HBM4VT – WG 2
Sled simulation setup

Lopez-Valdes et al. 2017

SCIENCE
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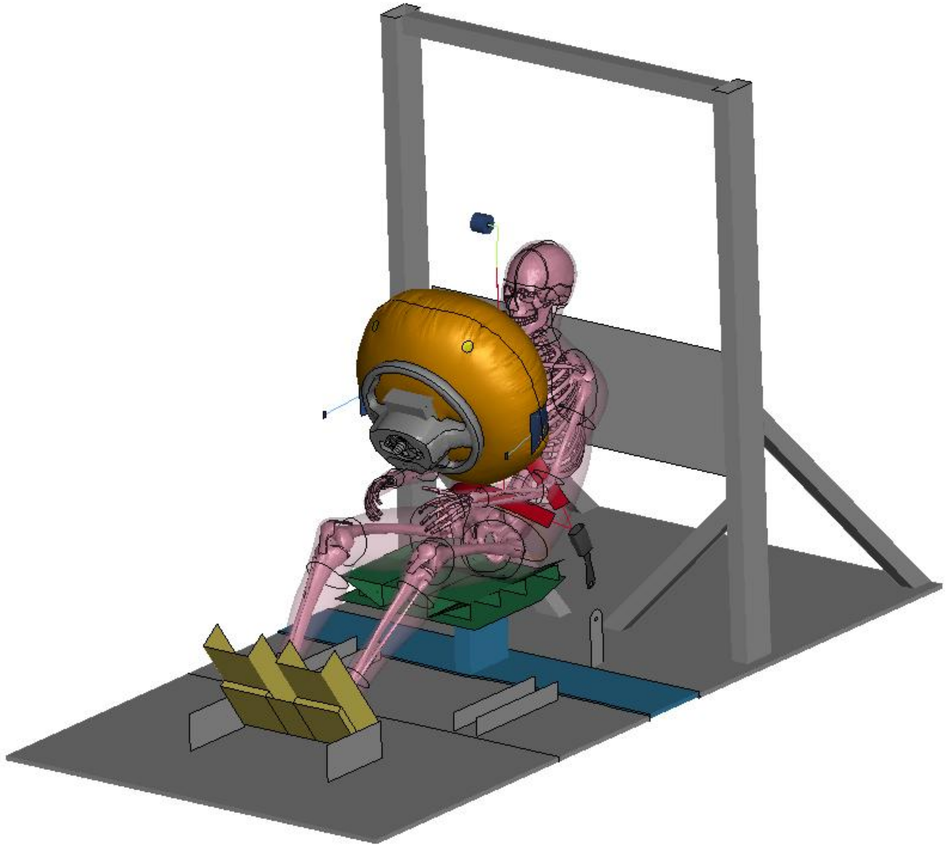
General Overview

Model Setup

Far side sled tests by Lopez-Valdes et al. 2017

Key factors to replicate from PMHS tests:

- HBM seated on rigid seat
  - Seat belt fitted
  - Hands on lap
  - Lower extremities on footrest
- Pre inflated Airbag
- Sled acceleration in x direction
- Head trajectory measured
- Belt forces in shoulder and lap belt measured



Development notes

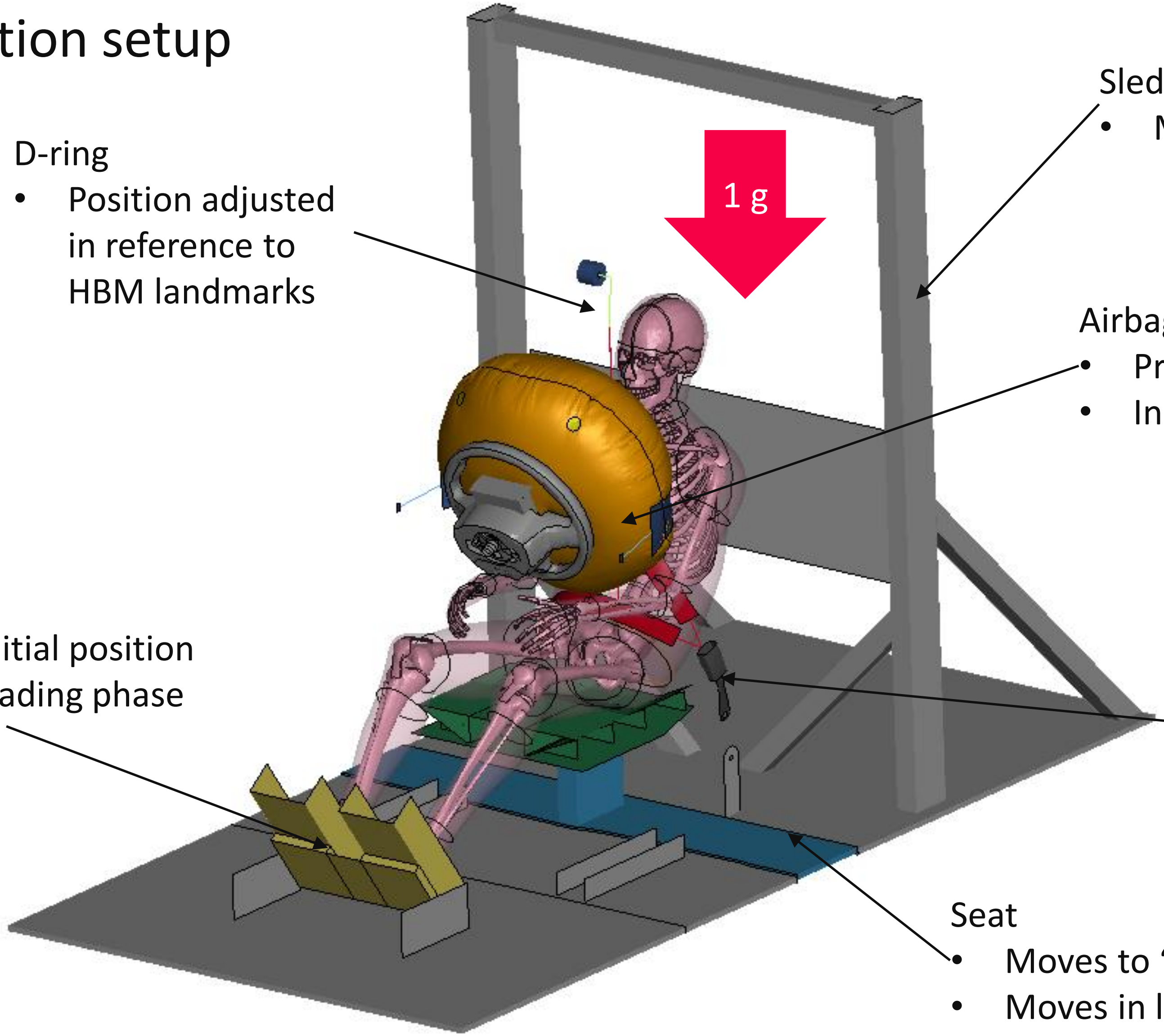
LS-Dyna version used for development:

