HBM4VT – WG 2
Sled simulation setup

Shaw et al. 2009

TU Graz
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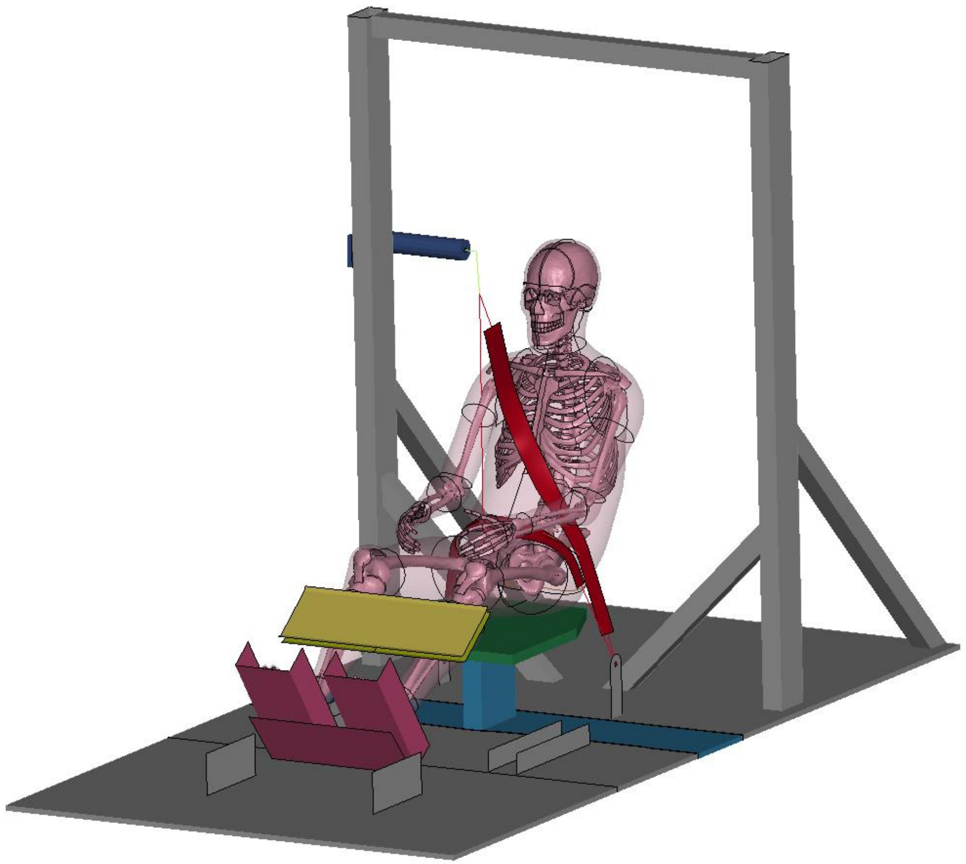
General Overview

Model Setup

Frontal sled tests by Shaw et al. 2009



Key factors to replicate from PMHS tests:

- HBM seated on rigid seat
  - Seat belt fitted
  - Hands on lap
  - Lower extremities fixed
- Sled acceleration in x direction
- Head trajectory measured
- Seat forces, footrest forces and knee support forces measured
- Belt forces in shoulder and lap belt measured

Development notes

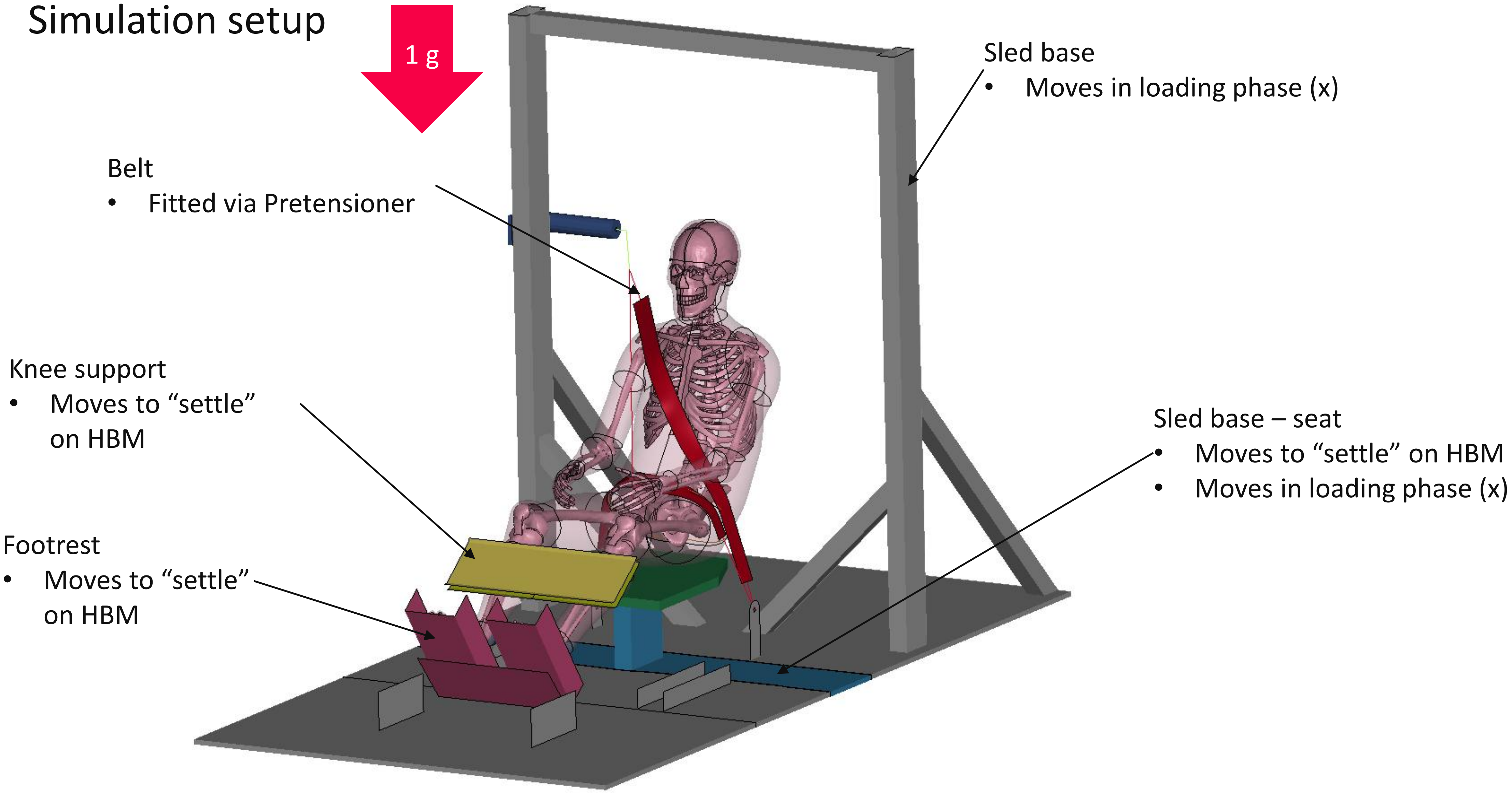
LS-Dyna version used for development:

- 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

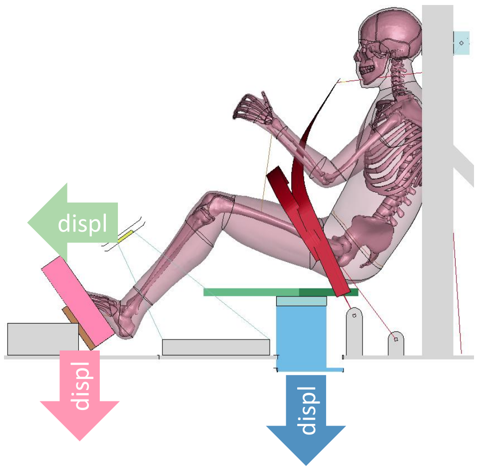


Simulation phases

Initial model

HBM positioned in target position
- HBM in standard driver posture

Testbed transformations

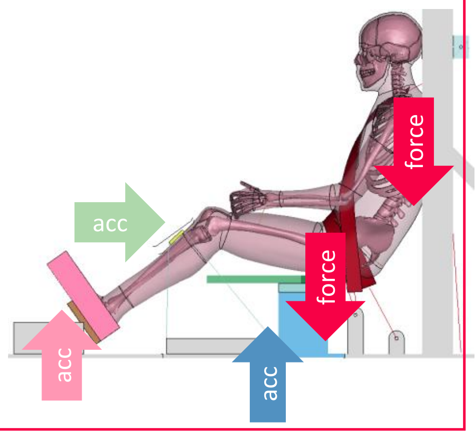


Position
- HBM is rotated to reach target sternum angle for AM50 or AF05 anthropometry

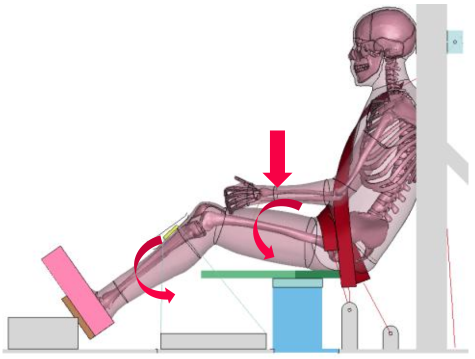
Testbed
- Seat is moved downwards
- Footrest is moved downwards
- Knee support is moved away from HBM

Settling phase

Testbed settling and belt fit
- HBM pelvis and spine constraint
- No gravity



Hand positioning
- HBM pelvis and spine constraint
- No gravity



Testbed
- Seat is accelerated upwards with 1g
- Footrest is accelerated upwards with 1g
- Knee support is accelerated towards HBM with 1g

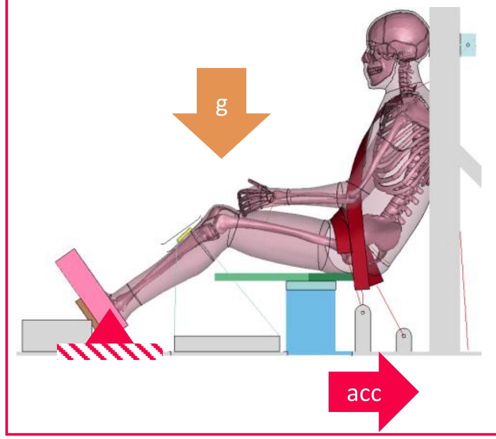
Belt fit
- Pretension force is applied to fit belt to HBM

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



Load
- Sled velocity applied in x direction
- Gravity applied
- Ankles constrained to footrest

