Human Body Model Positioning using Oasys PRIMER

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1   Introduction

Human body models (HBMs) are detailed bio-fidelic finite element models of the human body and are primarily used to simulate human body kinematics and injury responses and risks in a variety of simulated impact scenarios. The current generation of HBMs, such as the industry leading THUMS and GHBMC family of models, encompass different genders, ages, and physiques, including detailed skeletal structures, internal organs (including the brain) and other soft tissues like skin, flesh and ligaments. Some HBM model variants also include muscle-activation features to simulate changes in occupant posture, taking into account changes in musculature activity, prior to a vehicle collision. Thus, combined emergency manoeuvres and crash events, or other long duration crash events, can be simulated.

Compared to anthropometric test devices (ATDs), commonly known as crash test dummies, HBMs can simulate and analyse crash-related injuries in much greater detail. They allow repeated analysis over an unlimited range of accident patterns and loading conditions and can significantly reduce the expense and development lead times associated with physical crash testing.

One caveat is that HBMs are usually provided in two standard postures – occupant and pedestrian. The occupant posture is typically a driving posture in an upright position, whereas the pedestrian posture is a walking posture with fixed arm and leg angles. These standard postures are limiting and do not reflect the diversity of postures which an occupant (driver or passenger) or pedestrian can assume at the point of a collision. Furthermore, current trends in vehicle automation are expected to give rise to new seating postures such as forward or backward facing reclined seats. Due to the complexity of HBMs, however, these models are not provided with pre-configured information to aid positioning making it a very difficult and time-consuming effort.

In recent years, there has been growing interest to support quick and easy positioning of HBMs in Oasys PRIMER. Using industry-leading HBMs, this paper describes the modelling workflow to prepare a HBM for a simulation-based positioning analysis. A case study of positioning an average male occupant HBM in a front-sled model subject to a frontal impact load case is demonstrated.

2   Overview of occupant safety tools

The LS-DYNA pre-processer Oasys PRIMER provides a comprehensive solution for occupant safety applications to accelerate workflow using LS-DYNA:
- Seatbelt fitting including fully-fabric belts through explicitly meshed sliprings
- Pedestrian analysis setup tools for both head and leg impact load cases
- Seat foam pre-compression analysis to easily deform and remove initial penetrations between the occupant and seat
- Seat mechanisms
- Dummy positioning tools
- Combined simulation-based dummy positioning and seat foam pre-compression analyses, either as single-state or multi-stage analysis
- Powerful airbag folding tool called JFOLD®, which is available as an optional plugin to PRIMER
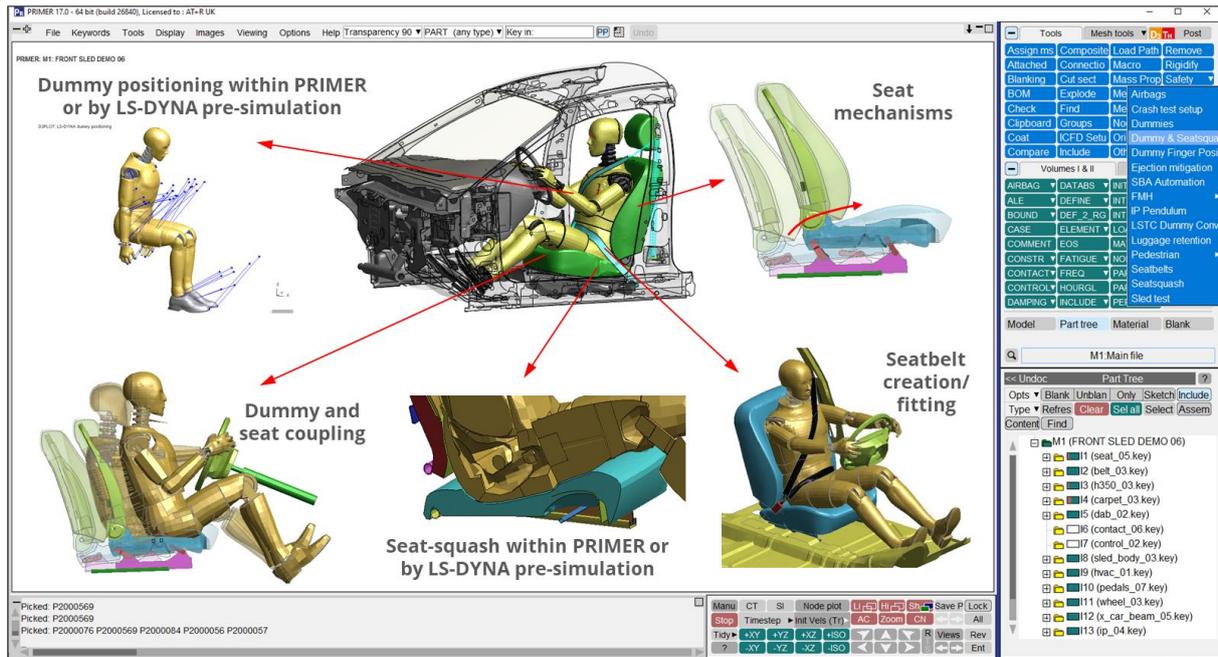
A summary of these tools is highlighted in Fig. 1.

