Tutorial 9

Simplified Truck Model with Dummy and Airbag
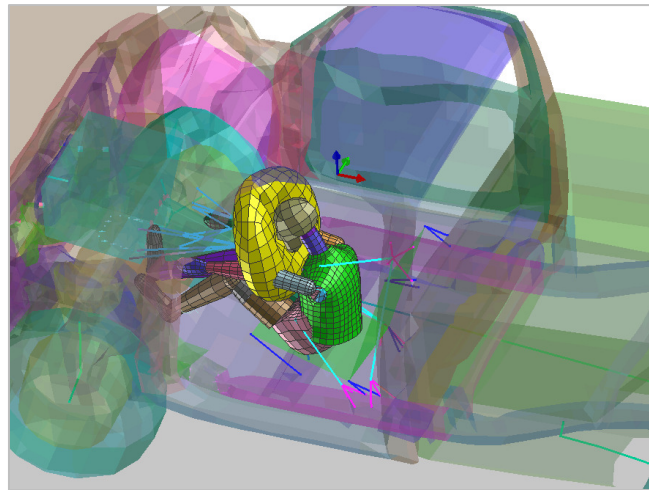
Problem description

Outline	Frontal crash of a simplified truck model against a rigid wall is performed. The model is an extension of the vehicle introduced in Tutorial 8 except it now includes safety features including a seat, dummy, belt restraint system and airbag.
Analysis type(s):	Explicit
Element type(s):	3D Shell elements, Rigid Bodies, Beams and Bars
Materials law(s):	Elasto-plastic, Airbag elastic membrane
Model options:	Boundary conditions, Spotwelds, Contacts
Key results:	Structural deformation, airbag inflation and occupant injury
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Background information

Pre-processor, Solver and Post-processor used:
- **Visual Crash PAM:** To examine the truck model.
- **Analysis (PAM-CRASH Explicit):** To perform the explicit Finite Element analysis.
- **Visual Viewer:** Evaluating the results for contour plots, deformations and time history information.

Prior knowledge for the exercise

This exercise is not worked through in detail and it is assumed that the reader has gained a good working knowledge of using **VCP** from tutorials 1 through 8. In particular it is important to be familiar with tutorial 8.

The completed model of the simplified truck, seat, dummy and airbag is provided and will be examined using **VCP**.

Note the model is for teaching purposes only and is a simplified representation of a crash and occupant safety model. Today industrial models will typically use several millions of elements and are highly complex.

Problem data and description

Units: kN, mm, kg, ms

Description: The simplified truck model has approximately 10,000 nodes and elements in 48 material groups. The airbag, dummy and seat have about 5,000 elements.

Loading: Impact mass of the truck is 1300kg which impacts the rigid wall at 13,88m/sec.

Material: The materials used are mainly elasto-plastic mild steel, except the airbag which is elastic fabric.
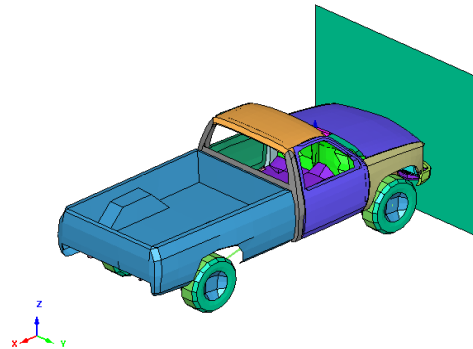
Supplied datasets

The completed truck model comprises of the main file (.pc) which also reads five include files (.inc).

