was available for a generic cockpit mock-up of a 1.5-3.0 ton helicopter. The cockpit setup of the present MADYMO model is similar to that of the generic cockpit mock-up in many aspects although they are not the same. The attention for MADYMO simulations is here focused on the cockpit part of the model.

The pulses used in the simulations were based on those recorded during the actual sled tests and therefore they were not pure triangular shapes. A preliminary airbag system was incorporated in the MADYMO model. Comparisons of pilot dummy movement between test results and MADYMO predictions are presented in Figure 5 for the HS1 scenario and Figure 6 for HS2 scenario, with good agreement.

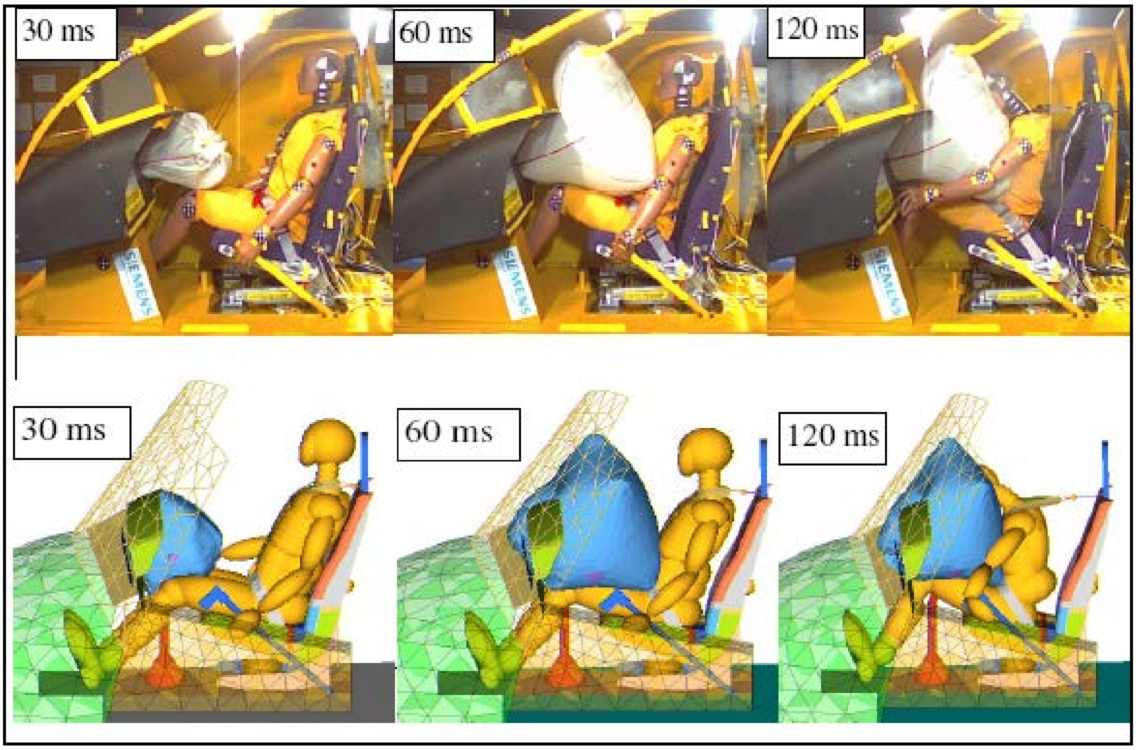


Figure 5 MADYMO Simulations of Bell UH-1D cabin/cockpit model compared with sled test data of a generic cockpit mock-up for the HS1 scenario

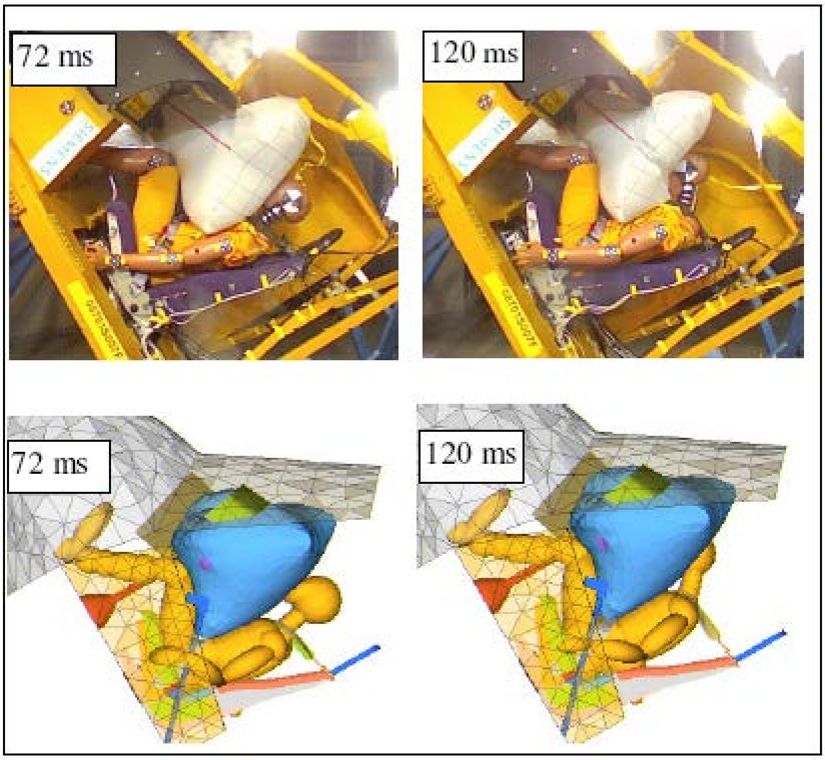


Figure 6 MADYMO Simulations of Bell UH-1D cabin/cockpit model compared with sled test data of a generic cockpit mock-up for the HS2 scenario

The vertical forces in the upper lumbar spine obtained from the MADYMO simulation and sled test are shown in Figure 7 for the HS2 scenario. The MADYMO simulation predicts a trend of the spinal force similar to the sled test but with a higher peak value of 8 kN in the simulation compared to 7 kN in the test. Figure 8 gives the head accelerations obtained from MADYMO simulation of the Bell UH-1D cabin/cockpit model and the sled test of a generic cockpit mock-up for the HS2 scenario. A general good agreement can be seen between the predicted and test results of the head acceleration. The peak values of the horizontal head accelerations are 20 g from the simulations, compared to 22 g from the test.

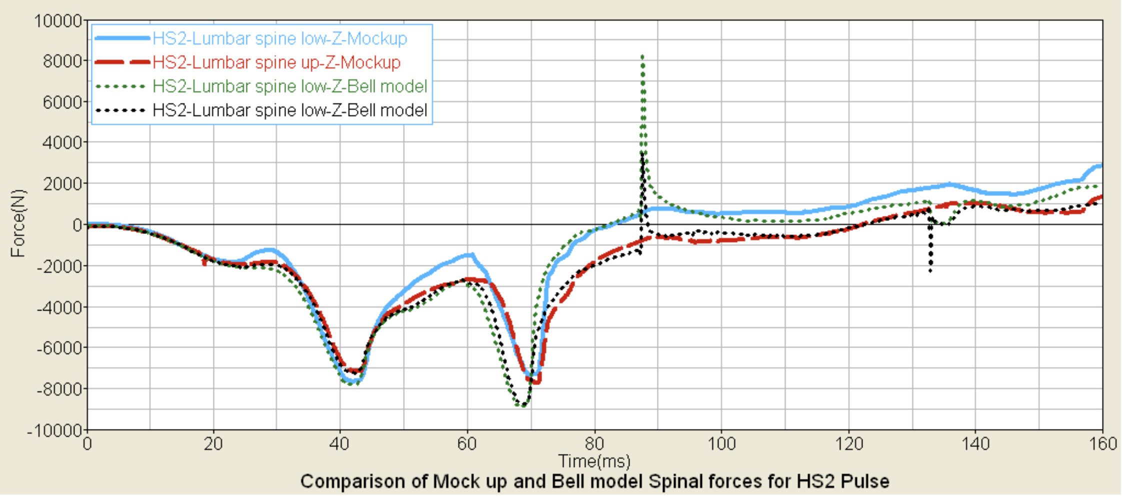


Figure 7 Upper and lower lumbar spinal forces of pilot dummy obtained from MADYMO simulation of Bell UH-1D cabin/cockpit model and the mock-up model for the HS2 scenario