- R12.2_217 mpp single precision (R12.2-217-gfcd6dde0c9)
- Time step: dt2ms = -4.44E-4 ms (tssfac = 0.9)

HBMs used in testing:

- THUMS v4.1 50th percentile male
- THUMS v4.1 95th percentile male
- VIVA+ v1.0.0 50th percentile female

Simulation setup



D-ring
- Position adjusted in reference to HBM landmarks

Sledbase
- Moves in loading phase

Airbag
- Pre inflated
- Initial contact to HBM

Footrest
- Moves to initial position
- Moves in loading phase

Belt
- Fitted via Retractor
- Load limiter in shoulder belt

Seat
- Moves to “settle” on HBM
- Moves in loading phase

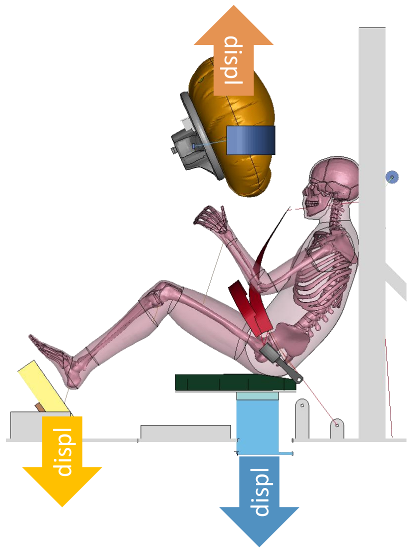
Simulation phases

Initial model

HBM positioned in target position

- Rotation to reach 30° sternum angle

Seat and airbag transformation



Seat

- Seat is moved downwards

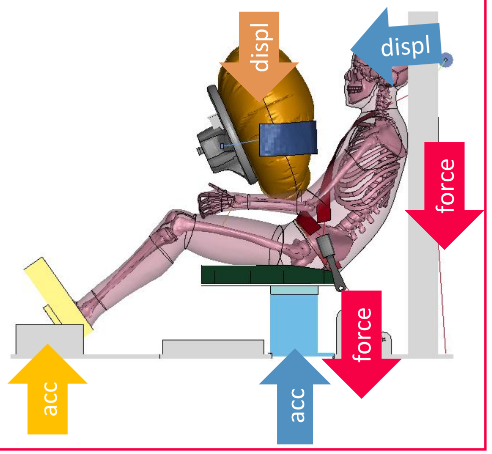
Airbag

- Airbag is moved upwards

Settling phase

Testbed settling and belt fit

- HBM pelvis and spine constraint
- No gravity



Testbed

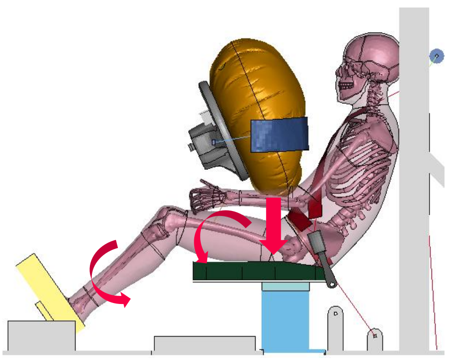
- Seat is accelerated upwards with 1g
- Footrest is accelerated upwards with 1g
- Airbag is moved to target position

Belt

- Pretension is applied to fit belt
- D-ring is moved to target position

Hand and leg positioning

- HBM pelvis and spine constraint
- No gravity



Hands

- Hands move to target position

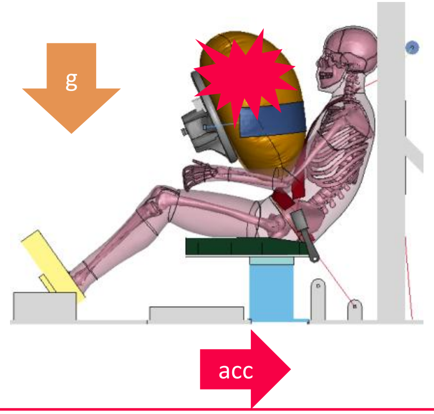
Legs

- Femur is rotated to reach target angle
- Tibia is rotated to reach target angle

Loading phase

Load application

- HBM constraints released
- Gravity applied
- Sled loading applied
- Airbag inflated



Load

- Sled velocity applied in x direction
- Gravity applied
- Airbag inflated
- Belt load limiter