Fig.1: *Overview of occupant safety tools in Oasys PRIMER*

Oasys PRIMER's positioning capabilities have been recently extended to HBMs with the aid of pre-configured positioning metadata and tools to allow users to interactively achieve realistic articulation and positioning of HBMs, covering a wide range of postures. These models are prepared for simulation-based positioning, which is briefly introduced in the next section.

3   Simulation-based positioning

Pre-simulation-based positioning is one popular method of positioning HBMs. In Oasys PRIMER, the 'marionette' method is adopted whereby the user defines a target position by interactively moving specific body regions. Once a desired target position is achieved, PRIMER automatically creates cables that will "pull" the HBM into position during an LS-DYNA analysis. LS-DYNA writes out a dynain output file at the end of each specified positioning stage of the analysis. The 'dynain' file is simply a set of keyword data that captures the *final state* of a model so that the results and deformed nodal coordinates can be imported back into the original model as input for other subsequent analyses. This process is illustrated in Fig. 2.

One of the advantages of simulation-based positioning is that initial penetrations that can occur during traditional 'rigid body' pre-processor positioning are avoided. Also, during the positioning analysis, the simulation considers all the complex internal material properties and contacts that are defined in the occupant and seat model. This makes simulation-based positioning more realistic.

Both single and multi-stage positioning analysis are supported. A single-stage positioning analysis is where PRIMER creates just one set of cables to pull the occupant into position. Alternatively, it is possible to specify any number of intermediate stages within the positioning analysis, known as 'multi-stage' positioning. In this scenario, PRIMER creates multiple sets of cables in series. For example, the user may want to move the hands over the steering wheel in one stage and move the legs in the second stage and so on. LS-DYNA writes out a dynain file containing the updated nodal coordinates at the end of each positioning stage. This approach allows the user to specify several different end positions in one analysis – so slightly different positions can be achieved without having to go back and redo much of the initial part of the analysis.
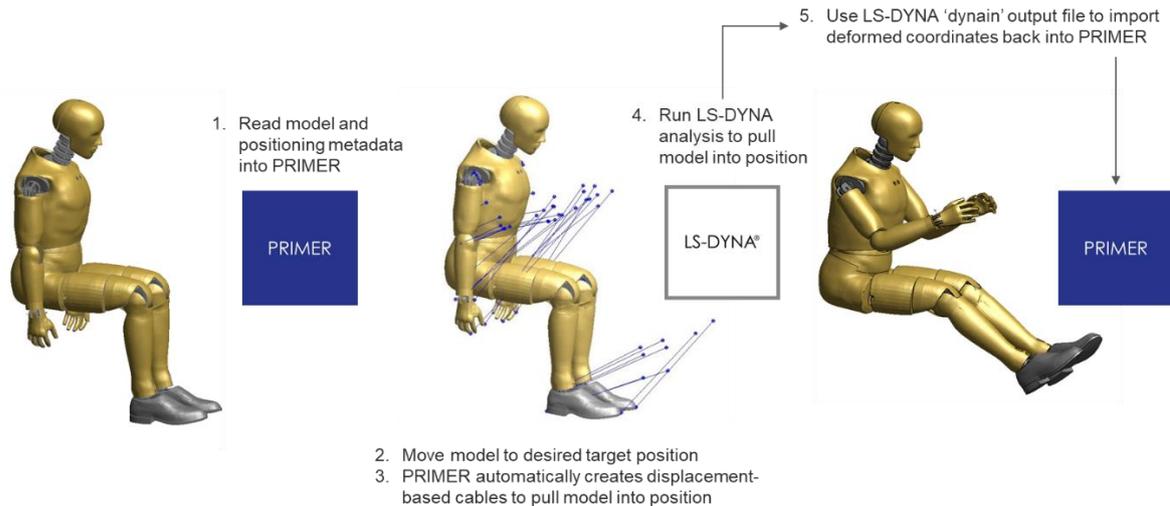
Fig.2: Simulation-based positioning workflow in Oasys PRIMER (Humanetics HIII model)

4 Body positioning metadata

Body positioning of HBMs involves using a positioning tree, which is a collection of ordinary LS-DYNA entities such as nodes, elements, materials etc. but with extra PRIMER-specific data to define body parts relationships, i.e., define how parts of the body are connected and in what order. This metadata includes realistic stop angles to ensure appropriate relative movement between the various parts of the model, and representative bio-fidelic joint detailing, for example, bending and straightening of the spine, and realistic shoulder/clavicle movement. Postural changes can be achieved by interactively changing the joint angles. Once a target position has been defined, PRIMER automatically creates cables to pull the HBM into position during an LS-DYNA analysis.