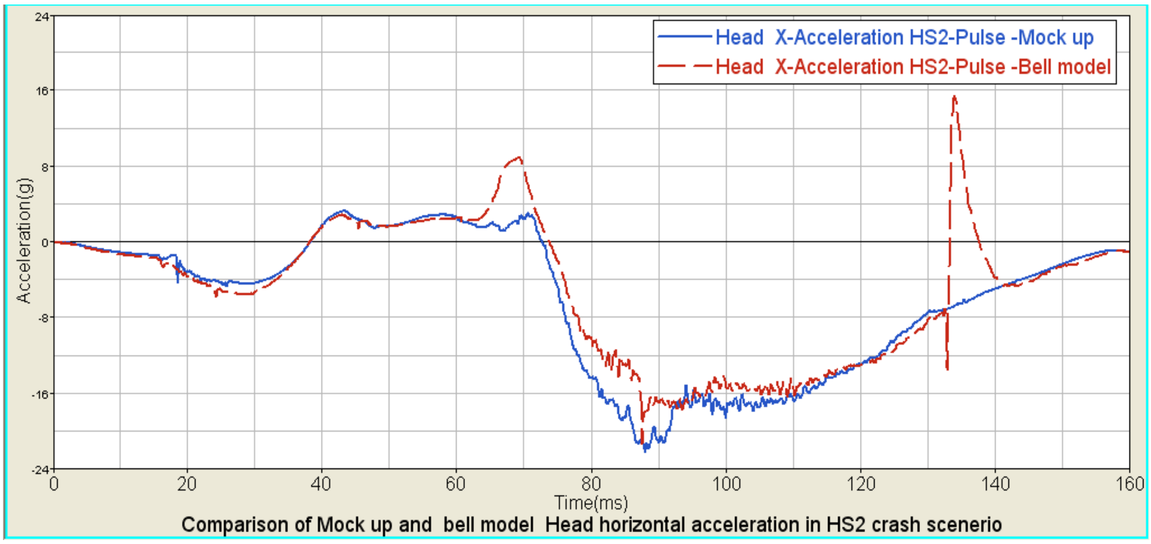


Figure 8 Pilot head acceleration obtained from MADYMO simulation of Bell UH-1D cabin/cockpit model and the mock-up model for the HS2 scenario

**Simulation of Full-scale Baseline Drop Test**

The Madymo cabin/cockpit model was used to simulate a full-scale drop test of the Bell UH-1D helicopter on hard ground. The planned impact conditions were as follows: impact velocity vx = 12.8 m/s, vz = 7.9 m/s, and pitch angle of the floor $\theta = 8.8^{o}$. The acceleration pulses at the floor locations of the pilot seat, the forward-facing seat and the side-facing seat were generated by simulations with the UH-1D DRI-KRASH model carried out by DLR. The DRI-KRASH model included a structural representation of the fuselage and as such separate pulses were available for each seat location. The comparison of dummy movements of baseline drop test and simulation model is shown in below Figure 9 and the comparison of injury curves is shown in Figure 10.

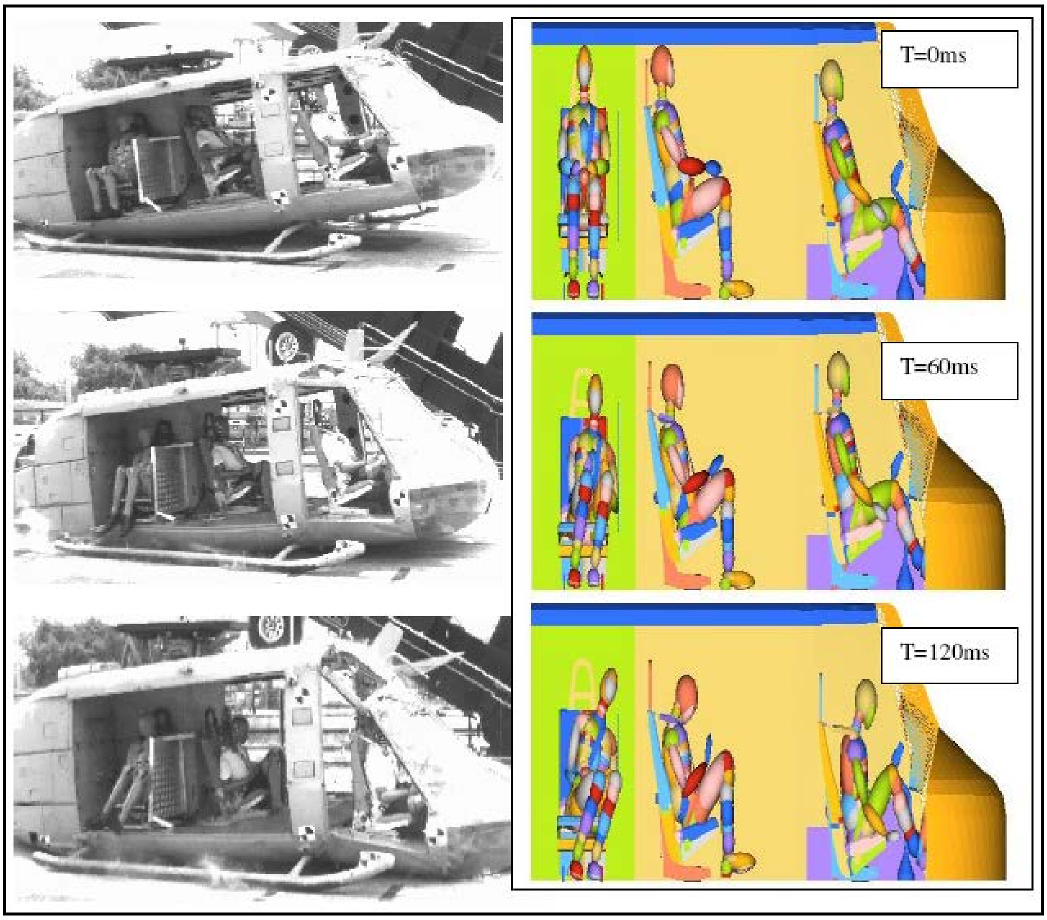


Figure 9 MADYMO Simulations of full-scale drop test with the Bell UH-1D cabin/cockpit model

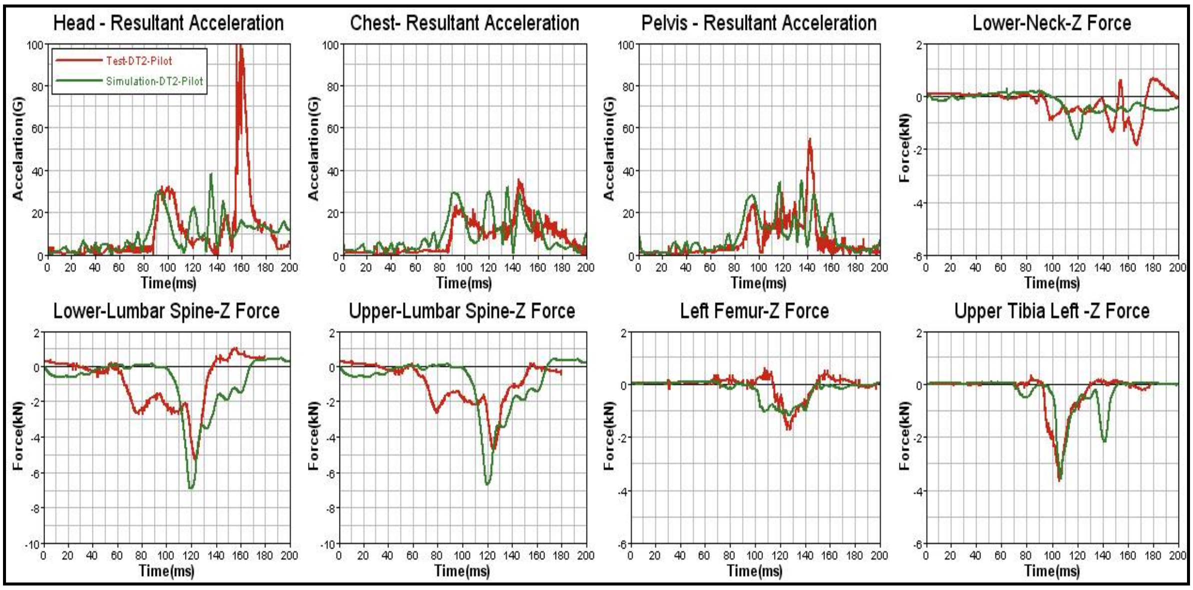


Figure 10 Comparison of Pilot Injury curves from simulation with drop test data

The baseline drop test was performed using the 4-point harness system for all occupants and without the airbag for pilot seat. A major improvement was made towards the final drop test by investigating several new innovative harness systems developed by AFG. These systems were built up as a MADYMO model concept study and were tested by several simulation runs. The best harness configuration was found for each seat system and parameters such as the triggering time to fire the pretensioner and the pretensioner forces were established through simulation. The best position for the airbag and the triggering time to fire the airbag was also established at this stage. The effectiveness of the new restraint system concepts was measured using the IrSiX (**I**nju**r**y **S**everity **I**nde**x**) factor method (5). This method is not required by legislation but is a practical and acknowledged procedure used within the automotive industry. The IrSiX parameter is defined as:

$$\text{IrSIx} = \sum \text{Weighting} \frac{\text{Load Value}}{\text{Load Limit}} \cdot 1000$$

With respect to the equation the sum of all weighting factors is 1 so that the load index (IrSiX) will be 1000 if all the load values reach their limit.

**Simulation of Full-Scale Final drop Test (Optimised Safety Layout)**

After performing the parameter study the new concepts were implemented in the final drop test. The MADYMO simulation model was developed according to the final drop test setup and the final test results are correlated.

The new concepts implemented in the final drop test were:

- Airbag implemented. Airbag position and TTF (Time to Fire) values are determined using MADYMO simulations. Head contact with IP surface and Windshield is avoided with the implementation of airbag.
- New harness systems has been modelled and performed parameter study to determine the best PTF (Pre-Tension Force) and TTF values using MADYMO simulations for each seat and occupant
- Pilot seat modelled using x-harness or 4-point harness with airbag.
- Both Passenger seats are modelled using Body centred Harness system.
- But both passenger seats uses different PTF and TTF values compared to pilot seat.
- New seat cushion material is investigated and implemented in the final drop test to reduce the lumbar spine load.