Simulation phases

Velocity of all HBM nodes set to 0

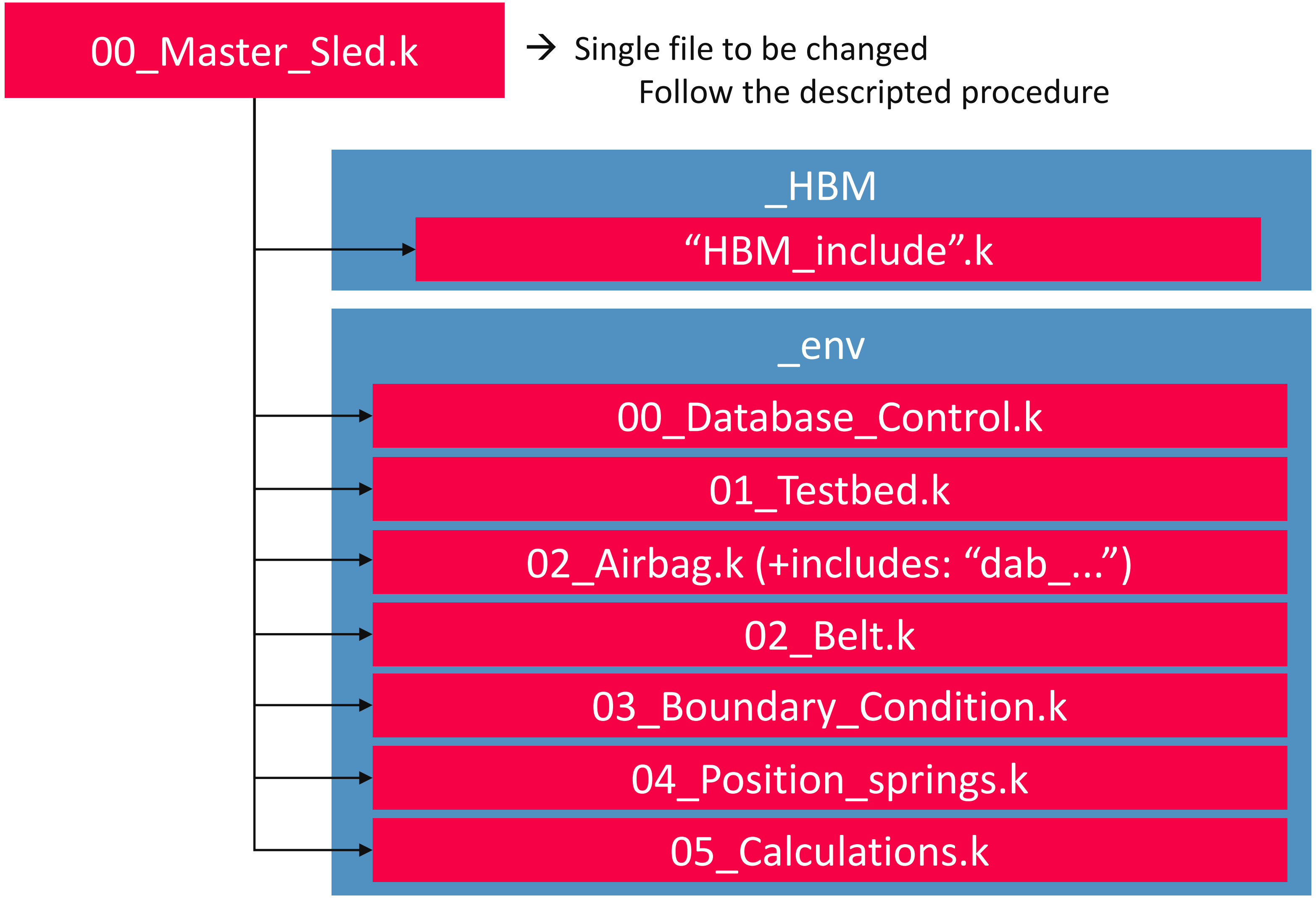
Settling phase	Loading phase
Pelvis and thorax of HBM constraint	No constraint
Femur rotates to target angle	Positioning beams deleted
Tibia rotates to target angle	Positioning beams deleted
Hands move to target position on thighs	Positioning beams deleted
1g applied on seat and footrest to “settle” on HBM	Load movement applied
D-ring moves to target position	Moves with testbed
100N pretension force applied	Load limiter in shoulder belt
Airbag moves downwards to target position	Airbag inflated
Contact between HBM and testbed	Gravity applied

Time

SetHBM | *tload*

loadSt

Overview – belt load case



→ Single file to be changed
Follow the descripted procedure

→ Add your HBM-include in the folder „_HBM"

Procedure

Setting the parameters

Set the include file

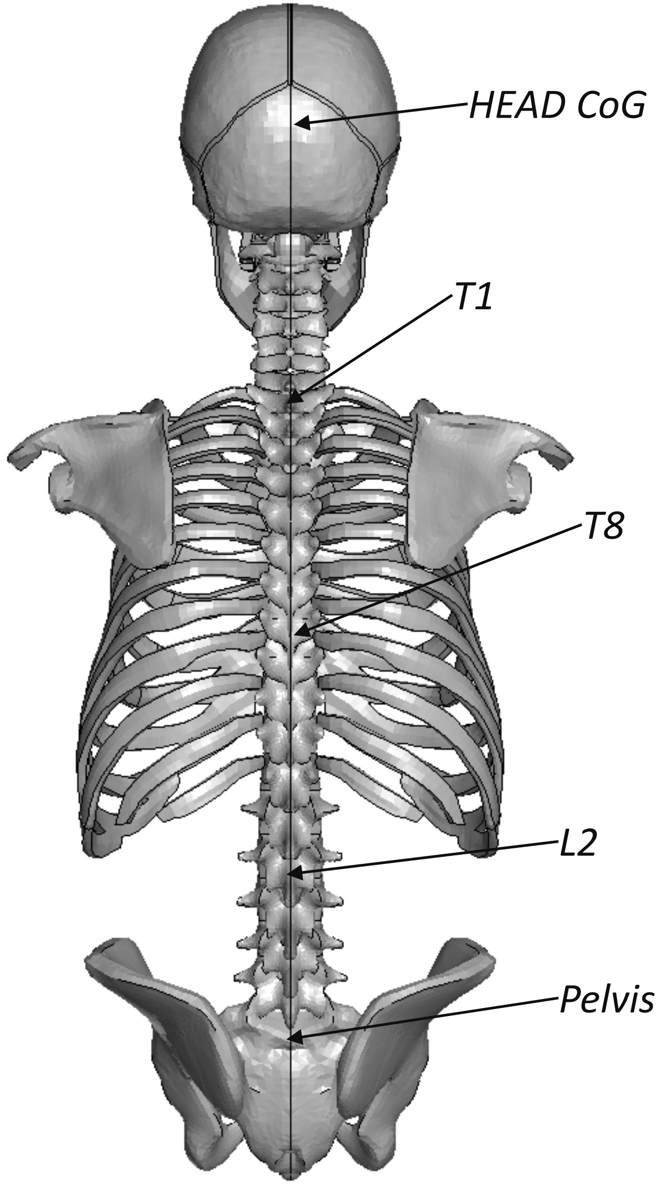
1) Put the main HBM file in the folder directory "_HBM"
2) Open the main HBM file in a pre-processor
3) Open the file 00_Master_Sled.k in a text editor
4) Define the main HBM file in the I N C L U D E S section
5) Follow the instructions from STEP 1 to STEP 9