The key points are:
- A HBM is made up of a series of 'assemblies', each of which contains one or more parts and node sets. For the purposes of positioning each assembly is assumed to move as a rigid body, although its definition may include both rigid and deformable components for the purpose of analysis.
- Assemblies are connected in a hierarchy in which 'parent' and 'child' relationships are strictly defined. For example, the pelvis is 'parent' to the upper leg, which in turn is 'parent' to the lower leg, which is 'parent' to the foot. Thus, the foot is a 'child' of the lower leg, and great-grandchild of the pelvis. This relationship is illustrated in Fig. 3.
- Generalised joint stiffness definitions between assemblies define the (local) axes a child may rotate about with respect to its parts and specifies the position on the parent about which the child rotates. These joint stiffness definitions include stop angles of rotation based on anthropometric data to ensure realistic articulation of joints.
- The 'root' part, generally the lower torso or pelvis, is assumed to rotate about the dummy 'h-point'.

The tree positioning data is saved as metadata that lives alongside the analysis data, and it is this metadata that allows the user to position HBMs within the Oasys PRIMER software. This metadata is denoted by post *END keywords and so are ignored by the analysis code. It is important to note that this metadata is not modifying the original HBM model in any way, this additional information sits on top of the original model and is used only for positioning. The user simply includes the metadata file in the main HBM underlined unmodified keyword file.

All the traditional dummy models on the market are provided with a positioning tree created by the manufacturer (e.g., Humanetics, WorldSID, LST). Due to complexity of HBMs, however, no such data is provided.
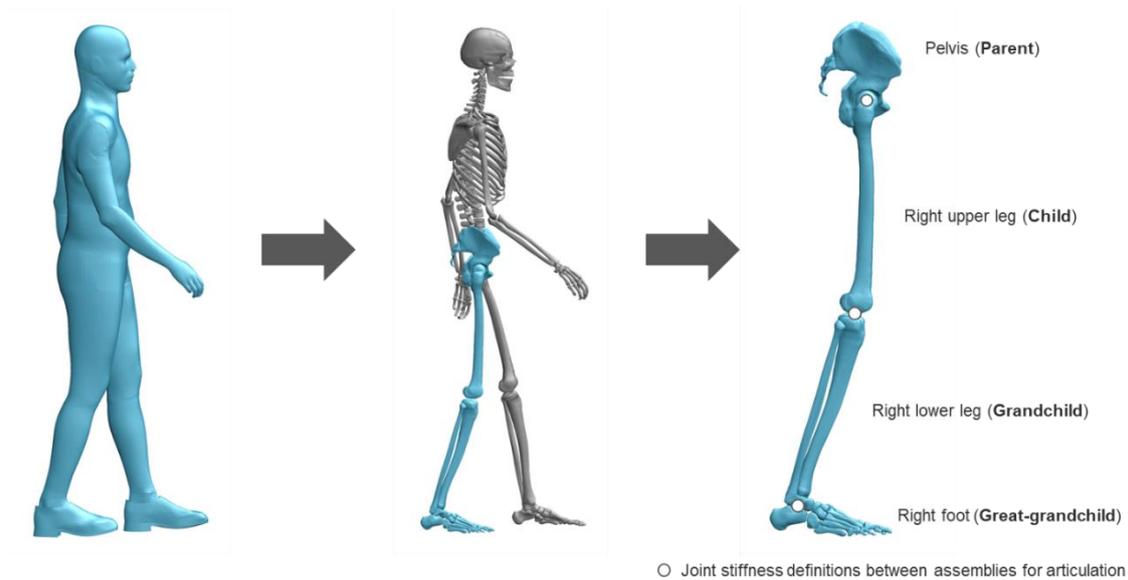
Fig.3:   Illustration of parent-child hierarchical relationship of pelvis assembly (GHBMC M50-P v1.6)

To make it easier to visualise the relevant parts when positioning, an Oasys PRIMER properties file is also provided to change the default visual attributes of the HBM.