The dummy kinematics for the final drop test are shown in Figure 11 and indicate good agreement between simulation and the physical drop test.

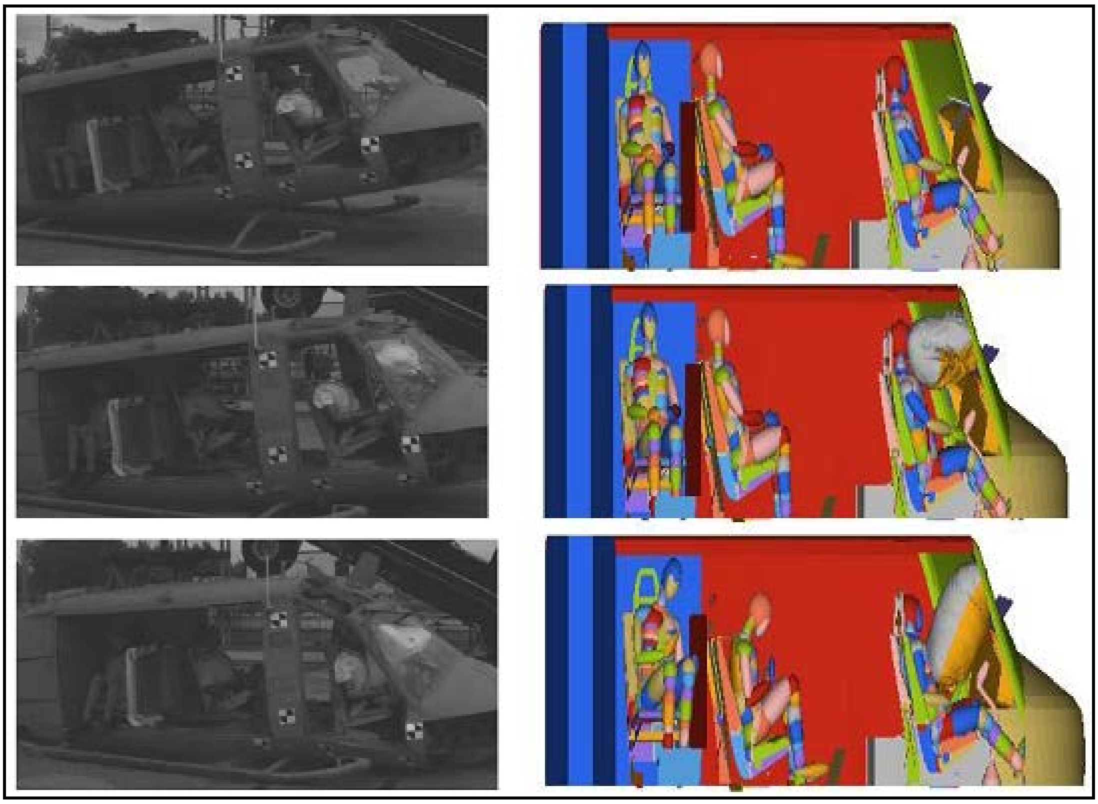

Figure 11 MADYMO Simulations of full-scale drop test with the Bell UH-1D cabin/cockpit model

**Conclusions**

The work presented here has demonstrated that it is possible to develop multibody system based models of helicopters and simulate appropriate crash scenarios that are unlikely to involve gross structural failure where analysis with an explicit nonlinear finite element code or a program such as DRI-KRASH would be more suitable.

The work described made use of MADYMO computer simulations to investigate the effectiveness of helicopter occupant protection systems and to establish optimum configurations before committing to physical testing. The modelling methodology was based on a mixed use of multibody and finite element techniques, in which a subsystem cabin/cockpit model was used for the occupant protection studies. The work has demonstrated that computer simulation can form a valuable part of any large scale programme of work looking at developing new safety systems and using computer simulation at various stages to support non destructive sled testing and full scale drop tests.

## References


1. Frimberger, M., Wolf, F., Scholpp, G., and Schmidt, J. Influence of Parameters at Vehicle Rollover. SAE 2000-01-2669, presented at SAE International Body Engineering Conference, Michigan, October 2000.

2. Walters, C.L., Creation of an MSC/DYTRAN Landing Gear Model with Rigid Joint Modelling. 59th Annual Forum of the American Helicopter Society, Phoenix, 2003.

3. Zhang Y. and Blundell M. Multibody Systems Simulations of Helicopter Rollover Scenarios, 5th International KRASH User's Seminar, Milan, September 2005.

4. E Uhl, 'HeliSafe®TA Improving Occupant Protection in Case of Helicopter Crash', The Fifth International KRASH User's Seminar (IKUS5), Milan, Italy, CD, 28-28 Sept 2005.

5. HeliSafe®TA, 2006. AFG, Memorandum AFG-32-0021 "The use of IrSix-factor"

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**6th International KRASH Users' Seminar (IKUS6)**

**15 – 17 June 2009, Stuttgart, Germany**

# HELISAFE TA Project

- Helisafe TA (Helicopter Occupant Safety Technology Application) is an EU funded 6th Framework Specific Targeted Research Project that aims to develop improved levels of occupant crash protection for civil helicopters
- The project involves 12 European partner companies and institutions

# Main Activities

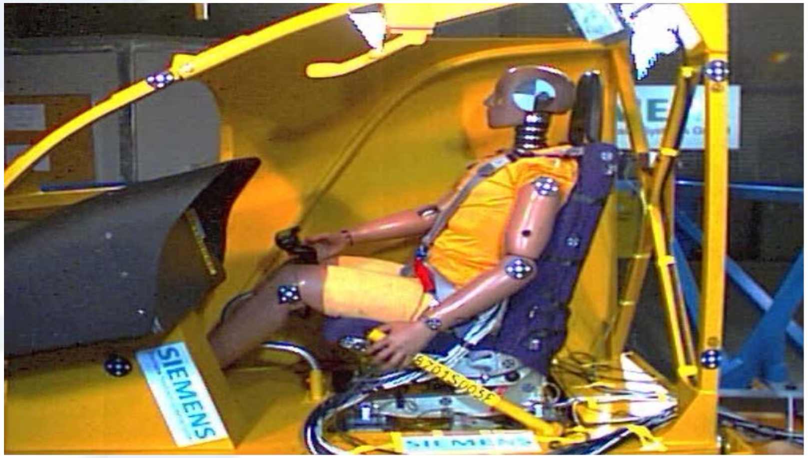
- A major feature of the project is an integrated programme of :
  - Full scale helicopter crash tests
  - Developing occupant protection concepts
  - Crash test dummy development
  - Laboratory based cabin/cockpit mock-up sled tests
  - Supporting computer simulation

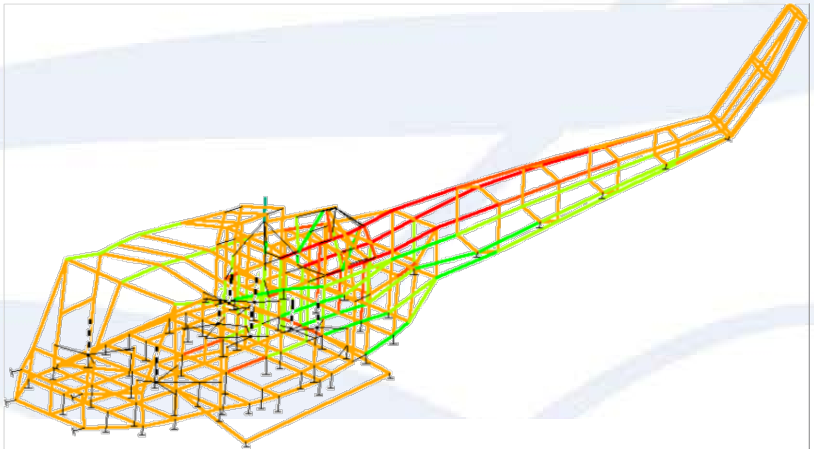
# Helisafe TA Partners

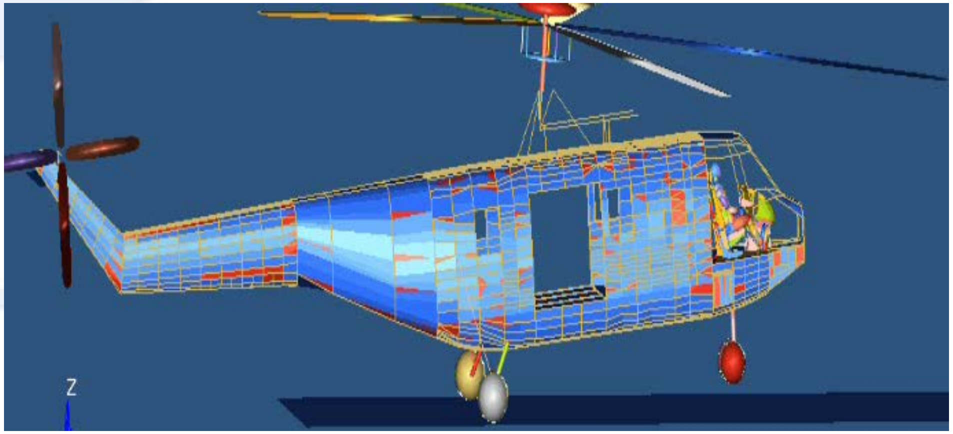
- AUTOFLUG (D)  The project co-ordinator
- CIDAUT (ES)
- CIRA (I)
- DLR (D)
- EUROCOPTER-SAS (F)
- EUROCOPTER (D, a subsidiary of EUROCOPTER-SAS)
- POLITECNICO DI MILANO (I)
- PZL Swidnik S.A. (PL)
- TNO Automotive, Safety R&D (NL)
- SRS (D, a subsidiary of SIEMENS)
- COVENTRY UNIVERSITY (UK)
- UNIVERSITY DELFT (NL)