- Note: If you need to change previously defined parameters, walk through the subsequent steps again and check if parameters need to be updated. E.g. the coordinates of the landmarks need to be updated, if the position of the HBM changes.

Instrumentation requirements

- Equip your HBM with the required output
  - Head CoG
    - *ELEMENT_SEATBELT_ACCELEROMETER required to provide local output
  - T1, T8, L2 and Pelvis
    - *DATABASE_HISTORY_NODE_ID
    - Refer to following public documents:
      - Vertebrae: TB024 Pedestrian Human Model Certification, Annex B
      - Pelvis: Report on PMHS 494, 492. ATD Thoracic response test development, NHTSA, 2011
  - Strains in cortical bones of pelvis and ribs

- Note: make sure your output rate is at least 10kHz for contact and nodal outputs since CFC filtering is applied in Jupyter notebook
- Update all node IDs in the HBM ID-file in "…\data\metadata" accordingly (see THUMS/VIVA+ files for examples)



Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define sternum angle and ID offset
6) Define attachment nodes for positioning beams
7) Measure angles and landmark locations
8) Check for intersections
9) Run simulation and check results

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case

Goal:

- Define the preferred restraint condition

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters
3) Definition of the HBM position and orientation

Goal:

- Define factor to scale environment to the unit system of the HBM
- Define whether HBM wears shoes
- Define the position and orientation of the HBM
- Use this point as origin and rotate HBM to bring it in supine position

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define sternum angle and ID offset

Goal:

- Define sensible HBM contact set
- Define parameters for positioning of the HBM

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define sternum angle and ID offset
6) **Define attachment nodes for positioning beams**

Goal:

- Define how extremities are moved during settling

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define sternum angle and ID offset
6) Define attachment nodes for positioning beams
7) **Measure angles and landmark locations**

Goal:

- Measure the femur and tibia angle and the location of the landmarks

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define sternum angle and ID offset
6) Define attachment nodes for positioning beams
7) Measure angles and landmark locations
8) Check for intersections

Goal:

- Check for intersection of the HBM to the sled

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters
3) Definition of the HBM position and orientation
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5) Define sternum angle and ID offset
6) Define attachment nodes for positioning beams
7) Measure angles and landmark locations
8) Check for intersections
9) Run simulation and check results

Goal: Adapt settling or load time if necessary

STEP 1

Definition of the load case

Two restraint conditions are available. Set only one flag to 1

- RCa: Restraint condition A
  - Load limiter force: 2.5kN
  - Airbag pressure: 16 kPa

- RCb: Restraint condition B
  - Load limiter force: 2.0kN
  - Airbag pressure: 11 kPa

→ The Position of the HBM and the airbag as well as the sternum angle will be defined depending on the chosen restraint condition

	RCa	RCb
Deviation of H-point location in x [mm]	5.0	1.0
Sternum angle [°]	24.2	32.7
Airbag x-position [mm]	As close as possible to HBM	As close as possible to HBM
Airbag z-position [mm]	707.0	623.7

STEP 2

Definition of the unit system of the HBM

Define the scale factors depending on the unit system of the HBM

- *U_Scal*: 0.001 for unit system t-mm-s
- *U_Scal*: 1 for unit system kg-mm-ms

→ The testbed environment will be scaled by *U_Scal* to the preferred unit system

Define the correct unit system in the assessment Jupyter notebook

- ms_mm_kg
- s_mm_ton

Attention: all parameters in the **main key file** need to be defined in the unit system **kg-mm-ms**

Define if the used HBM wears shoes or not

- *Shoes:* set to 0 if HBM wears shoes
- *Shoes:* set to 10 if HBM wears NO shoes

→ Footrest is positioned +10mm in x and z direction if HBM doesn‘t wear shoes (represents thickness of sole)

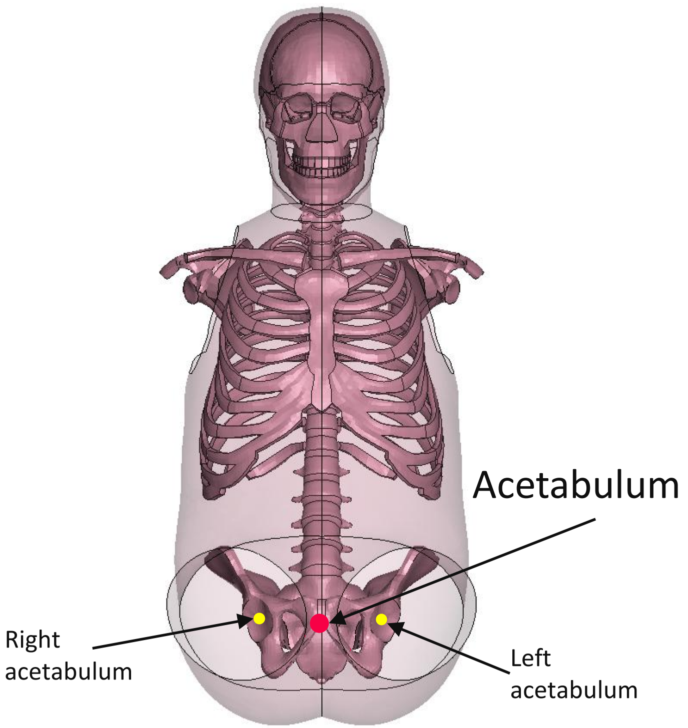
STEP 3

Definition of the HBM position and orientation

Define the coordinates of the location of the acetabulum centre point (AC) between the left and right acetabulum (in midsagittal plane):