5   Setting up a positioning analysis in Oasys PRIMER

This section describes the steps to position and articulate a HBM model to a specific target position using the latest positioning tools in Oasys PRIMER. The positioning tool is accessible via the '**Safety → Dummy & Seatsquash**' tool in PRIMER and a floating window, shown in Fig. 4, will appear to guide the user through a series of steps to create the LS-DYNA analysis. The LS-DYNA positioning method and workflow is summarised in Fig. 5.
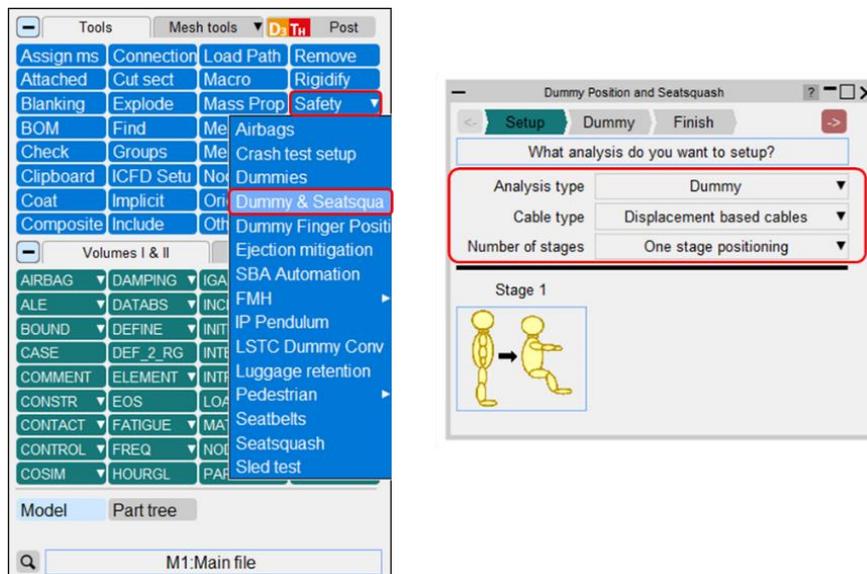

Fig.4:   Dummy and Seatsquash positioning tool in Oasys PRIMER

Fig.5:   HBM positioning workflow in Oasys PRIMER

Step 1: Move the HBM to the starting position

Before using this tool, the user must save the starting position using PRIMER's traditional positioning methods, as the saved position is used to create the entities required to 'pull' the HBM into position. This initial model should contain just the HBM model.

To move the model, use the **Orient** tool and **Translate/Rotate -> Dummy** function to translate/rotate to the start position. Alternatively, **Safety -> Dummies->Position->Translate/Rotate** can also be used.

Save the model after moving it to the start position. The next step is to include the positioning metadata file in the main HBM keyword file.

Step 2: Specify target position

Select the '**Dummy and Seatsquash**' setup tool and a floating window will appear to guide the user through the process of creating the model, previously shown in Fig. 4.

The first stage is to select the type of analysis. The options are:
1. Analysis type
   a. Dummy -> Seat: Setup a combined HBM positioning and seatsquash analysis
   b. Dummy: Setup a HBM positioning analysis only
2. Cable type
   a. Displacement-based cables: Only this cable type is supported for HBM positioning. A displacement is applied to the cables to ensure the HBM will end in the final position at the end of the analysis.
3. Number of stages
   a. One stage: Position the HBM (and optionally squash it into the seat) in one stage. An example of a combined position and seatsquash analysis is shown in Fig. 6.
   b. Two stage: Position the HBM in one stage and then squash it into the seat in a second stage
   c. Multi-stage: Position the HBM in more than one stage. Multiple intermediate stages are defined for positioning the HBM.

The next few panels will prompt the user for various inputs such as which nodes the cables should be attached to, the analysis time, the stiffness for the cables etc. Most of this information is pre-configured in the provided positioning metadata file, which contains all the necessary information to produce the positioning cables.