Simulation phases

Velocity of all HBM nodes set to 0

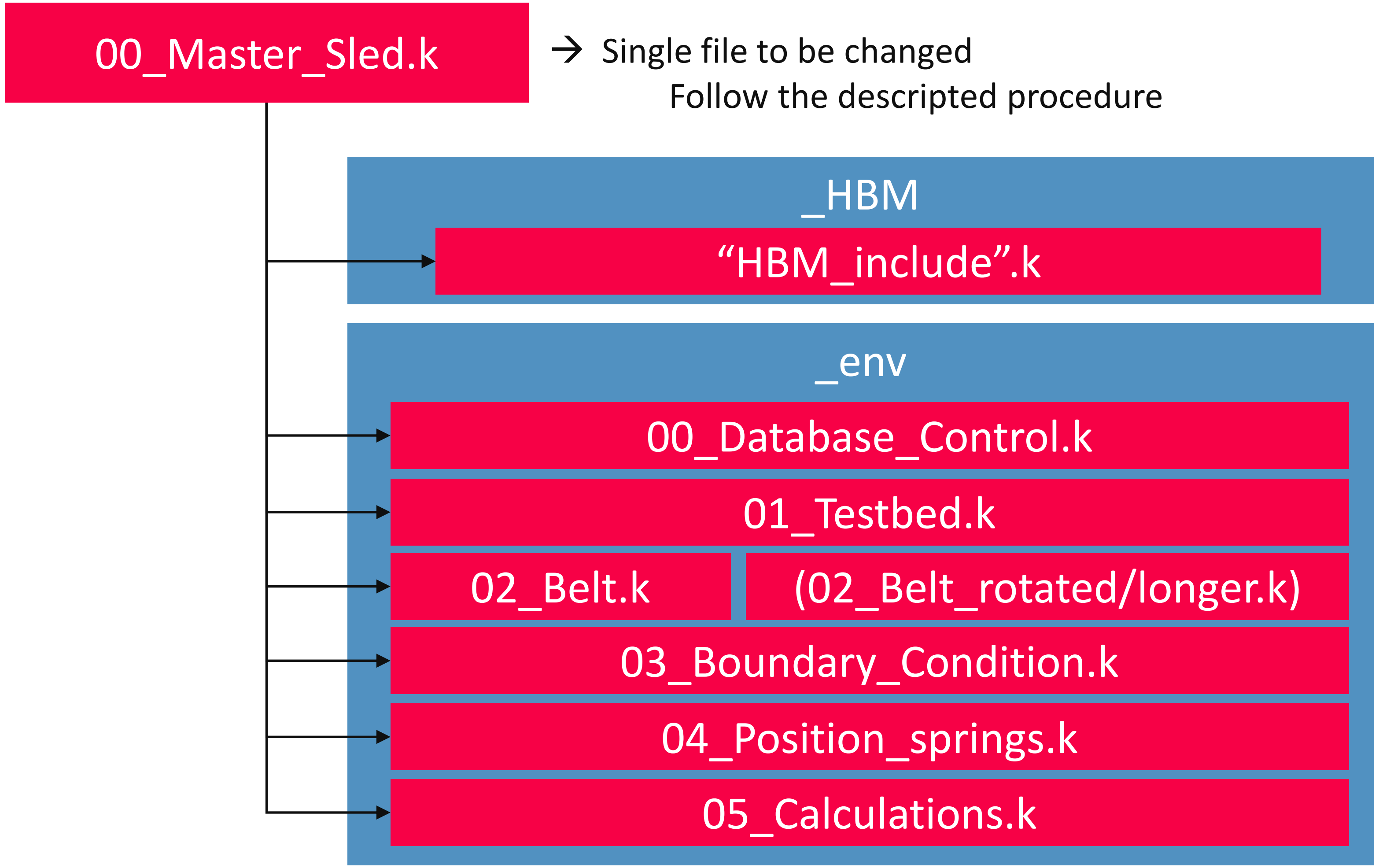
Settling phase	Loading phase
Pelvis and thorax of HBM constraint	No constraint
Femur rotates to target angle	Positioning beams deleted
Tibia rotates to target angle	Both tibia constrained to sled base
Hands move to target position on thighs	Positioning beams deleted
1g applied on knee support to “settle” on HBM	Load movement applied
1g applied on footrest to “settle” on HBM	Load movement applied
1g applied on seat to “settle” on HBM	Load movement applied
100N pretension force applied	No pretension and no load limiter
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“

→ Rotated belt model and rotated and longer belt model provided in case of intersections of "02_Belt.k" to HBM. Use only if necessary.

Procedure

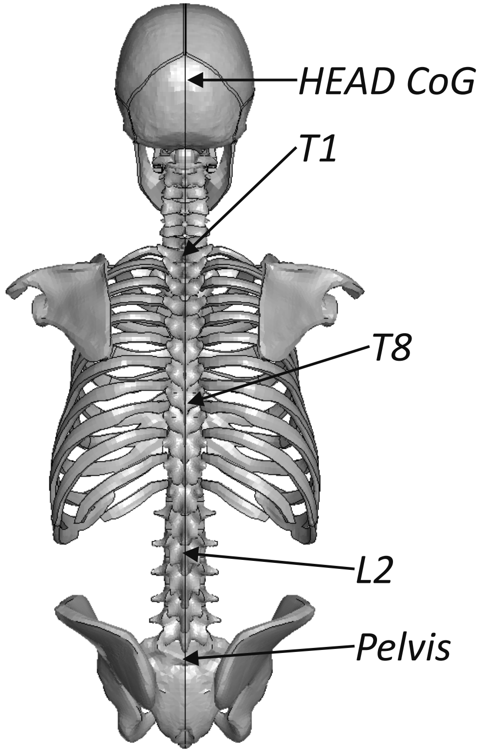
Setting the parameters

Set the include file

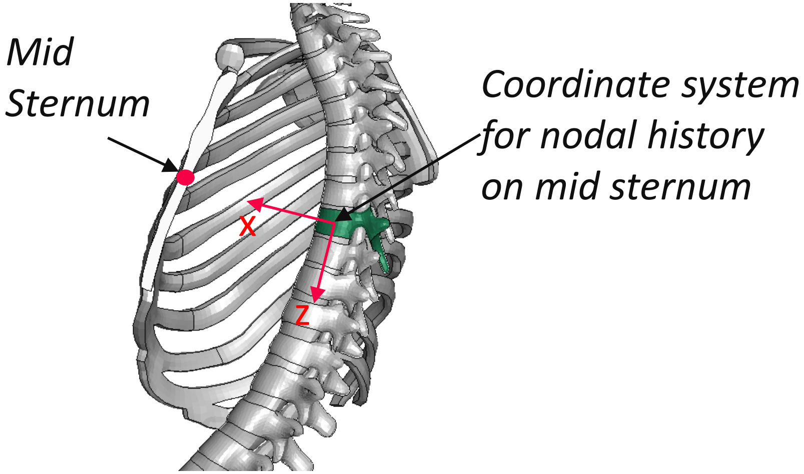
1) Put the main HBM file in the folder directory "_HBM"
2) Open the main HBM file in a pre-processor
3) Open the file 00_Master_Sled.k in a text editor
4) Define the main HBM file in the I N C L U D E S section
5) Follow the instructions from STEP 1 to STEP 8

- 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]
  - Chest deflection between mid sternum and T8
    - *DATABASE_HISTORY_NODE_LOCAL_ID on the mid of the sternum with local coordinate system (REF=2) fixed to T8 with the axis as illustrated
    - Refer to following public document:
      - https://www.osccarproject.eu/wp-content/uploads/2022/12/OSCCAR_D_5.2.pdf
  - Strains in cortical bones of pelvis and ribs