# Main Activities

Coventry University



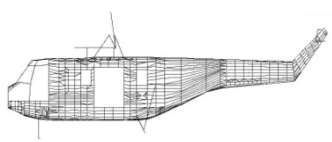


# Overall Simulation Activity Helisafe TA

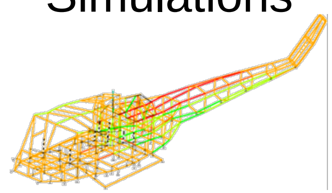
**AFG**
Reference Scenario

**EC-SAS**
SAMCEF EC Model

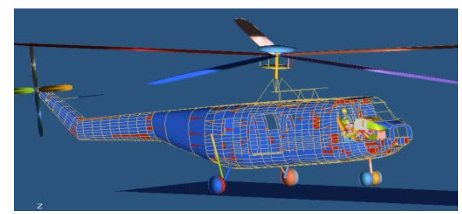
**EC-SAS**
Finite Element Simulations



**DLR**
DRI-KRASH Simulations



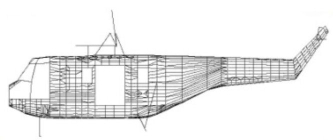
**CU**
Madymo/ADAMS Simulations



**Computer Simulations**
1st Baseline Drop Test
Roll Over Case
Real World Scenarios (influence of surface, crash angles…)
Secondary and Multiple Impacts

# Full Helicopter Model Data Management at CU

**EC-SAS**
SAMCEF data set



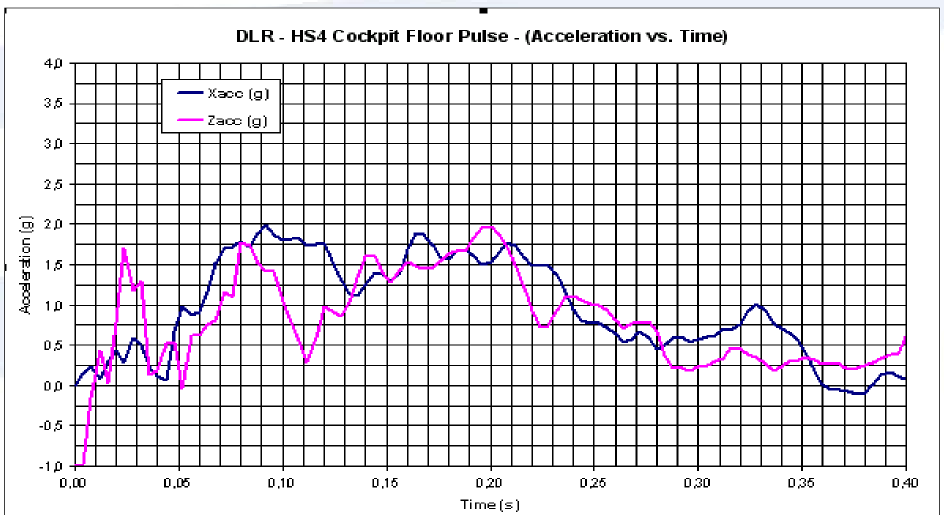
**CU**
Data translation programs
FORTRAN, MATLAB, EXCEL

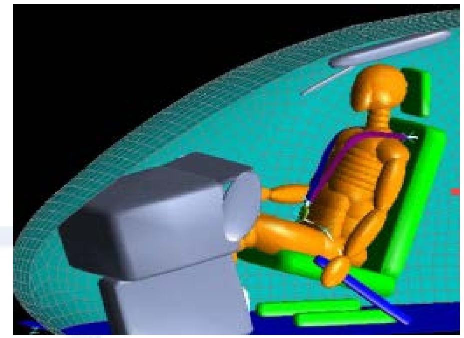
**Madymo**
Models

# Overall Simulation Activity in Helisafe TA

Coventry University

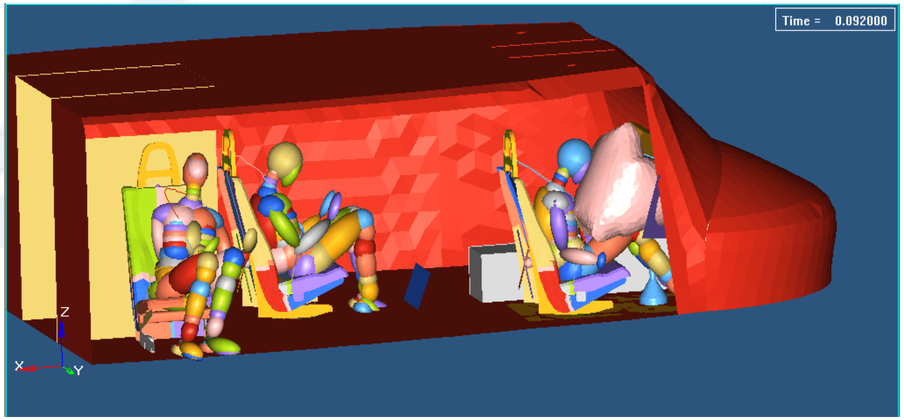
**Computer Simulations**
1st Baseline Drop Test
Roll Over Case
Real World Scenarios (influence of surface, crash angles…)
Secondary and Multiple Impacts



# Simulation work at Coventry

- To develop multi-body based simulation models in Madymo that could be used to simulate full helicopter crash scenarios
- To develop subsystem cockpit/cabin models for more detailed investigation of occupant protection systems



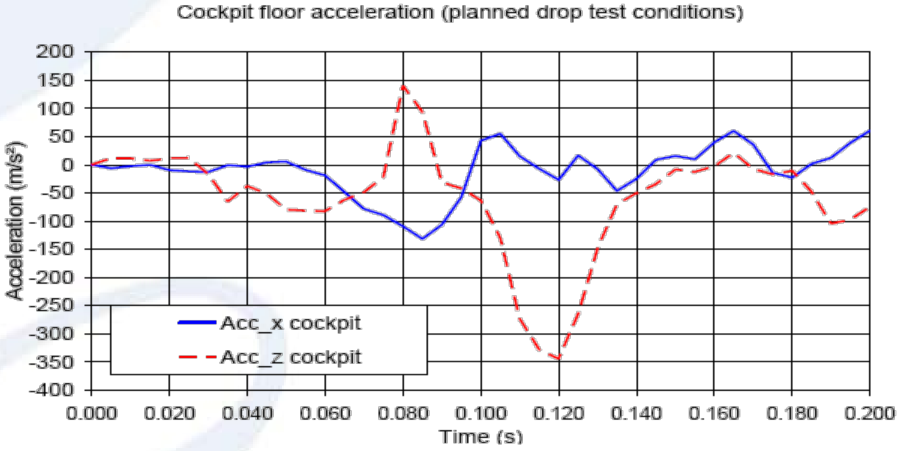
# Full Scale Crash Test at CIRA

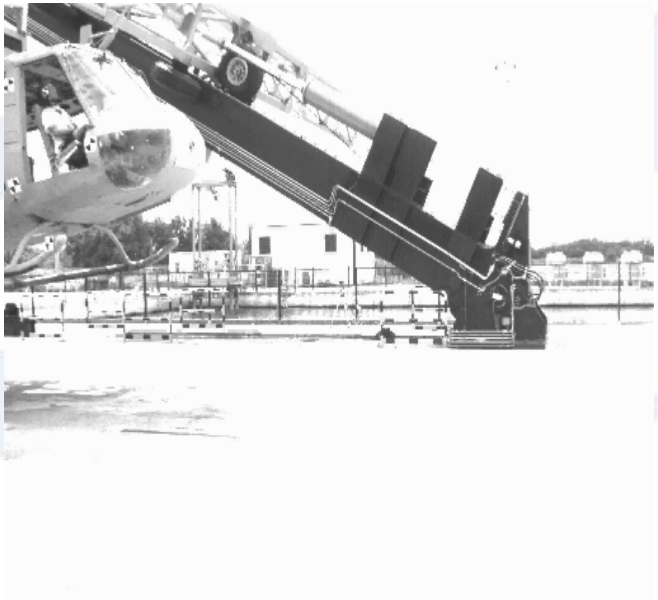
- The first of a series of full scale drop test has been completed at CIRA. The tests will be performed to match a chosen reference scenario. Base line tests will provide local input crash pulse data for the simulation models
- Impact velocity 15.05m/s ($V_x$=12.8m/s, $V_z$=7.9m/s), pitch angle 5° nose up