> **TruckFront_H3_Bag_Belt.pc**

The include files are:

Truck.inc	for the truck data
Hybrid3.inc	for the model
Driver_belt.inc	for the belt system
Barrier_front.inc	for the impact barrier
Bag1.inc	for the airbag

Contents

Part 1: Using VCP to examine the truck and safety features

**Starting Visual-Crash PAM and examining the model**

Start **Visual Crash PAM** and open the truck model using **Open File**, select the file:

> **TruckFront_H3_Bag_Belt.pc**

This will automatically read in the five .inc files

Positioning and centering of the model

As in tutorials 1 through 8 the various viewing tabs can be used, together with the mouse, to change viewing angles, position and type of viewing.
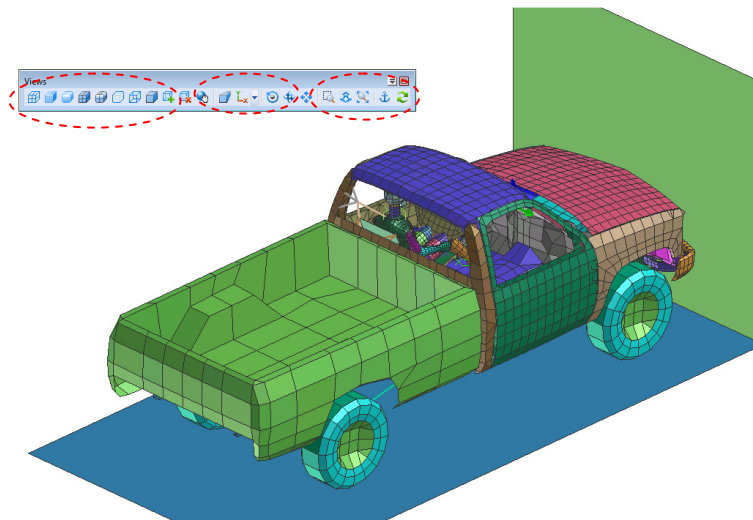
In the same manner as done in Tutorial 8 we shall look at the different model entities. Again, this is most easily done via the explorer window by clicking on the entity of interest and opening it in Edit mode with the right mouse key. The following gives some brief details of the entities assigned to this truck model:

Parts and Materials: There are 107 parts with each having its own materials. The parts and material numbers are identical and are grouped in the following table. It is possible in the Parts list of the explorer panel to view individual parts, or groups of parts.

Part/Material Groups	Representation
1 through 45	Vehicle
2001	Front barrier
2002	Ground
3001 through 3050	Dummy (Hybrid 3[1] 50%)
3501 - 3502	Seat + attachments
4001 - 4002	Belt + attachments
5001	Bag
5002 - 5003	Steering wheel + attachments

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[1]   There are many different dummy's designed for front and side impact. The main (current) dummy for front crash is the Hybrid 3. This is also available as male and female and in different weights. The 50% male dummy used here, for example, represents the average human weight for a male.

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Initial Velocities: These are the same as tutorial 8 with the truck having an initial impact velocity of 13.89m/sec.

Contacts: The truck self contacts as the same as in tutorial 8, but in this case a rigid wall definition is used for the truck to wall and truck to ground impact.

In addition there are separate contact definitions for the airbag-dummy and the airbag-steering wheel so that important impact forces imparted to the dummy can be monitored.

There are other contacts for the dummy parts and the dummy-seat and dummy-belt.

Rigid bodies: Many additional rigid bodies are used for the dummy. This simplified dummy uses rigid bodies for body parts with calibrated joints connecting them and giving the model the correct kinematics. It is a CPU efficient approach that can only give limited information on dummy loadings and injury criteria.