- Note: The required output rate is defined in the file “00_Database_Control.k”
  - 10kHz for contact and nodal outputs since CFC filtering is applied in Jupyter notebook
  - The output rate for strain output is defined via a curve to only generate data in the crash phase
- 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) Define ID for contact and constraints sets
5) Define angles and ID offset
6) Define HBM posture and check for intersections
7) Define attachment nodes for positioning beams
8) Estimate D-ring position
9) Run simulation and check results

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of global HBM parameters

Goal:

- Define which load case is to be simulated
- Define factor to scale environment to the unit system 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) Define ID for contact and constraints sets

Goal:

- Define the position and orientation of the HBM
- Use this point as origin and rotate HBM to bring it in supine position
- Define sensible HBM contact set and part to be constrained

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) Define ID for contact and constraints sets
5) **Define angles and ID offset**

Goal:

- Define sternum angle and ID offset if necessary

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 angles and ID offset
6) Define HBM posture and check for intersections

Goal:

- Measure femur and tibia angle
- Move seat in case of intersections

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) Define ID for contact and constraints sets
5) Define angles and ID offset
6) Define HBM posture and check for intersections
7) **Define attachment nodes for positioning beams**

Goal:

- Define how extremities are moved during settling and fixed during loading

Overview on stepwise simulation setup (see following slides)

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5) Define angles and ID offset
6) Define HBM posture and check for intersections
7) Define attachment nodes for positioning beams
8) Estimate D-ring position

Goal: Define D-ring location to achieve target shoulder belt angle

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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6) Define HBM posture and check for intersections
7) Define attachment nodes for positioning beams
8) Estimate D-ring position
9) Run simulation and check results

Goal: Adapt settling or load time if necessary

STEP 1

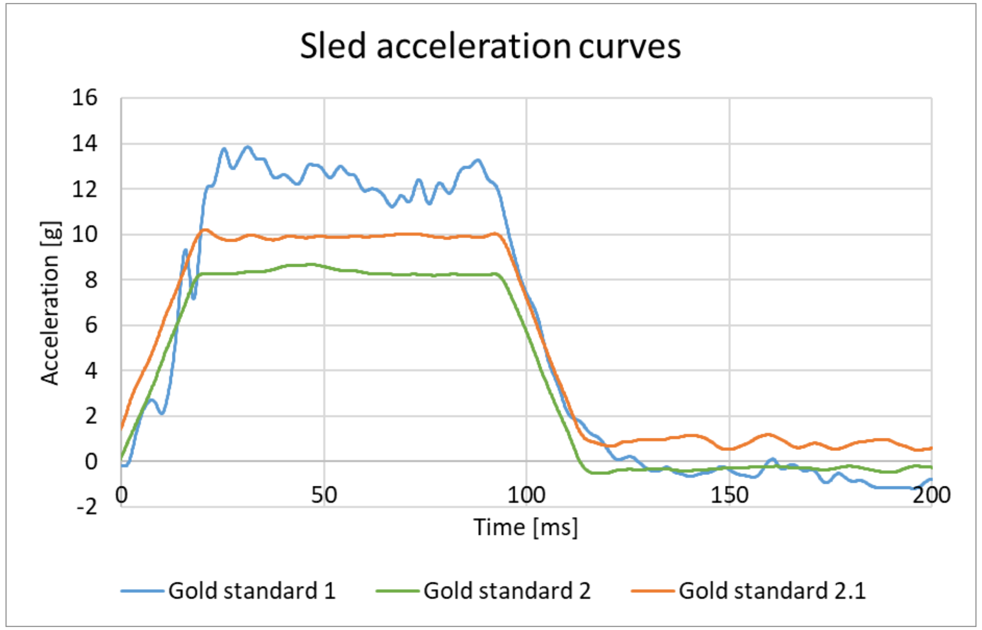
Definition of the load case

Define the load case to be simulated

set only one flag to 1 and the others 0

- *GS1* = Gold Standard 1: 40kph, no load limiter
    - Only PMHS data for AM50 available
- *GS2* = Gold Standard 2: 30kph, 3kN load limiter
    - Only PMHS data for AM50 available
- *GS21* = Gold Standard 2.1: 30kph, 2kN load limiter
    - Only PMHS data for AF05 available

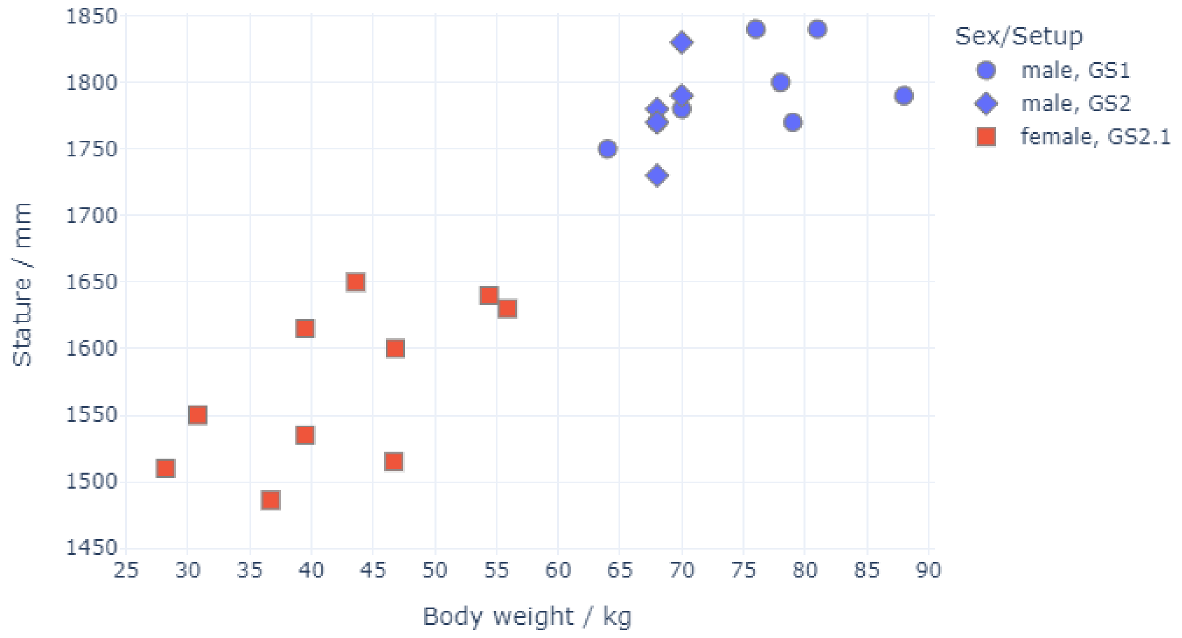
→ Chosen load case defines x-location of trochanter major and target angles for sternum, femur and tibia are defined as in the correspondent PHM-tests (mean values calculated from GS1, GS2 and GS2.1 tests)