For example, PRIMER requires three nodes per HBM assembly for positioning. These nodes are used to pull each assembly into their final position during an LS-DYNA analysis. These nodes have been pre-configured and specifically selected to be on a rigid or stiff part of the HBM assembly rather than soft tissue to avoid undesirable element distortion during positioning. It is recommended to click Next on the panels without changing any inputs.
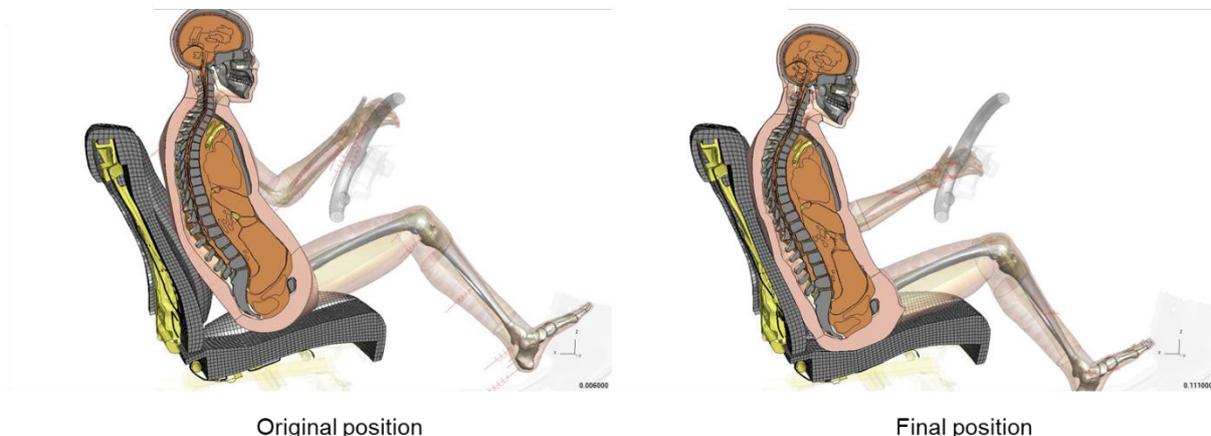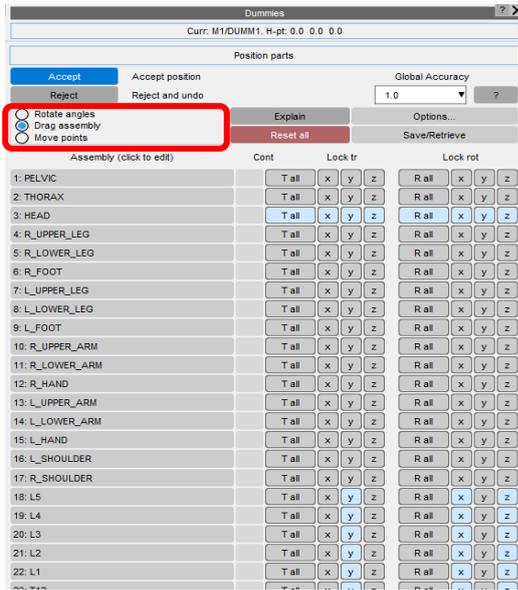

Original position   Final position

Fig.6:   Combined HBM position and seatsquash in one single stage (THUMS AM50-O v4.0)

The next step in the process is to specify the end position(s) (and optionally intermediate positions) by moving the HBM to the desired position using the interactive positioning options in the menu shown below.

Three modes of positioning are supported:
1. **Rotate-angles**: In this mode, explicit rotation of assemblies about their parent connection node takes place
2. **Drag assembly**: In this mode, 'free' dragging of the HBM takes place, combining translation and rotation
3. **Move points**: In this mode, points can be defined and edited, and 'free' movement performed by giving updated coordinates for them.

The user also has the option to restrain any assembly in various degrees of freedom to aid positioning. This may be beneficial to avoid miniscule postural changes in subsequent child assemblies. This can be achieved by toggling the **T** and **R** lock buttons in this panel.

If the multi-stage option was selected during the analysis setup, multiple intermediate positions can be defined for the HBM, as shown in Figs 7 and 8.
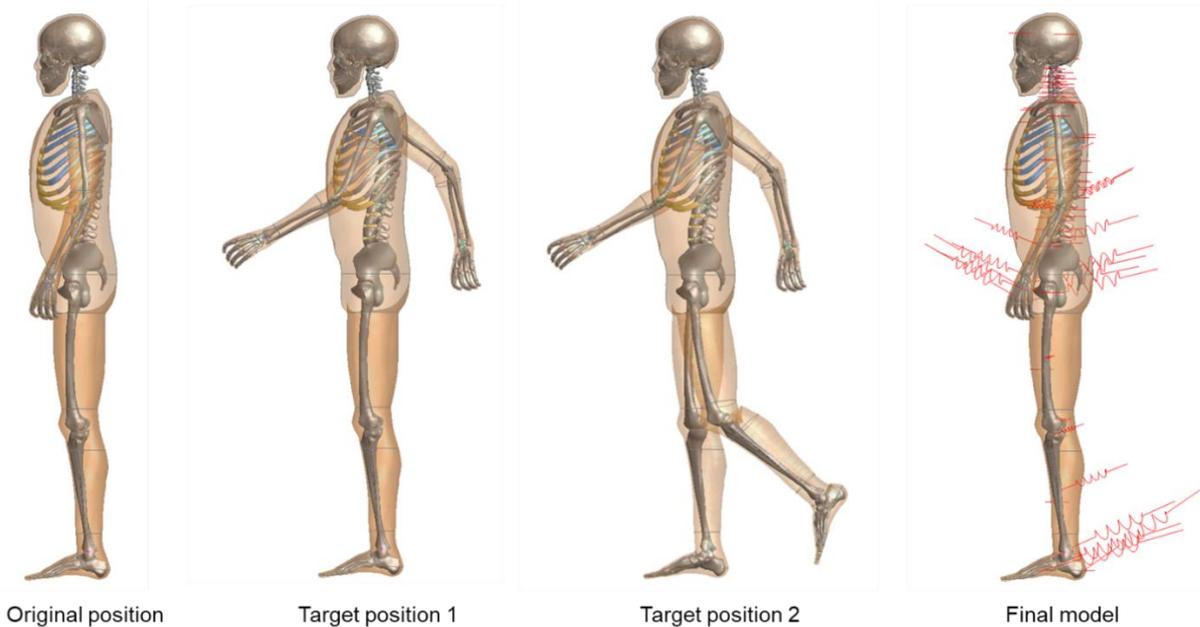