Outputs: Considerably more information in the outputs is specified and saved in the **.ERF** file. This mostly concerns nodal and element time history information for the dummy that can be used to evaluate deceleration and forces levels. This is used to compare with allowable injury criteria.
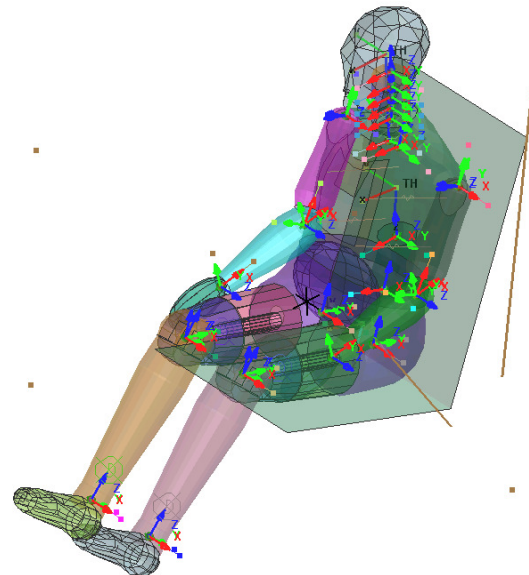
Safety options: In the explorer panel under Safety and Auxiliaries special feature are defined such as sensors to activate airbag inflation and the pyrotechnic pre-tensioner for the seatbelt. Simple sensors are used here that activate at a specific time, but is possible to use more complex criteria including deceleration levels at specific nodes (just like real sensors). The airbag inflation and belt models are also defined.

Timestep controls: In the control cards (option TCTRL) special timestep controls have been activated for mass and stiffness scaling to impose a timestep of 3.3μsec. All elements with a timestep below this value will have mass added at the start and stiffnesses changed during the crash to maintain this timestep.

This is partly done to make this model CPU fast for teaching purposes. These options can be used in structural analysis but great care should be taken as they can significantly modify the structure mass and stiffness.

Part 2: Examining and visualising some analysis results

Start **Visual Viewer and** open the results file,

**TruckFront_H3_Bag_Belt_RESULT.erfh5**

If information on the model units system is requested select MM, K, MS; this is important for plots and especially if any numerical filters are to be used.

As in tutorial 8 the system energy balance should first be checked and the take a look at deformations to make sure the model behaves as intended.

Global energy plots and numerical stability

The internal, kinetic and total energies of the system indicate that the solution is numerically stable (constant total energy). The system initial kinetic energy is almost entirely converted to plastic energy at 70msec; but some kinetic energy remains due to motion of the occupant and vehicle rebound velocity.

The total energy is essentially constant indicating the solution is numerically stable.
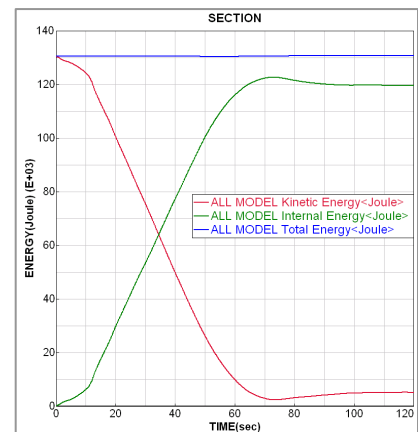
Deformations

Next it is best to check deformations and contacts to see if results are sensible. The following are examples for the full structure and for the dummy, airbag, belt and seat. The latter is done by visualising only parts 3001 through 5001. Use the animation controls to follow the crash sequence.