- *x_AC*: x-coordinate of acetabulum in the default HBM position with respect to the global coordinate system
- *y_AC*: y-coordinate of acetabulum in the default HBM position with respect to the global coordinate system
- *z_AC*: z-coordinate of acetabulum in the default HBM position with respect to the global coordinate system

→ The HBM will be transferred to the H-point of the seat



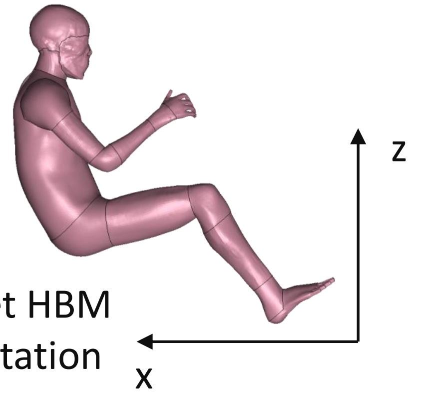
Default HBM position

Check the actual HBM orientation and compare to the target orientation as illustrated

Define the flag to 1 or -1 for all axes:

- *x_rt*: "1" for correct axis orientation and "-1" to rotate the model 180deg about the x axis
- *y_rt*: "1" for correct axis orientation and "-1" to rotate the model 180deg about the y axis
- *z_rt*: "1" for correct axis orientation and "-1" to rotate the model 180deg about the z axis

→ HBM will be rotated to reach target orientation



Target HBM orientation

STEP 4
Set ID for contact sets and constraints

Define the part set of HBM
- *P_hbm*: ID of the set including all HBM parts

→ This part set will be in contact to the testbed

Define the part set of all skin parts of the HBM
- *P_ski*: ID of the set including all skin parts of the HBM

→ This part set will be in contact to the testbed

Define the part set of HBM body without arms and legs
- *P_bdy*: Set ID of the set including the HBM body without arms and legs

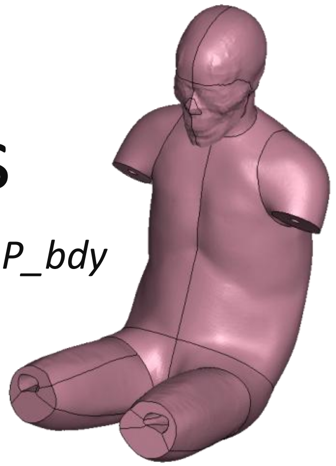
→ This part set will be in contact to the belt in the settling phase

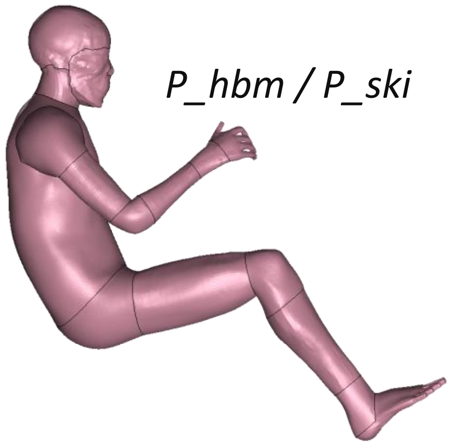
Define the mass of the HBM without legs
- *M_HBMt*: Mass of the HBM without legs in [kg]

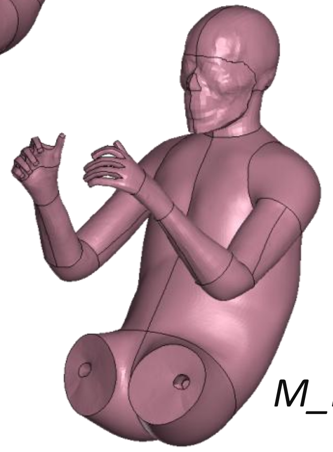
→ The mass of the seat will matched to the mass of the HBM without legs to reproduce a realistic settling behaviour

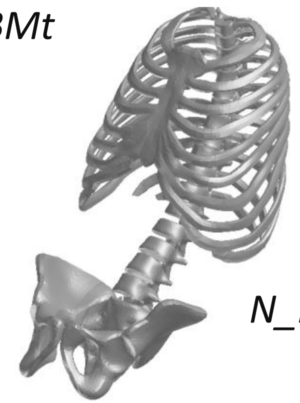
Define the node set including several nodes on the bones of the pelvis and the thorax (e.g. choose three nodes per bone, not all nodes of a bone are required to be constrained)
- N_bone: ID of the set including nodes on bones of pelvis, spine and ribs

→ This node set will be constrained in the settling phase (do not choose nodes belonging to rigid materials or rigid bodies)









STEP 5

Define sternum angle and ID offset

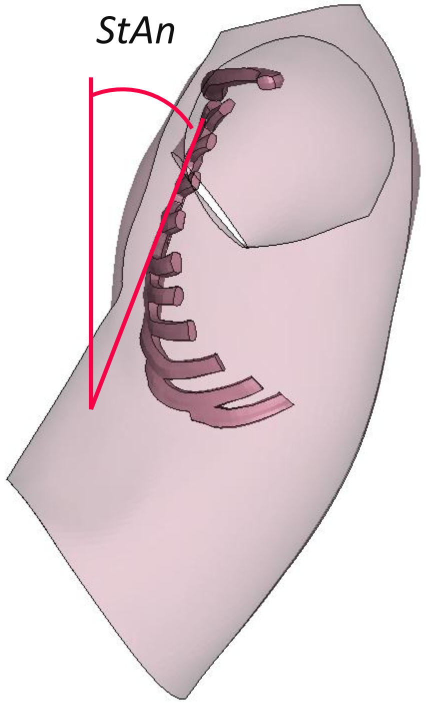
Measure the sternum angle between the center of attachment of 2nd and 4th rib relative to the frontal plane

- *StAn*: angle in default posture of HBM used here

→ The HBM will be rotated to archive a sternum angle of 30° against the vertical plane

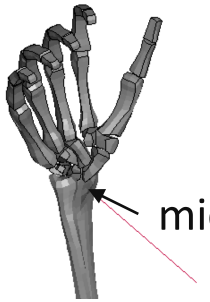
IF the testbed shares node IDs with the HBM, set an ID offset for the HBM

- *IDoff*: default: 0.