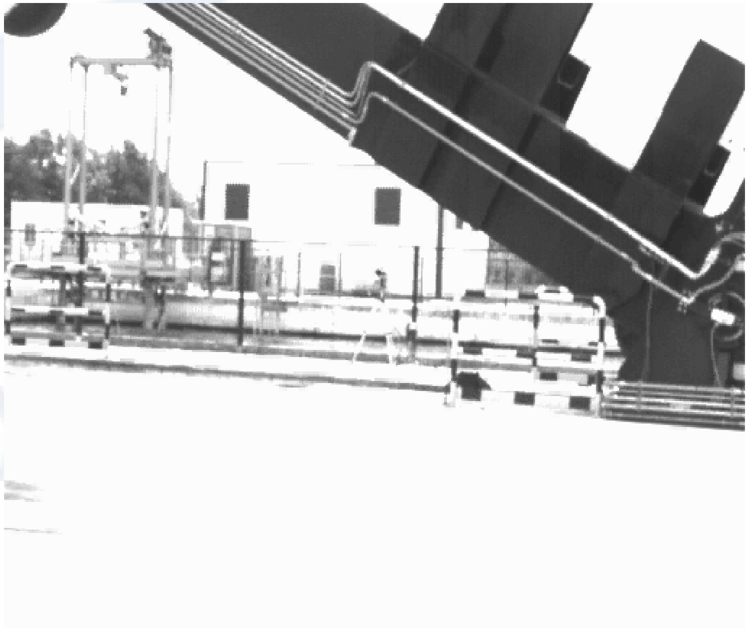
# Full Scale Crash Test at CIRA

- A final test will evaluate new safety concepts developed using computer simulation and a series of laboratory sled (inertial) tests with dummies and cockpit/cabin mock-up tests.
- The sled tests will be performed at CIDAUT and SRS (Siemens)