Note some simplification in the model: The airbag is especially simple consisting of two flat sheets and therefore contact between the arms and airbag is deliberately ignored. The seat is a further simplification and contact between the seat to dummy uses a special force versus displacement contact (Type 21) to approximate seat stiffness; in this case the dummy penetrates the seat, but this is correct behaviour for this contact type.
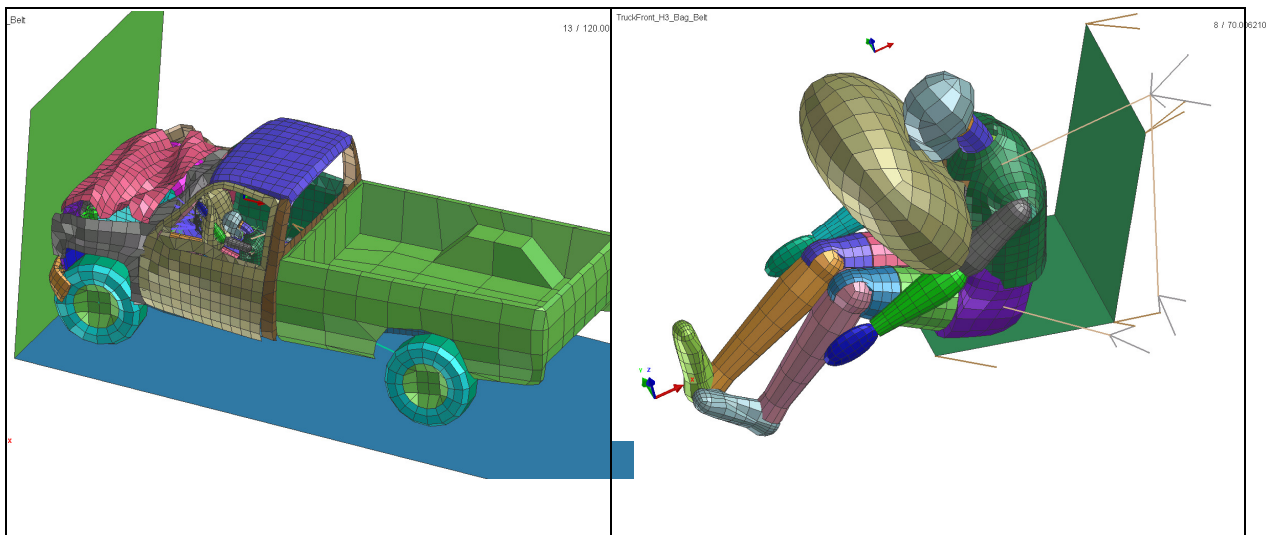
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Wall impact force time histories

The adjacent time history compares wall contact forces (from tutorial 8) with this tutorial.

Note the impact force for this model is available via the rigid wall contact force time histories. Also, the two impact forces cannot be merged via the Chase Curves feature as they are different types; instead both files and curves are opening in one Visual Viewer session and 'drag and drop' operations are made in the explorer panel to merge curves.
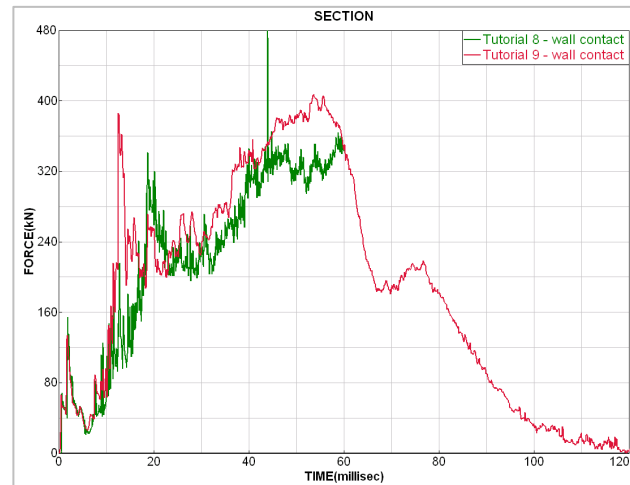
The added dummy mass does lead to higher impact wall forces; however, the difference is limited. Consequently, in practice the structure and occupant are often considered to be uncoupled. That is the structure can be designed/optimised without dummy's and the dummy safety devices (dummy, seat, steering wheel, airbag, belt and restraint systems) can be designed/optimised as a separate system. In this case a sub-assembly of these parts only is used with an imposed deceleration pulse (from test of the full car structure). Side crash involves strong structure-vehicle interaction and cannot be decoupled.

Injury criteria

The simplified dummy models has been especially developed to provide all necessary information on injury which can be compared with the test mechanical dummies. These include head decelerations, femur forces, neck loads and chest loads, amongst others.