Original position   Target position 1   Target position 2   Final model

Fig.7: THUMS AM50-P v4.0.2

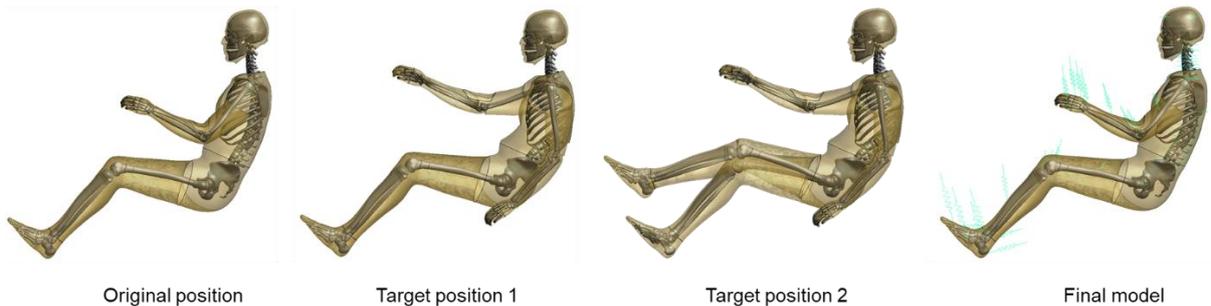Original position   Target position 1   Target position 2   Final model

Fig.8: GHBMC M50-O v5.1.1

Step 3 Write the model

PRIMER takes a few seconds to automatically create the cables and create a new model. Properties are automatically calculated for all the cables based on their length, to ensure the model is pulled into position in the specified time.

Step 4 Run the model(s) in LS-DYNA

The analysis is now ready to run in LS-DYNA.

Step 5 Import the updated nodal coordinates

Once complete, the analysis will produce a dynain file, which will have a name similar to "end_stage001_dynain". This file contains the deformed nodal coordinates from the analysis which can be imported back into the original model using PRIMER '**Tools -> Node import**' tool ready for the main analysis.

6   Front sled model

A practical example of positioning an average male occupant HBM in a front-sled model is demonstrated. A simplified front-sled model was developed based on the 2014 Honda Accord mid-size sedan full-vehicle, developed by EDAG, Inc under a contract awarded by NHTSA. The sled model consists of the front occupant space with all interior trims that are likely to come into contact with the occupant during the crash event. Interior elements include the steering wheel and columns, instrument panel with knee bolsters, seating for the driver, interior trim panels (door, b-pillar).

Occupant restraint systems for crash protection such as front control-volume (CV) air bag, seatbelt pretensioners and load limiters are also included. The existing 3-point seatbelt model with 1D sliprings was replaced with a fully-fabric seatbelt system including explicitly meshed sliprings using PRIMER's new advanced belt-fitting tool. This tool uses fabric shells over most of the seatbelt route, including through both sliprings, and overcomes common challenges associated with 1D and 2D belts such as belt-run out, instability during unloading, hang-ups at the slip rings and unrealistic contact friction.

An acceleration pulse from a full-vehicle frontal crash simulation, impacting a rigid wall at speed of 55 km/h, was applied to the sled model to resemble the actual vehicle motion.

Human body models of a 50th percentile male, developed by the GHBMC (M50-O v5.1.1) and THUMS (AM50-O v4.1), were both positioned in the driver seating position. Using PRIMER's positioning tool, the occupant model was placed in the driver's seat with the hands on the steering wheel and the feet on the pedals. A positioning analysis was performed where the model was pulled into position over a 150 ms time period. The deformed nodal coordinates were then imported back into the original model as input for the main front sled crash analysis, as illustrated in Figs 9 and 11. All simulations were run using LS-DYNA MPP SP R11.2 using 16 cores.