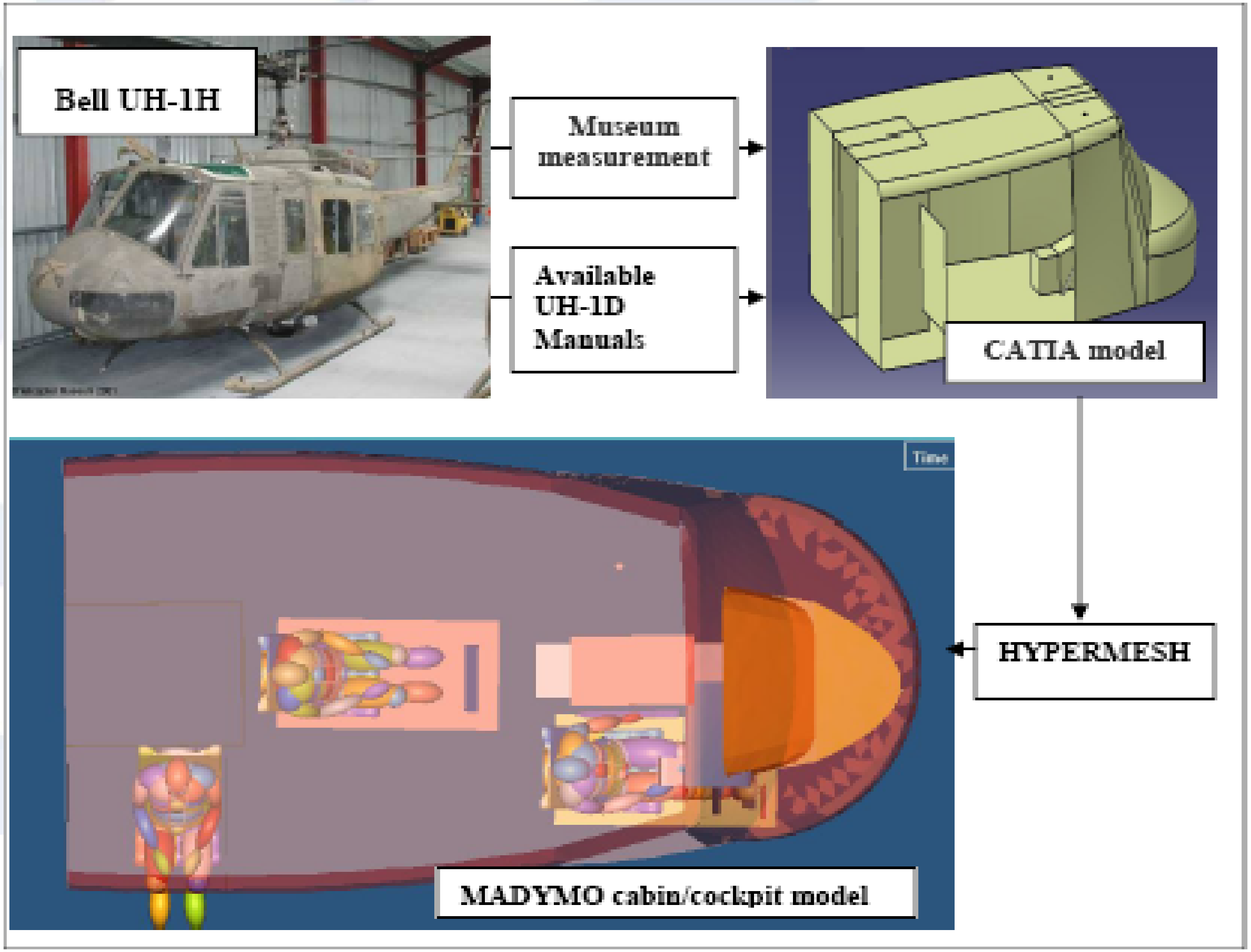
# Full Scale Crash Test at CIRA



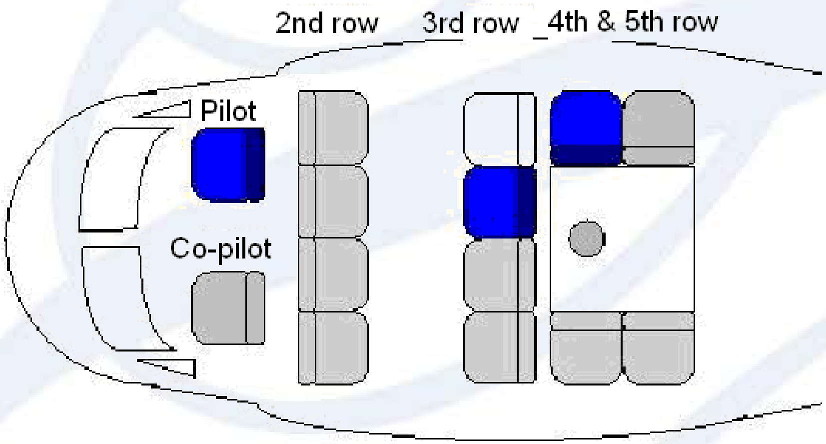



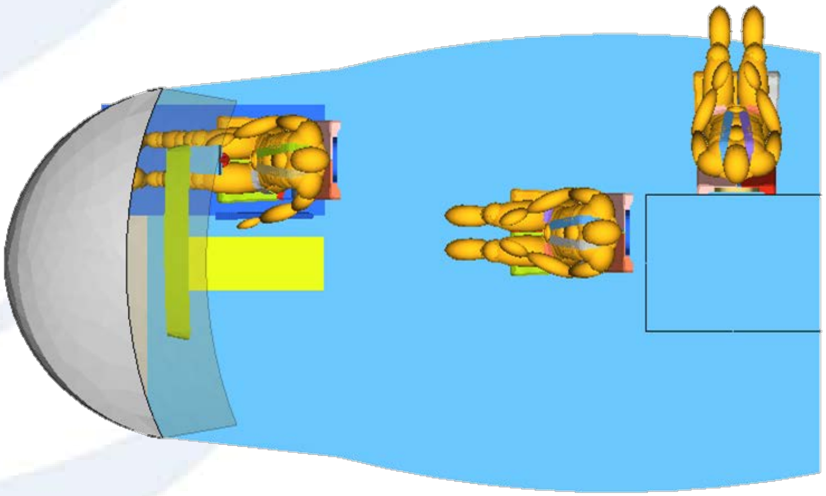


# Cockpit and Cabin Modelling

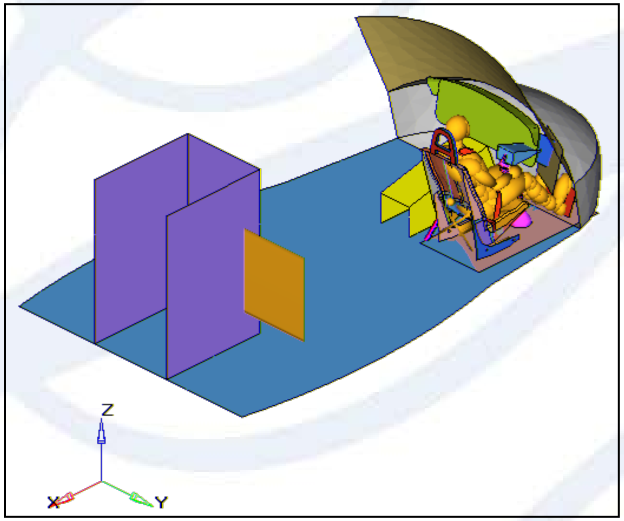


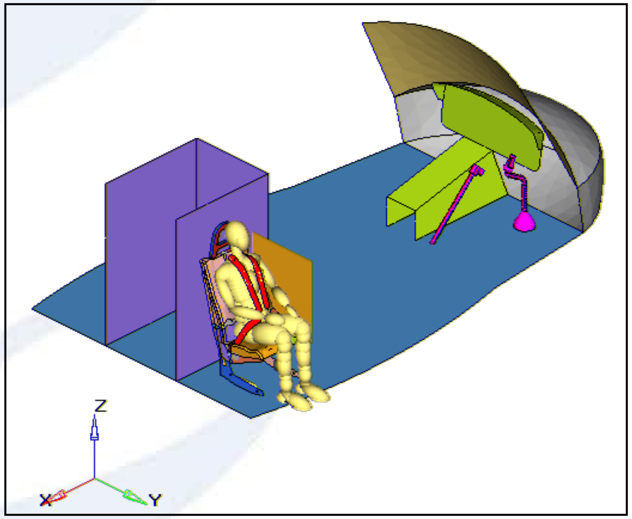
# Madymo Modelling

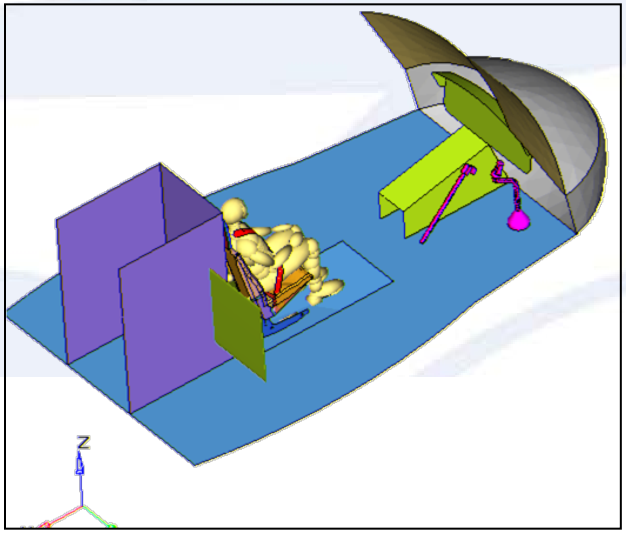


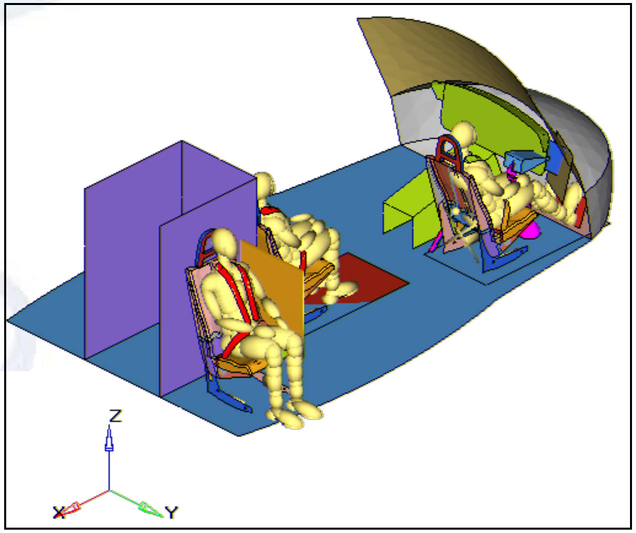



# Model integration



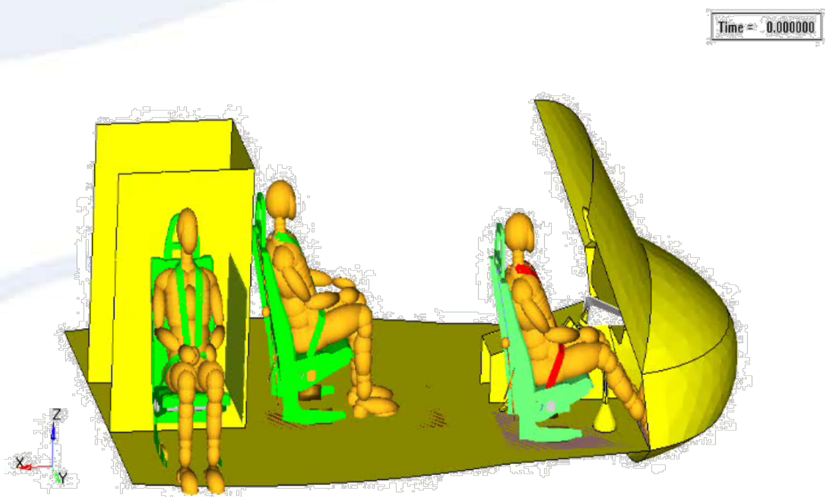



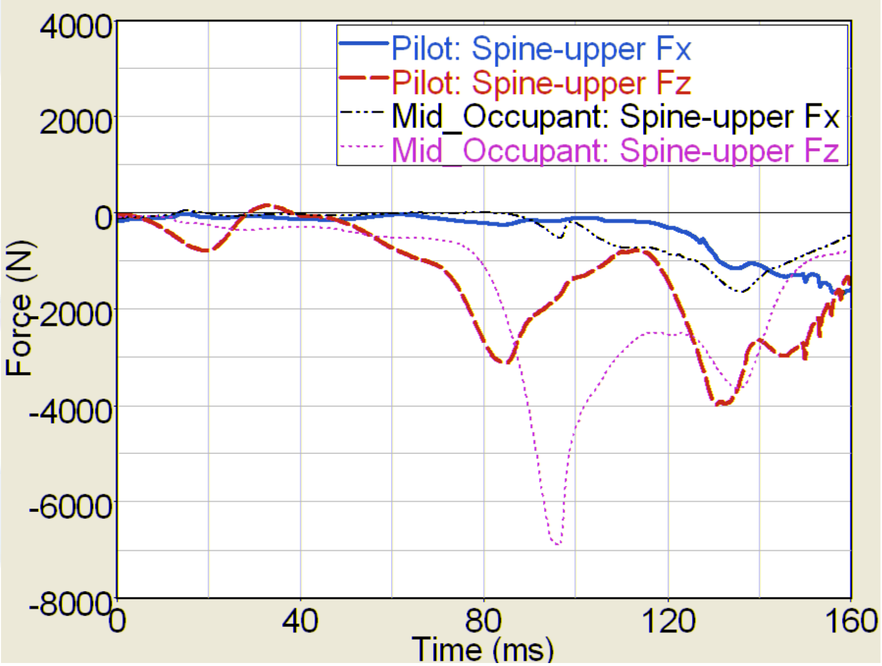
# Dummy Responses & Safety Systems

- Model acts as a rigid 'inertia rig' with local acceleration pulses applied to dummies and seats
- Model allows testing of new safety concepts (harnesses/airbags)
- Model could be used to simulate full-scale or sled tests
- Potential to vary layouts and investigate crash pulses for further scenarios



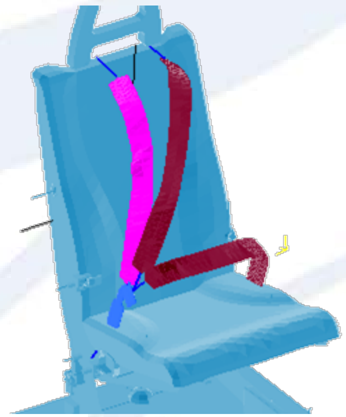
# Typical Measured Response

- Upper lumbar spinal forces of pilot and forward-faced dummies obtained from Madymo Simulations of full-scale drop test with the Bell UH-1D cabin/cockpit model