As an example part 3032 are 4 sternum springs in the chest (shown in red) which deform as loaded by the airbag, seatbelt or steering wheel. The design requirement is that these (total) loads do not exceed 10kN.
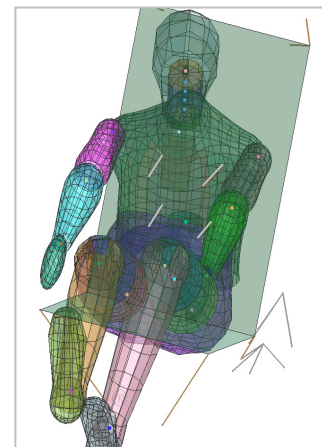
The time histories for these 4 spring are stored in the .ERF file (elements 300764 through 300767). The 4 spring time histories are plotted adjacent and shown that the sum is about 4-5 kN which is well below the allowable limit (10kN).

Also seen from this graph is the forces initiate at 40msec which is the time at which the belt pre-tensioner is triggered. In the phase 50+msec the forces are also influenced by the airbag contact.
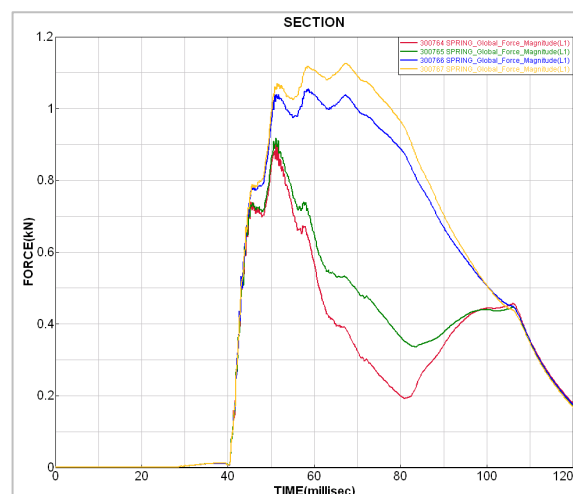
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The seatbelt is modelled as a simple set of bars (Part 4002). Within this part two elements; namely, 400017 (lower belt) and 400019 (upper belt) are saved for time history plots of belt forces. Details of the belt system and the two element time histories are shown below.
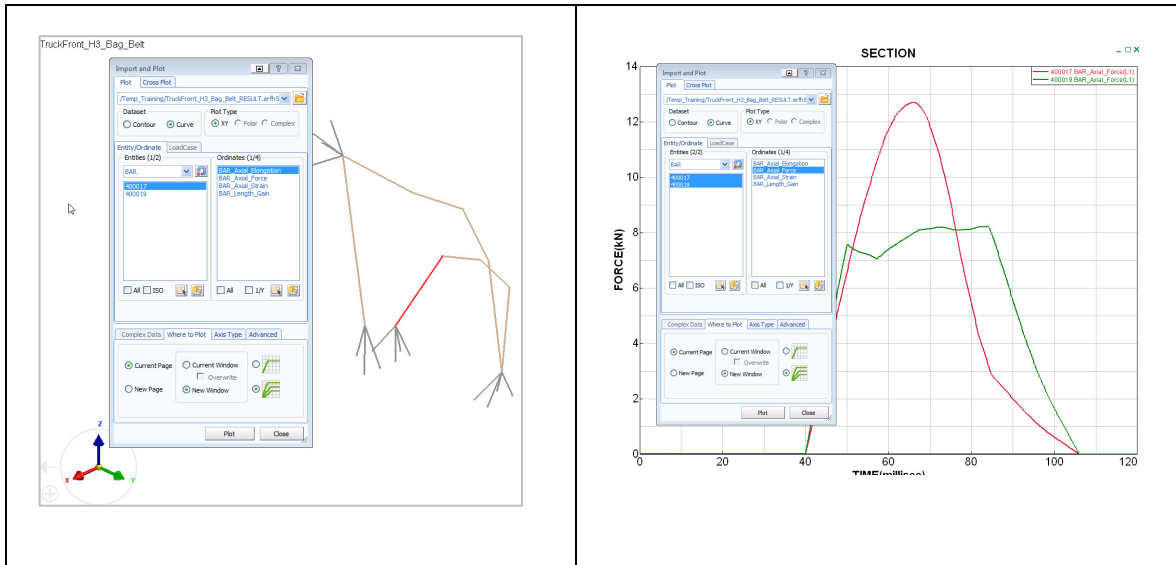
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Injury criteria

The following gives detailed criteria used for mechanical and FE dummies used in car crash simulation. For the purposes of this training exercise the 'simplified interpretation' are used here.