	GS1 (AM50)	GS2 (AM50)	GS2.1 (AF05)
Deviation of H-point location in x [mm]	-16.0	-7.4	0.3
Sternum angle [°]	20.7	24.0	14.2
Femur angle [°]	8.1	11.4	12.7
Tibia angle [°]	36.7	33.8	31.3

STEP 1
Definition of the load case

- You can run either setup with your HBM
- However, note that the reference PMHS data is only available for certain combinations of anthropometry and setup type (cf. plot on the right)



Important note:
The PMHS data available for the selected setup type is plotted as a reference in the notebook, even if the HBM used in the simulations does not have similar anthropometry.

S T E P 2

Definition of global HBM parameters

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)

S T E P 3

Definition of the HBM position and orientation

Define the coordinates 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 rotated about this point

Define the coordinates of the trochanter major:

- *x_TM*: x-coordinate of trochanter major in the default HBM position with respect to the global coordinate system
- *z_TM*: z-coordinate of trochanter major in the default HBM position with respect to the global coordinate system

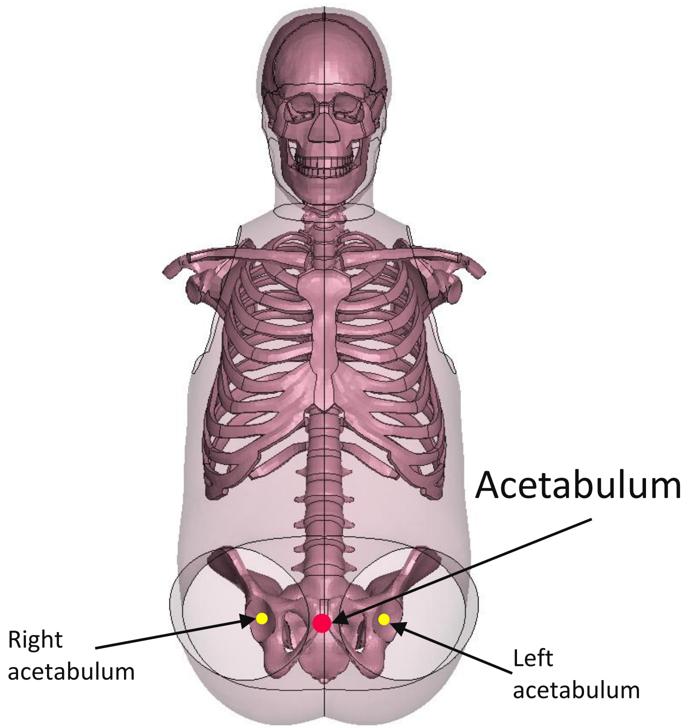
→ The HBM will be transferred to the origin

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

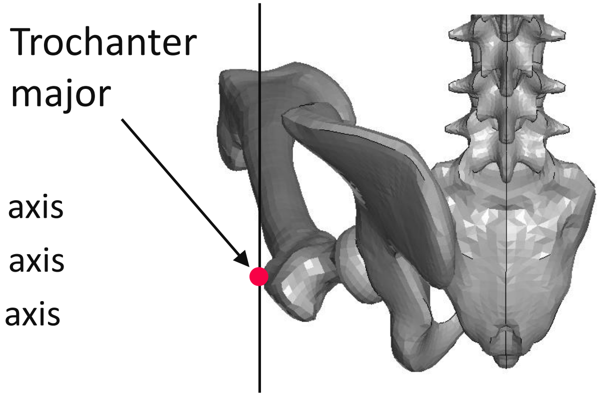
Define the flag to 1 or -1 for all axes:

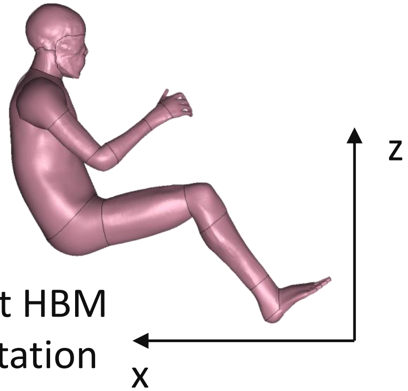
- *x_rt*: “1” for correct axis orientation and “-1” to rotate the model 180deg about the x axis
- *y_rt*: “1” for correct axis orientation and “-1” to rotate the model 180deg about the y axis
- *z_rt*: “1” for correct axis orientation and “-1” to rotate the model 180deg about the z axis

→ HBM will be rotated to reach target orientation



Default HBM position





Target HBM orientation

STEP 4

Define ID for contact and constraints sets

Define the node set including all nodes of the HBM

→ Velocities of the nodes within this set will be set to zero

- *N_hbm*: Set ID of the set including all nodes of the HBM

Define the part set of the HBM

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

→ This part set will be damped

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 the HBM body without arms and lower legs

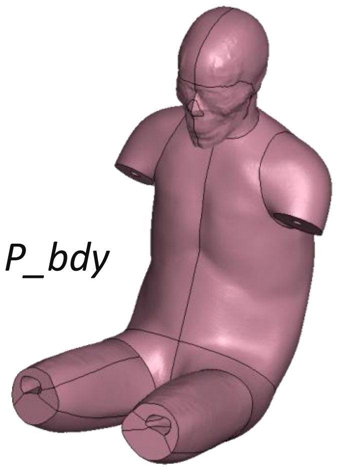
- *P_bdy*: ID of the set including the HBM body without arms and lower legs