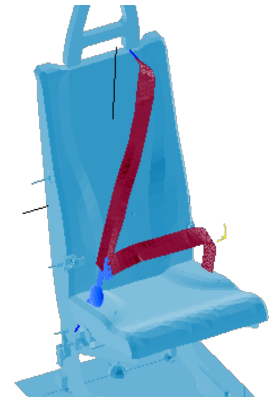


# Development of new Harness Design Concepts

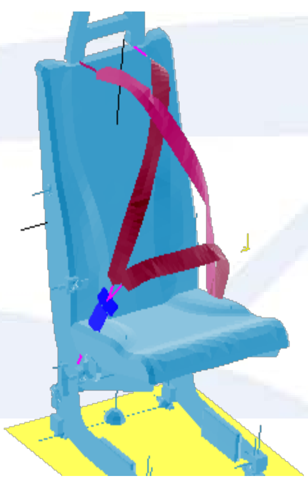
Body centred harness



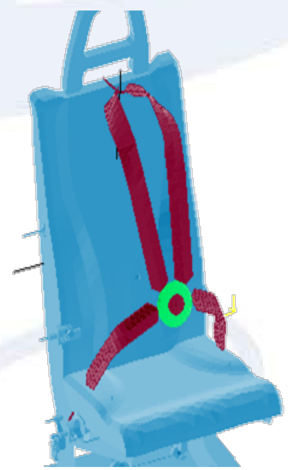
3/4 point harness



3 point harness



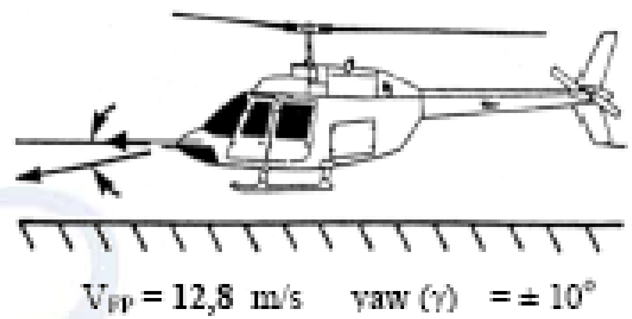
X-harness

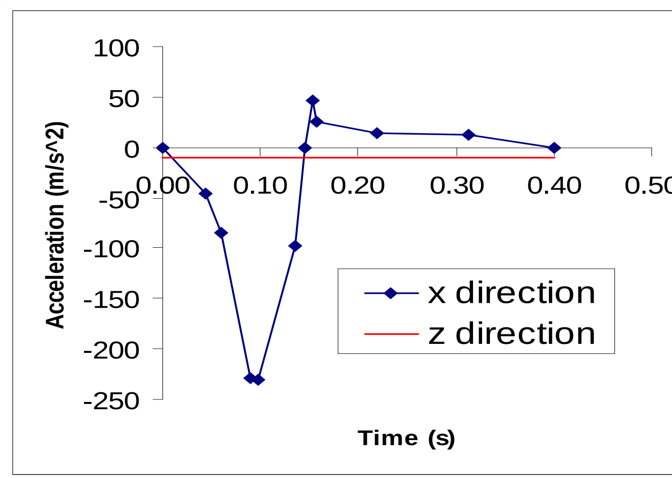


4-point harness

Triangle harness

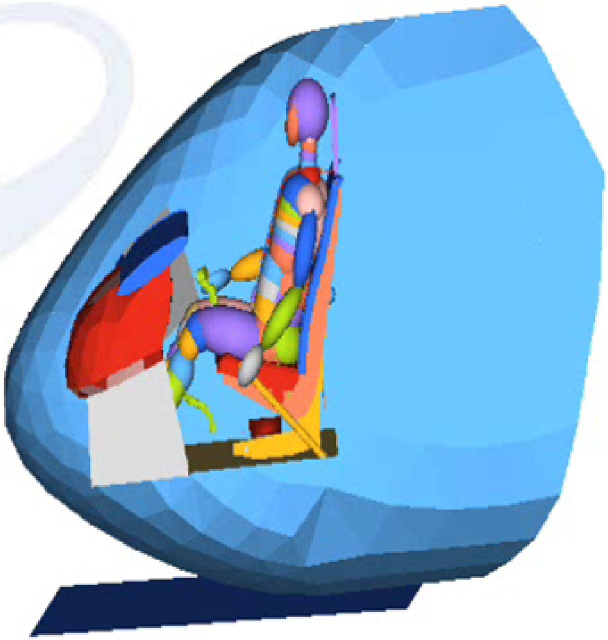
# Sled test (HS1 pulse)

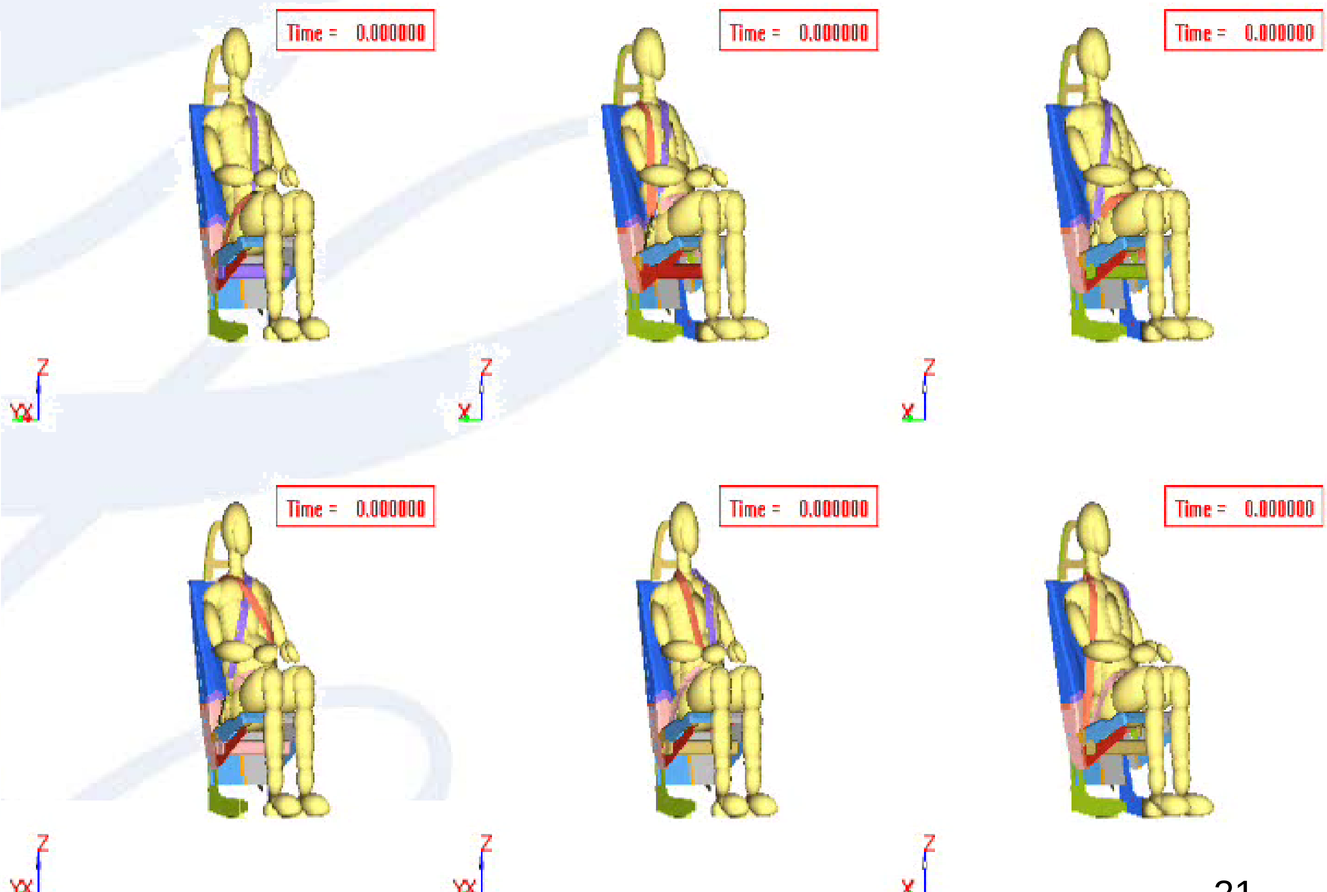
# Frontal Impact Simulation

- HS1 horizontal pulse

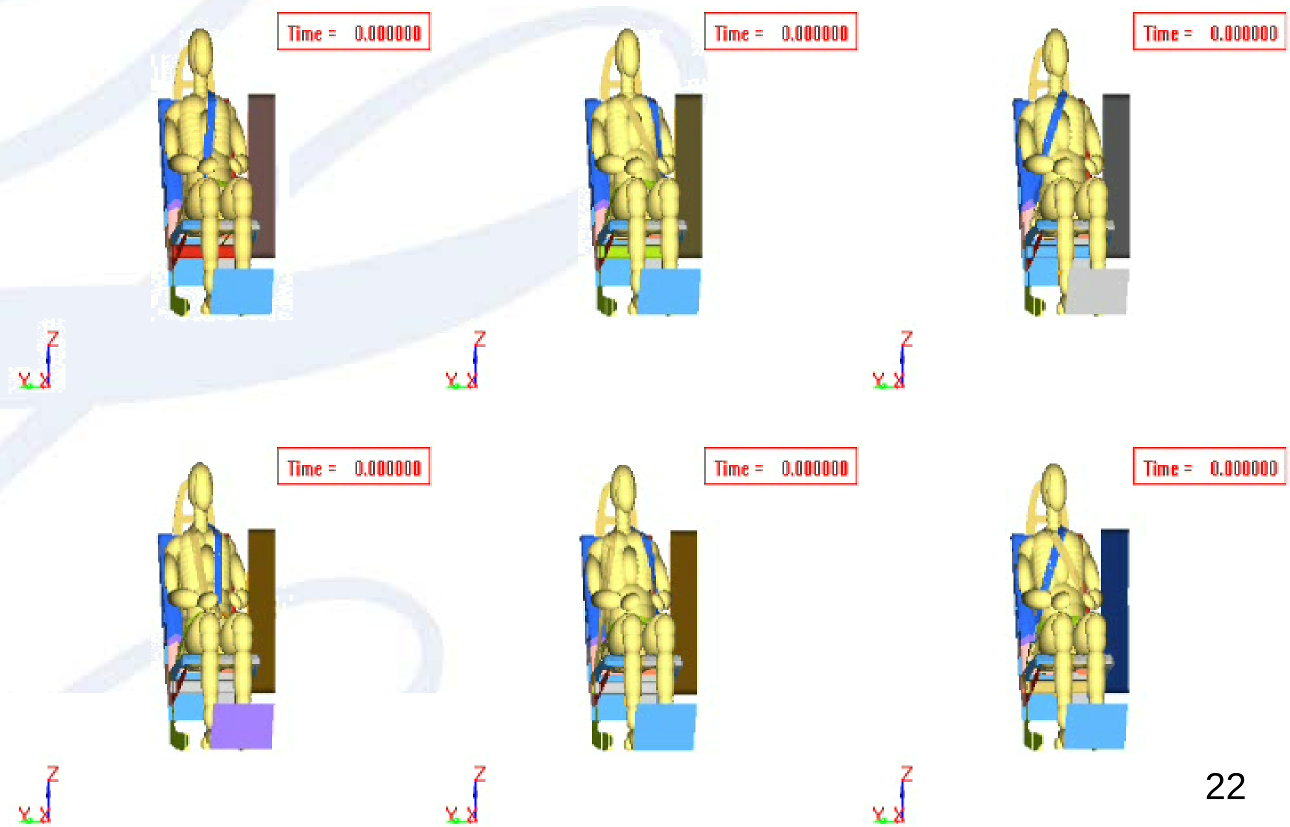
# Harness Design Concepts for front Seated Occupants