Simplified interpretation

Head
4 punkte (points) HIC^2 36 < 650
0 points HIC 36 > 1000

Neck
4 points Tension force < 2.7 kN
         Shear force < 1.9kN

0 points Tension force >3.3 kN
         Shear force > 3.1kN

Chest
4 points Compression < 22mm
         Compression > 50mm

Upper leg
4 points Tension force < 3.8 kN
0 points Tension force > 9.07 kN

Knee
4 points Movement < 6mm
0 points Movement > 15mm

Lower leg
4 points Compression force < 2.0 kN
0 points Compression force > 8.0 kN

Foot
4 points Movement (brake pedal) < 100mm
0 points Movement (brake pedal) > 200mm

## Injury criteria: Evaluation from FE dummy model

In the FE dummy model time history information on specific nodes and elements are stored in the (.ERF) output file to determine the above injury criteria. The following illustrates three examples.

With Visual Viewer open the results file (**TruckFront_H3_Bag_Belt_RESULT.erfh5**) and start the time history plot window **File > Import and Plot.**

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[2]   The head injury uses a so-called HIC criteria which is an integral measurement of peak acceleration over a specific period of time (usually 36 msec). HIC is dimensionless.

Body part	Measurement	Method to extract data (from the .ENF file)
Head	Acceleration Curve and special operations for injury HIC value	Type: Node and select: THLOC Head Node Component: Translational_Acceleration_local_Magnitude Click on the displayed curve (it will appear black) and then with the right mouse key (Tools > Injury numbers…) Activate HIC 36 Windows and the same plot tab

HIC36 = 576
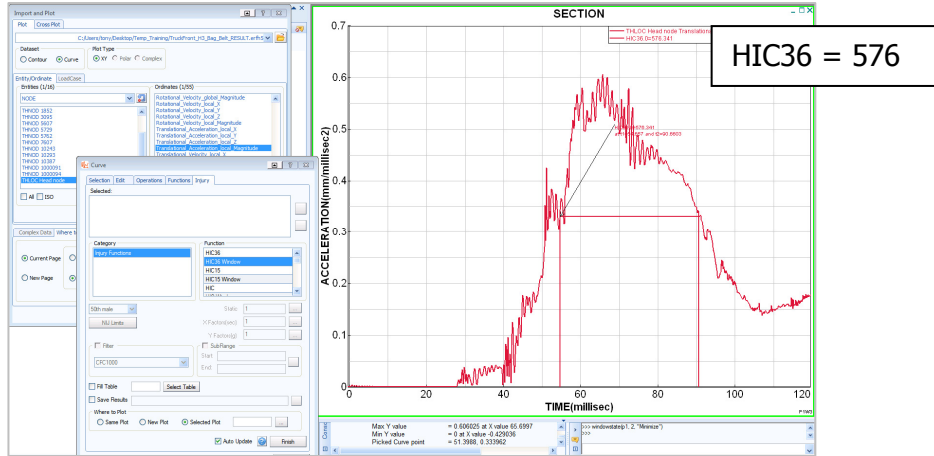
Sternum (chest)	For compression (displacement)	Type: SPRING6DOF Select the Sternum (chest) springs Component: SPRING_Relative_displacement_Magnitude