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

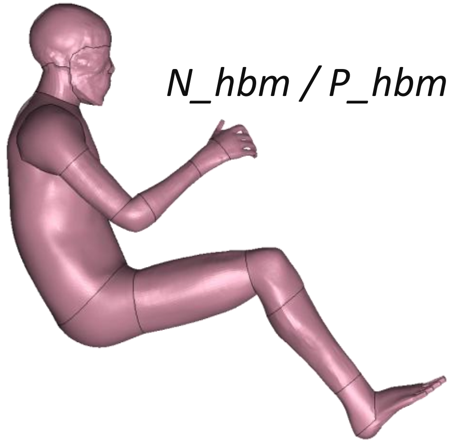
Define the mass of the HBM without legs

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

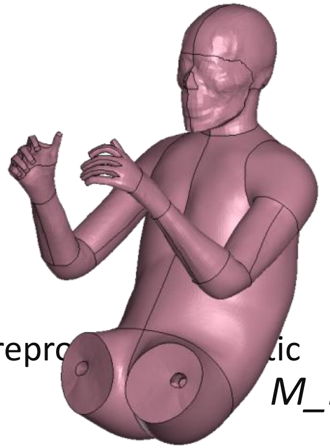
→ The mass of the seat will be matched to the mass of the HBM without legs to repro ic settling behaviour



P_bdy



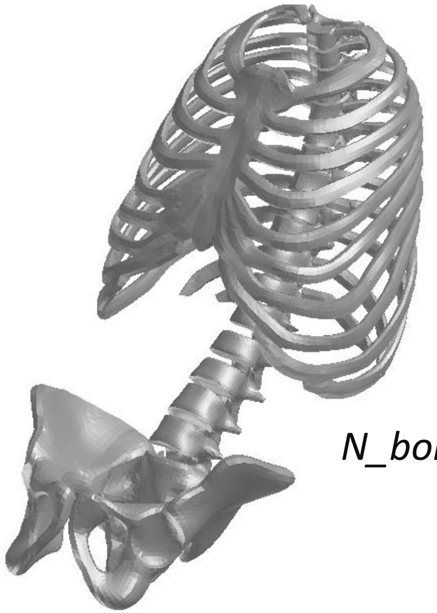
N_hbm / P_hbm / P_ski



M_HBMt

STEP 4

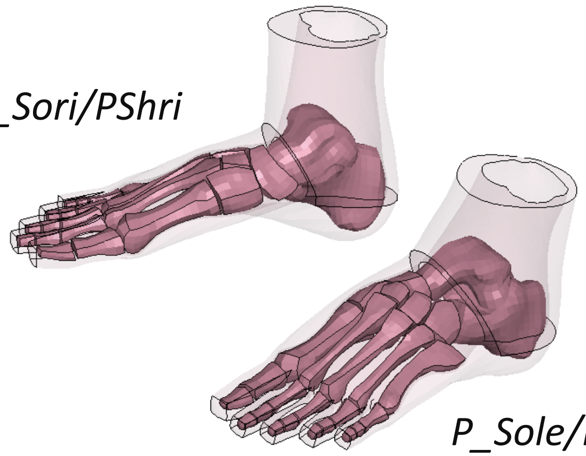
Define ID for contact sets and constraints



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)



Define the part set including all solid parts of the left and right foot (bones, flesh, ligaments and shoes if applicable)

- *P_Sole*: ID of the set including all solid parts of left foot
- *P_Sori*: ID of the set including all solid parts of right foot
- *P_Shle*: ID of the set including all shell parts of left foot
- *P_Shri*: ID of the set including all shell parts of right foot

→ This sets will be constrained to the footrest in the loading phase

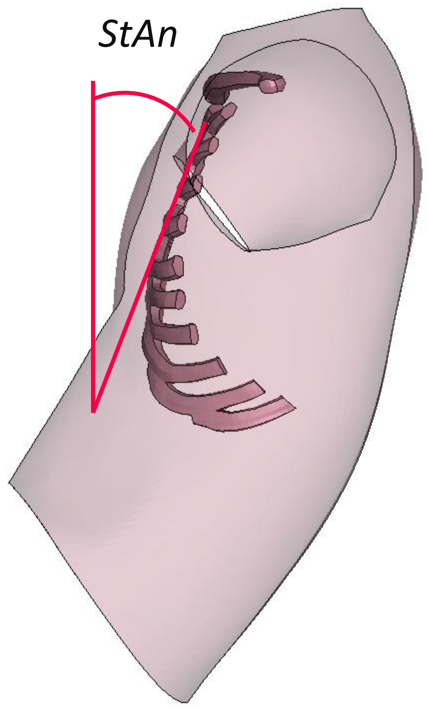
If the simulation terminates with an error due to both constraints active or the model lacks on shell or solid parts in the feet, define an empty set to pass by the corresponding constraint.

STEP 5
Define 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 achieve the target sternum angle depending on the anthropometry



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

- *IDoff*: default: 0.

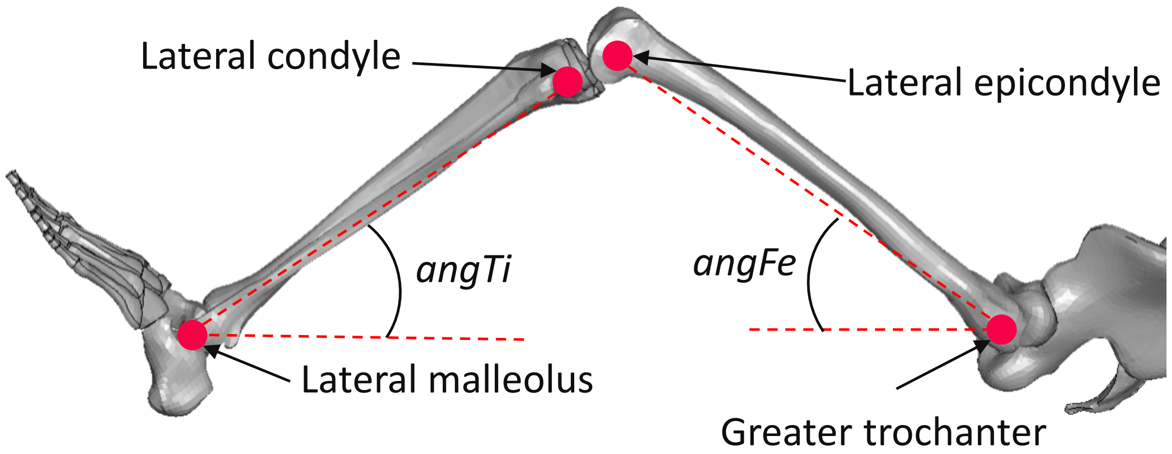
STEP 6
Define HBM posture and check for intersections