STEP 6

Define attachment nodes for positioning beams

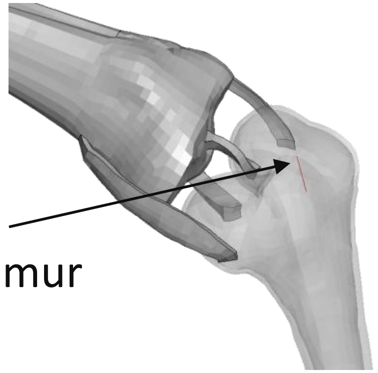


Save the file “00_Master_Sled.k” and open it in a pre-processor

Node IDs for the landmarks to be positioned

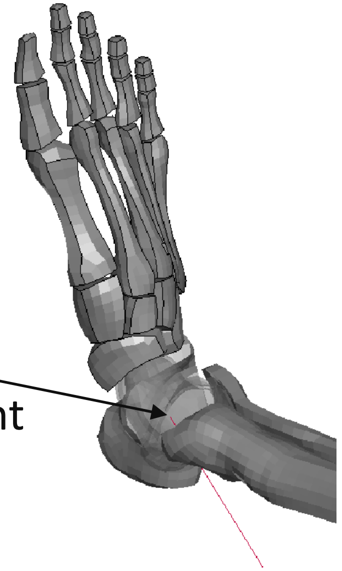
ri = right, le = left

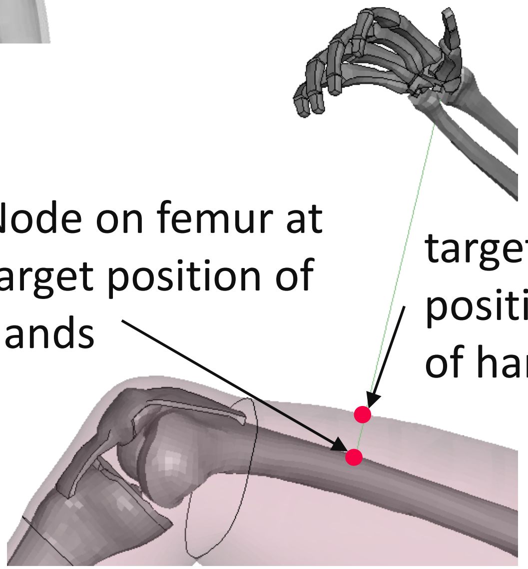
- *N_rari/N_rale*: Node at mid of distal radius
- *N_tari/N_tale*: Node on femur at target position of hands
- *N_feri/N_fele*: Node at mid of distal femur
- *N_anri/N_anle*: Node at mid of ankle joint



Coordinates of landmark nodes in updated “00_Master_Sled.k” file

- X...: x-coordinates of chosen landmarks in positioned model
- Y…: y-coordinates of chosen landmarks in positioned model
- Z…: z-coordinates of chosen landmarks in positioned model





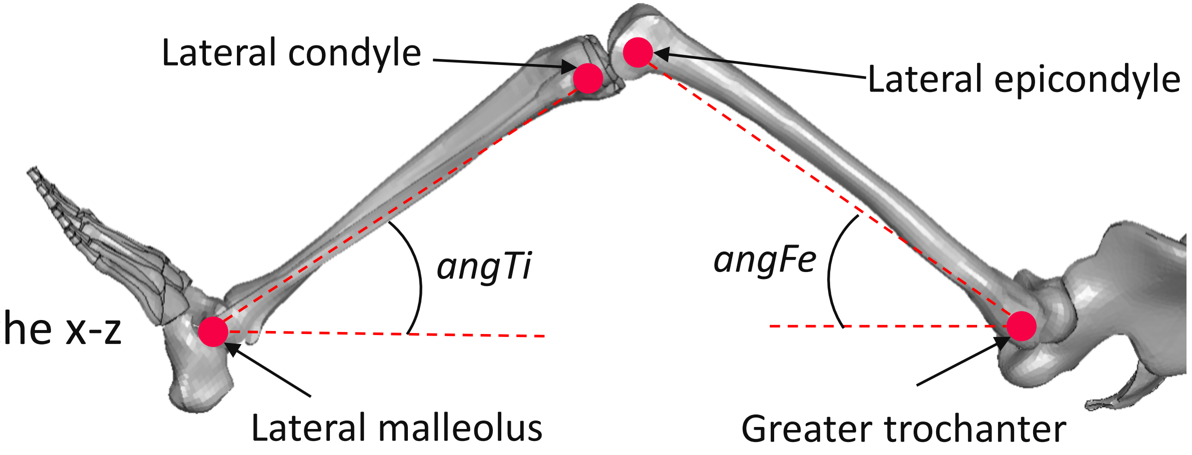
STEP 7

Define HBM position

Measure the femur and the tibia angle to the horizontal axis in the x-z plane in the positioned HBM on the sled

- *angFe*: femur angle defined as a positive value
- *angTi*: tibia angle defined as a positive value

→ The target positon of the knee and the ankle will be defined to archive a femur angle of 11° and a tibia angle of 40° to the horizontal plane