Chest compression = 36mm
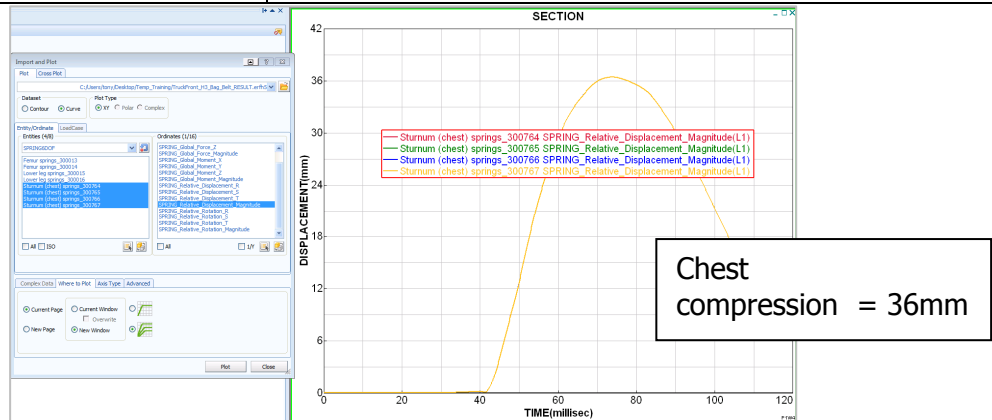
Upper leg	For Force	Type: SPRING6DOF Select the Femur (upper leg) springs Component: SPRING_Global_Force_Magnitude

Upper leg compression = 2.7 kN
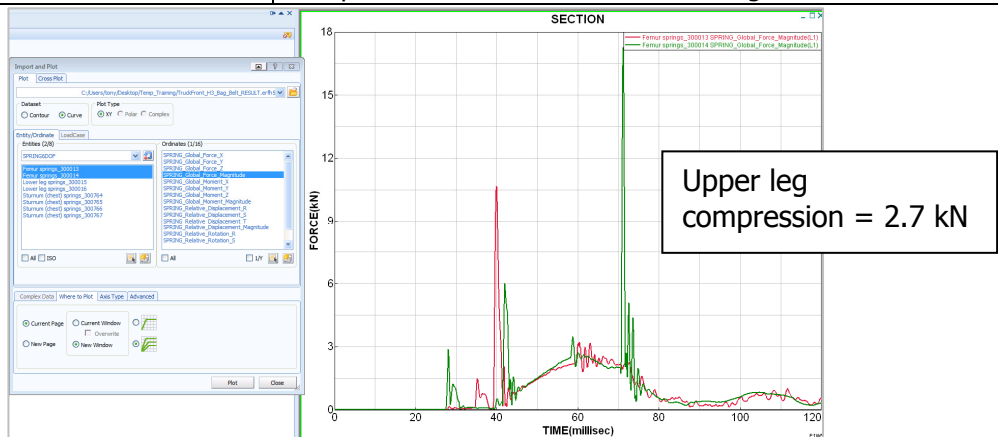
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Exercise: Airbag inflation

A simple exercise can be undertaken to investigate the effect of the airbag on the occupant injury. The airbag uses a sensor to trigger the inflation at 20msec (see entity Auxiliaries > Sensors). A mass inflow of gas to the airbag is then prescribed in a function curve (see entity Auxiliaries > Functions > No. 5002). Modify this function curve to give three airbag types:

Hard inflation   - change the peak mass from 0.002 to 0.003 (i.e. +50%)
Medium inflation   - uses the existing peak mass 0.002 (model unchanged)
Soft inflation   - change the peak mass from 0.002 to 0.001 (i.e. -50%)

Note: For each study it is best to copy the .pc and all .inc files to new directories to avoid overwriting previous results.

You should obtain the results below: The hard bag does increase HIC, but is still below the limit 1000. The soft airbag is insufficient and serious head to steering wheel impact does occur at 92msec. For a proper assessment the other occupant injury criteria would also have to be studied.

Note: A proper optimisation would try to tune sensors, airbag properties (inflation and vents), seat belt for limiters and retractor properties to minimise injuries. Also, this would have to be done for a range of different dummy types.