Figs 10 and 12 show the occupant kinematics of a THUMS AM50-O v4.1 and GHBMC M50-O v5.1.1 model at 20ms intervals, respectively.

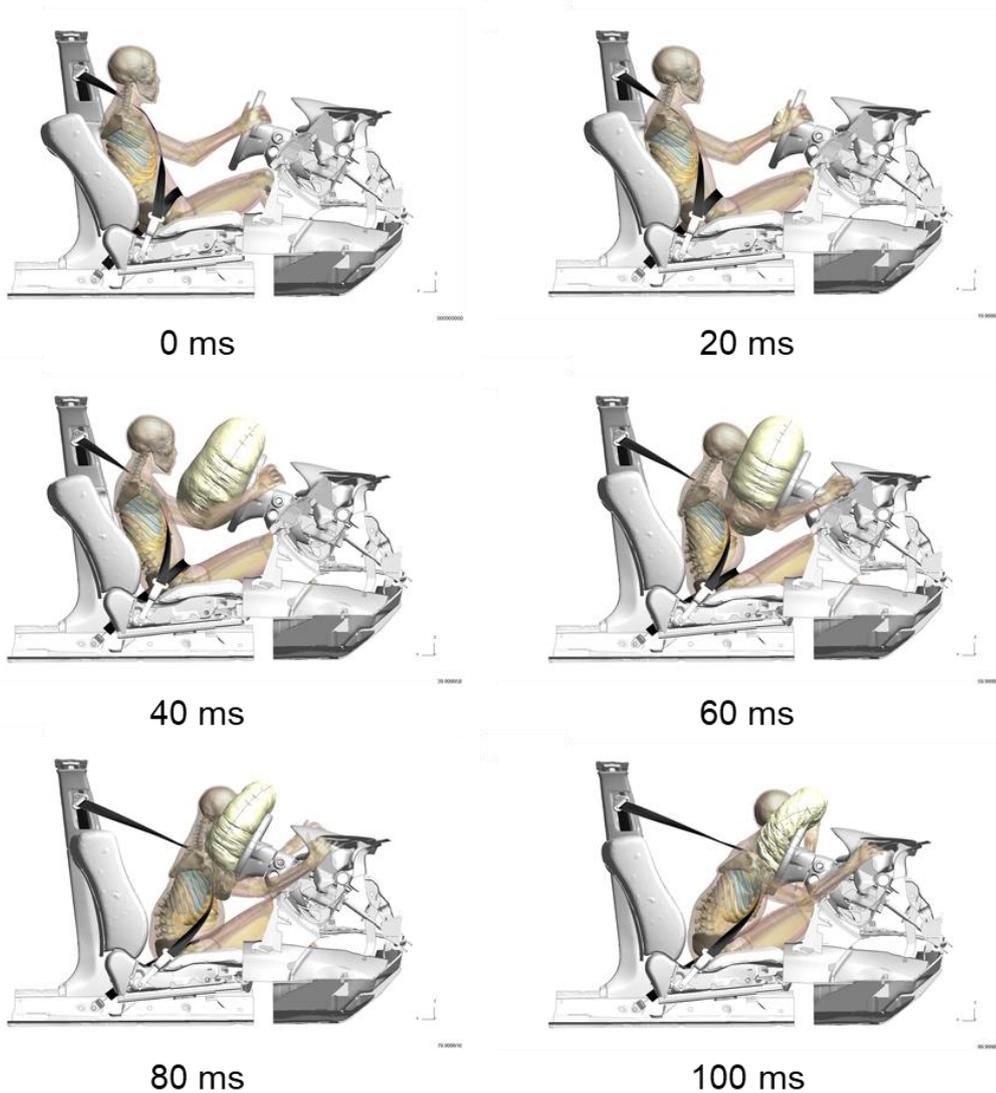*Fig.9:   Front sled impact model with THUMS AM50-O v4.1 occupant model positioned in driver seat*