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

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

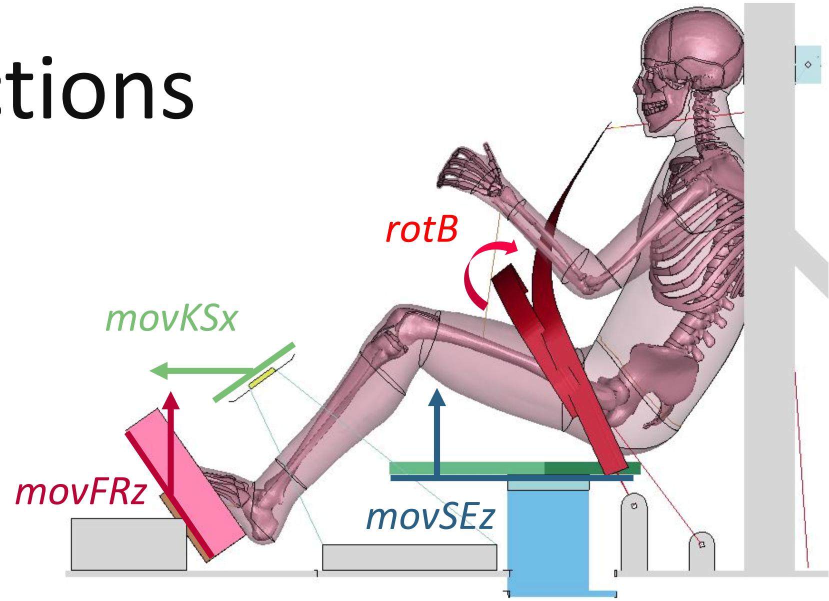
- *angFe*: femur angle defined as a positive value
- *angTi*: tibia angle defined as a positive value

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



STEP 6

Define HBM posture and check for intersections



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

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

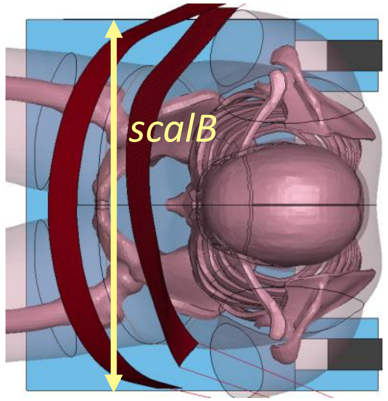
IF the HBM has intersections with the footrest, move footrest in z

Note: "Footrest" refers to the U-shaped shell parts. An intersection of the feet with the solid blocks parts is permitted and intended. The elements of the feet which lie within the solid parts at the end of the settling phase will constrained to the solid blocks via *CONSTRAINED_SOLID/SHELL_IN_SOLID_PENALTY_ID in the loading phase.

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

IF the HBM has intersections with the knee support, move knee support in x

- *movKSx*: moving distance of knee support in x (positive value = away from HBM)



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)

S T E P 7

Define attachment nodes for positioning beams

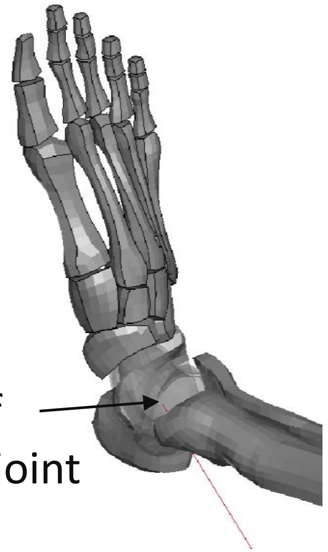
Node IDs for the landmarks to be positioned

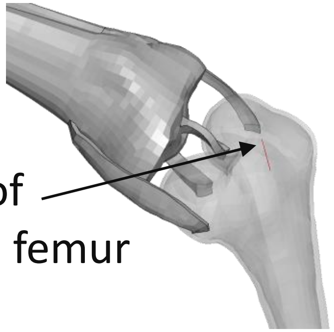
ri = right, le = left

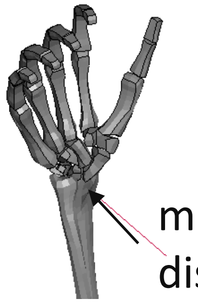
- *N_rari/N_rale*: Node at mid of distal radius
- *N_tari/N_tale*: Node on femur at target position of hands
- *N_feri/N_fele*: Node at mid of distal femur
- *N_anri/N_anle*: Node at mid of ankle joint

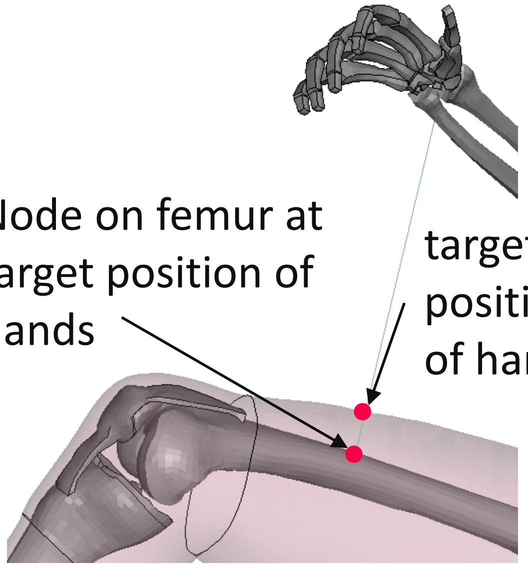
Coordinates of landmark nodes in updated “00_Master_Sled.k” file