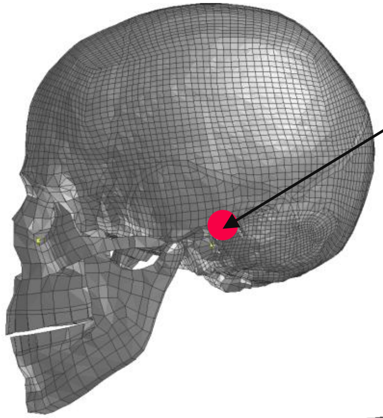
Measure the position in z of the superior margin of the external auditory canal

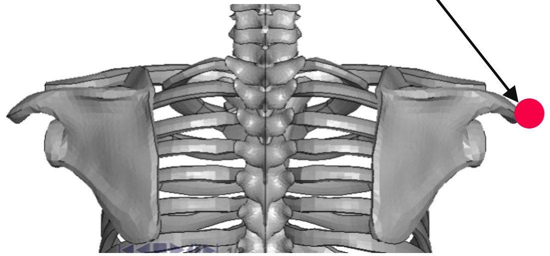
- *acus_z*: z-coordinate of the node at the superior margin of external auditory canal in the global coordinate system

Measure the position in y of the distal margin of the right acromion

- *acro_y*: y-coordinate of the node at the distal margin of the right acromion in the global coordinate system

→ The D-ring will be positioned to align in z with the superior margin of external auditory canal and has a lateral distance of 100mm to the distal margin of the right acromion





S T E P 8

Define HBM position

Save the file “00_Master_Sled.k” and open it in a pre-processor

IF the airbag has intersections to the HBM, move the airbag in z

- *movABz*: moving distance of airbag in z (positive value = upwards)

IF the HBM has intersections to the seat, move seat in z

- *movSEz*: moving distance of seat in z (positive value = upwards)

IF the HBM has intersections to the foot rest, move the foot rest in z

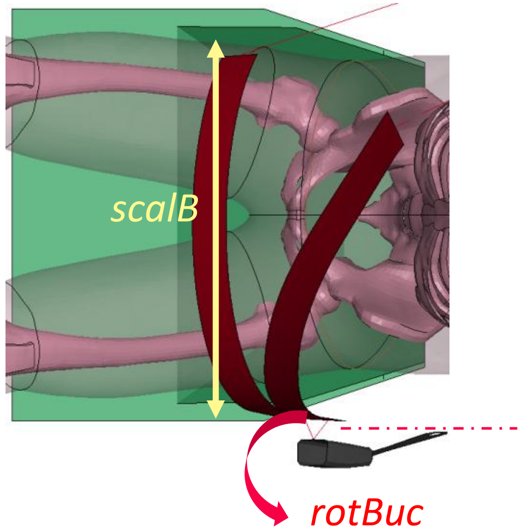
- *movFRz*: moving distance of foot rest in z (positive value = upwards)

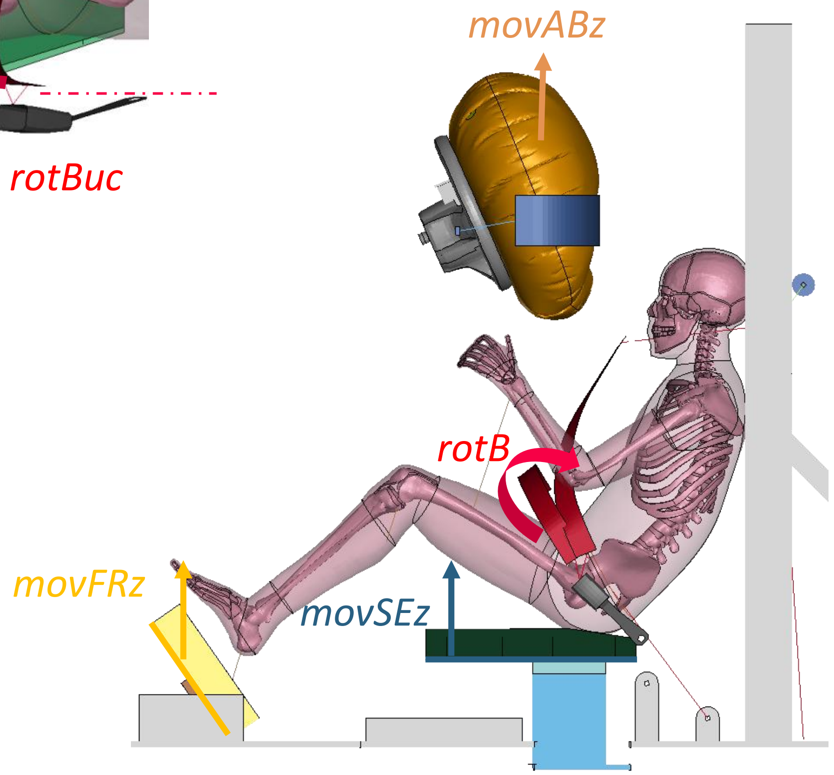
IF the lap belt has intersections to the HBM:

- rotate the lap belt about the y-axis
    - *rotB*: rotation angle in degrees about y-axis (positive value = rotation upwards)
- scale the lap belt in y-axis
    - *scalB*: scale factor of lap belt in y-axis (positive value = lap belt extends to the side)

IF the buckle has intersections to the HBM, rotate buckle about x

- *rotBuc:* rotation angle in degrees about x-axis (positive value = rotation outwards)





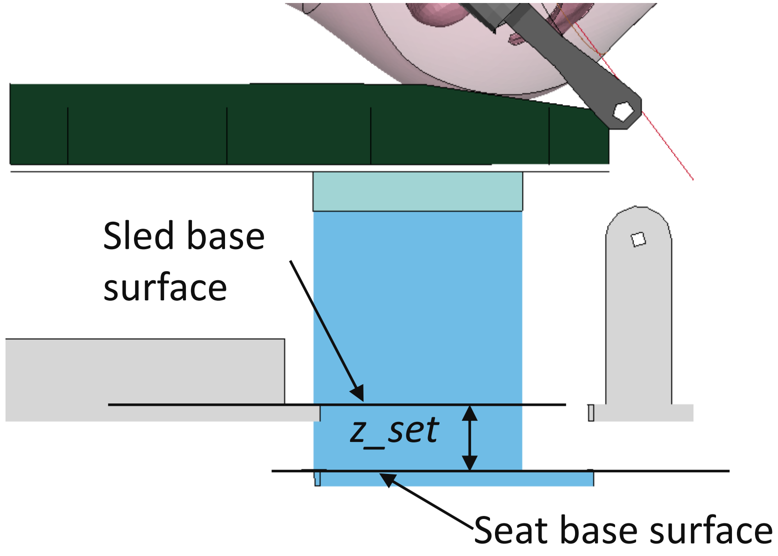
STEP 9
Run simulation and check results

Check the d3plot and adapt the parameter if needed:

Measure the distance between the seat base and the sled base in the settled model

- Distance < 5mm: neither a change of z_set nor a rerun of the simulation is required.
- Distance > 5mm: insert the measured value for z_set, update the z-coordinates of the nodes in step 7 and rerun the simulation.
    - *z_set*: distance in z (insert a positive value, if the seat base is below the sled base)

→ After the settling phase, the seat will be at the same height as is the PMHS tests



IF the start time for the belt settling is not satisfying, change time [ms]

- *SetB*: time when belt starts to settle (default: 100ms)

IF settling phase is not long enough, change duration

- *SetHBM*: duration of settling phase (default: 400ms)

STEP 9
Run simulation and check results

Check the d3plot and adapt the parameter if needed:

IF arm or leg positioning beams do not fully compress, increase tension force (insert value in kN)

- *FbeamA*: Tension force in arm positioning beams. default: 0.1 kN
- *FbeamL*: Tension force in leg positioning beams. default: 0.2 kN

Duration of testbed movement in ms. Change only IF load curve duration changes

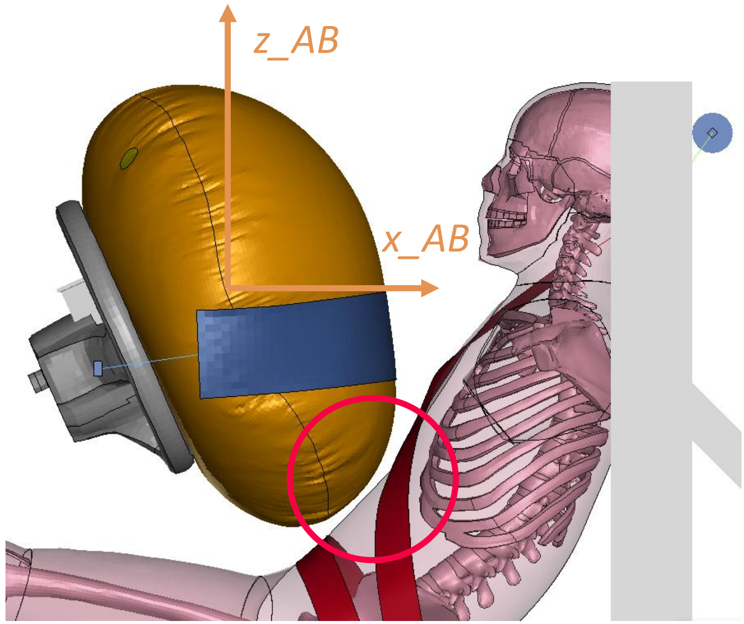
- *tload*: duration of loading curve (default 350ms)

Check the distance between the inflated airbag and the HBM thorax in x direction in the settled model. Modify the x-position of the airbag so that the inflated airbag does not touch the HBM thorax

- *x_AB*: x-distance, define a positive value to move the airbag towards the HBM

IF the steering wheel rim contacts the thighs in the settled model, move the airbag in z

- *z_AB*: z-distance, Define a positive value to move the airbag upwards



IF contact issues occur, modify DEPTH flag for contact HBM to environment

- *Depth*: default: 23

Final checks

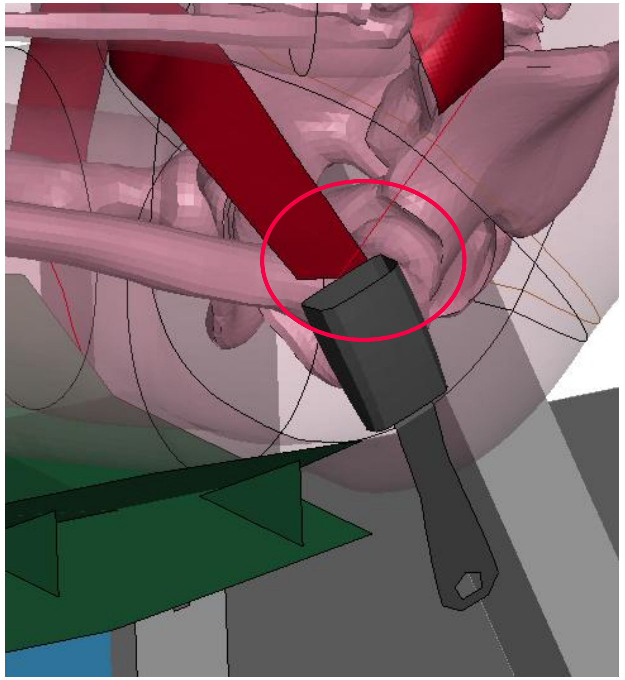
Check following values in the settled model (@ tSetHBM)

	Airbag position in x direction	**Seat base**
Restraint condition RCa	Inflated airbag as close as possible to the HBM	Should align with sled base in z direction ± 5mm
Restraint condition RCb	Inflated airbag as close as possible to the HBM	Should align with sled base in z direction ± 5mm

Error termination guide

“belt segment has free end“

- Issue: 2D belt is being pulled into slip ring
- Procedure: *Check simulation duration*
  - *IF the issue occurs when* the rebound phase has been reached:
    - Simulation results may be utilised for assessment purposes
  - *ELSE*
    - Check if arms are not included in part set *P_bdy*
    - Check for initial penetrations between the belt and the HBM, which may cause sticky nodes



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