0 ms

20 ms

40 ms

60 ms

80 ms

100 ms

Fig.10: Occupant kinematics of THUMS AM50-O v4.1 model

Fig.11: Front sled impact model with GHBMC M50-O v5.1.1 occupant model positioned in driver seat
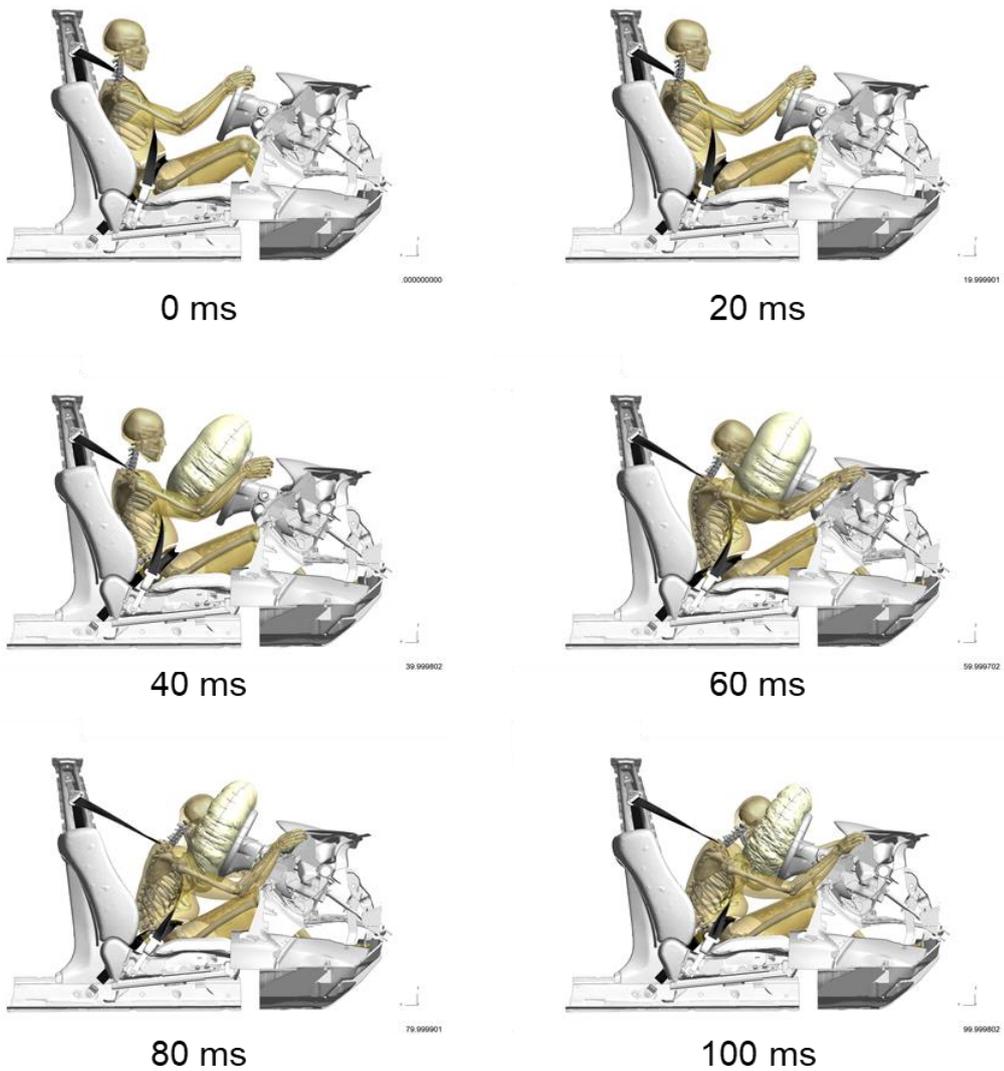

0 ms

20 ms

40 ms

60 ms

80 ms

100 ms

Fig.12: Occupant kinematics of GHBMC M50-O v5.1.1 model

7 Conclusion

HBM positioning trees are now available in the latest release of Oasys PRIMER for the industry leading GHBMC and royalty-free THUMS models.

All detailed occupant and pedestrian GHBMC and royalty-free THUMS models (v4, v5, v6) are supported.

In summary, PRIMER positioning trees:
- enable easy, interactive positioning of highly complex HBMs
- include realistic biofidelic joint detailing for example, bending and straightening of the spine, and realistic shoulder/clavicle movement
- include realistic stop angles to ensure appropriate relative movement between the various parts of the model
- include an Oasys PRIMER properties file which can be used to change the visual attributes of the HBM, making it easier to see the relevant parts of the model when positioning

A user positioning guide is also provided which details the process of setting-up pre-simulation positioning analyses using the latest release of Oasys PRIMER.

The HBM positioning trees are provided free-of-charge for Oasys PRIMER customers. To request a tree, or to discuss purchasing the Oasys Software, please get in touch with your local Oasys distributor.

Please visit our dedicated HBM webpage (https://www.oasys-software.com/dyna/models/hbm-trees/) for the latest HBM news and developments.

8 Literature

[1] Oasys® PRIMER 18.0 User Manual. Ove Arup & Partners Ltd: Solihull, UK, 2021