- HS1 loading is applied

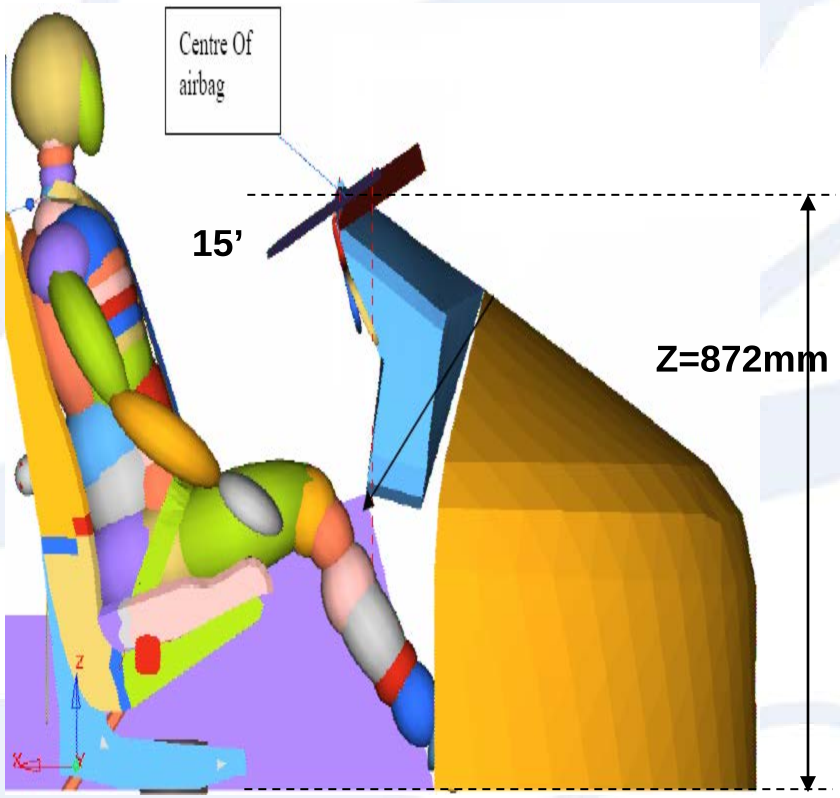



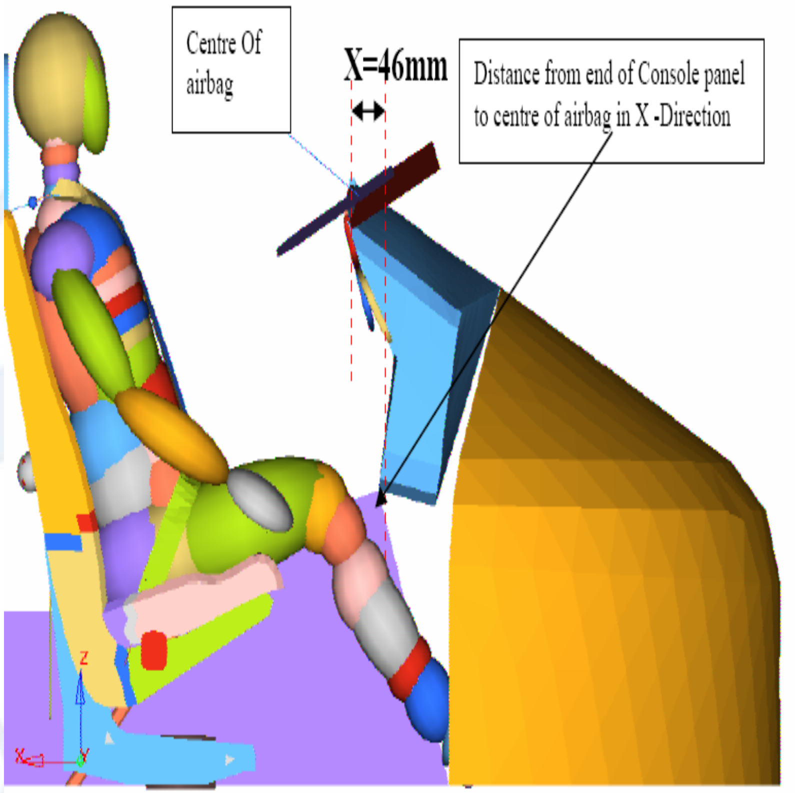
# Harness Design Concepts for Side Seated Occupants

- HS1 loading is applied



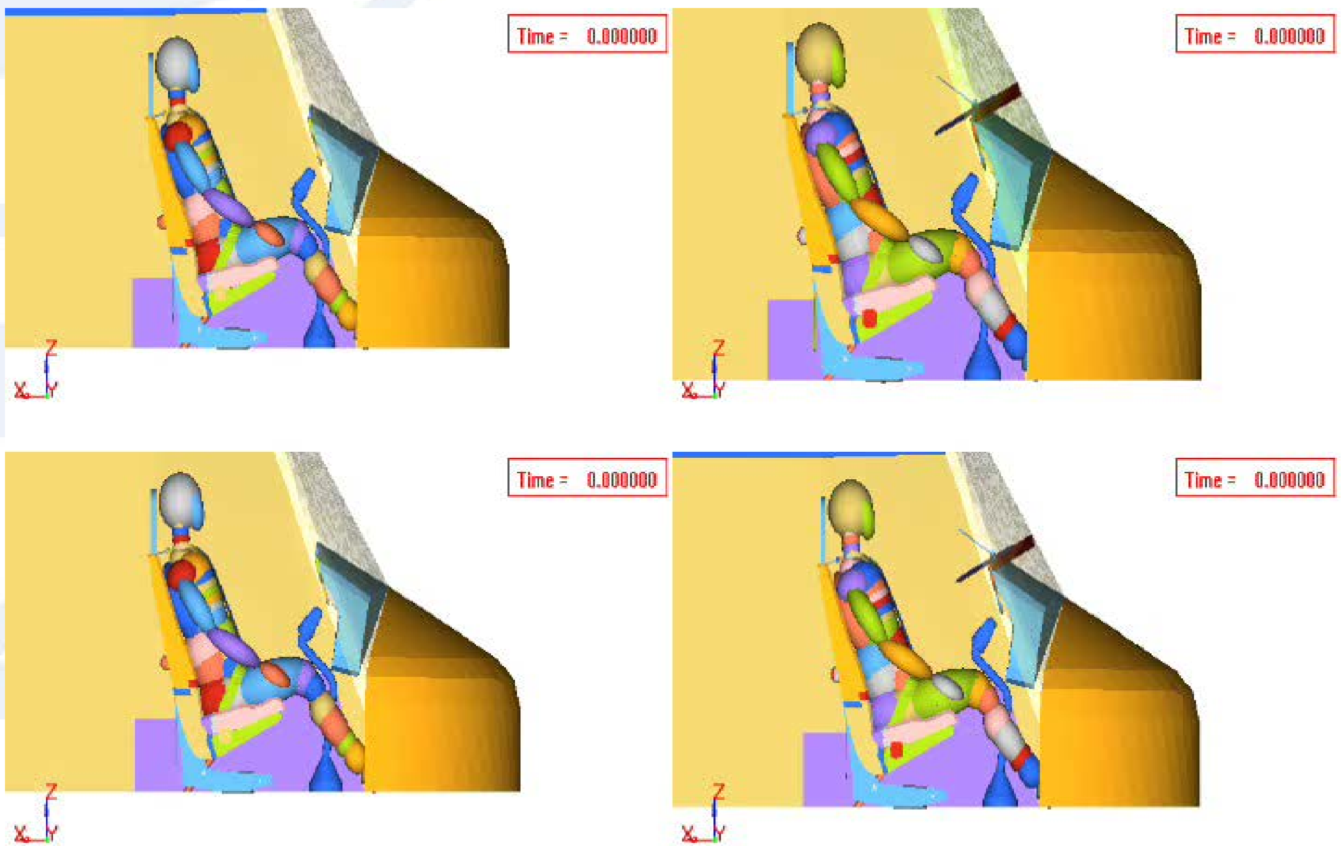
# Investigation of Airbag position



# Comparison of Dummy movements

- With and without airbag for HS1 and DT1 pulse



# Final Crash Test at CIRA

# Conclusions

- A generic helicopter has been modelled in Madymo
- The capability to include a model of the seat, dummy, restraint system and airbag in a full Madymo helicopter model has been demonstrated

# Conclusions

- A subsystem cabin/cockpit model has been developed for the test helicopter and can be used for the evaluation of new occupant protection design concepts
- The models have been demonstrated as capable of:
  - Simulating the evolution of a roll over event
  - Sled tests
  - Full scale crash tests

# Conclusions

Coventry University

- In front facing occupants the 4 point harness provided the best injury results
- For side seated occupants the body centered harness provided the best injury results
- The position of the airbag has been determined and was used in the final drop test