- 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







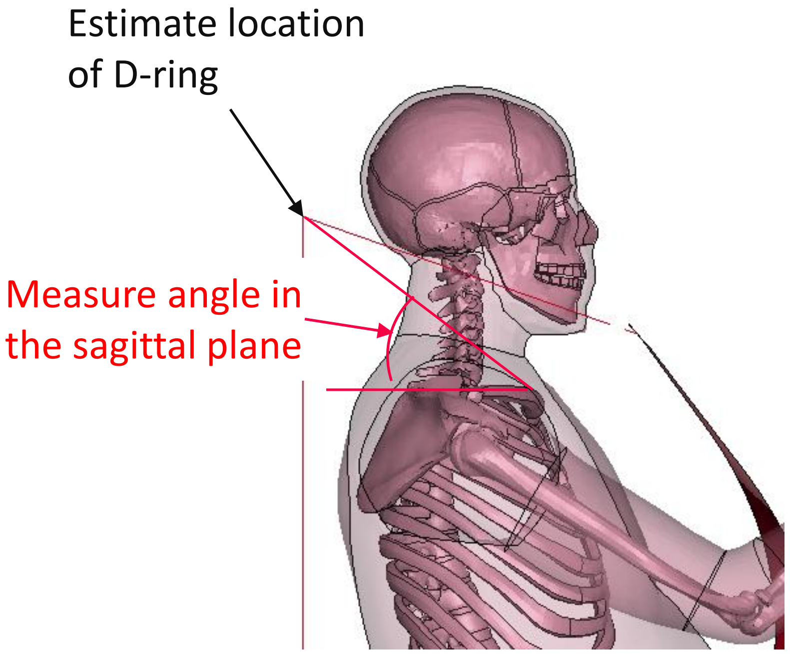


STEP 8
Estimate the D-ring position

<u>**Information on the procedure:**</u>

The position of the D-ring must be determined in order to achieve a specific shoulder belt angle. As it is not possible to measure this angle before the belt is fitted, it must be estimated (step 8). This is done by measuring the angle between the D-ring and the location on the clavicle, where the belt is assumed to detach from the HBM.

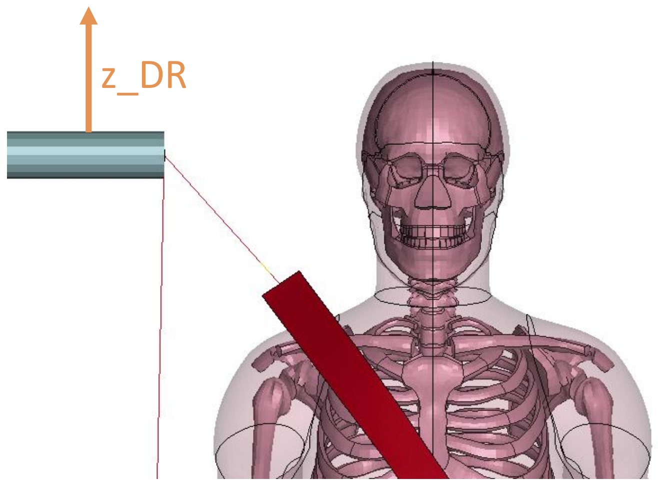
Once the simulation has been run (step 9), the actual shoulder belt angle is measured between the D-ring and the end of the 2D belt.



Measure the belt angle between the clavicle* and the D-ring in the sagittal plane. If the belt angle is within the given range depending on the load case, do not change z_DR.

Load case depending target angles:

- GS1: belt angle between 24 deg and 29 deg
- GS2: belt angle between 25 deg and 28 deg
- GS2.1: belt angle between 23 deg and 30 deg



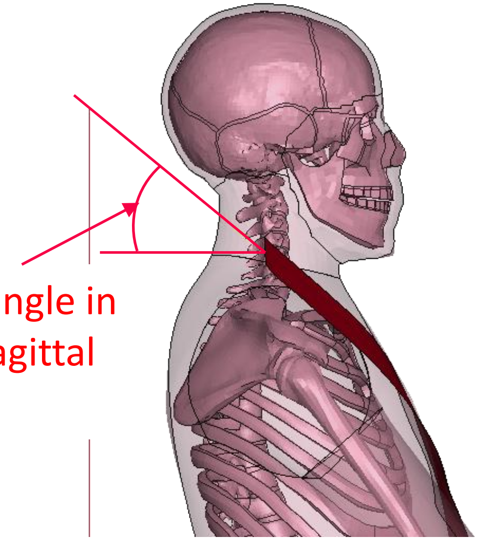
If the belt angle is not within range, estimate the necessary D-ring location in z direction to achieve the target angle (in the settled model) and adopt z_DR accordingly:

- *z_DR*: z translation of D-ring (positive z value: D-ring moves upwards)

*Note that, depending on the anthropometry of the used HBM, the point on the torso where you would expect the belt to detach from the HBM might differ. Choose a suitable node for your HBM (not necessarily on the clavicle).

STEP 9

Run simulation and check results



Measure the belt angle between the upper end of the shoulder belt and the D-ring in the sagittal plane (Calculation procedure is integrated in the assessment notebook). If the belt angle is NOT within the given range (depending on the load case), change z_DR accordingly in step 8.

Load case depending target angles:

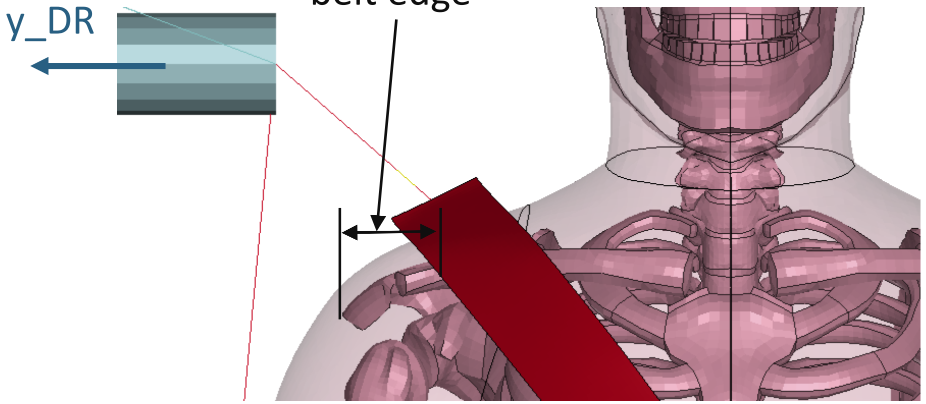
- GS1: belt angle between 24 deg and 29 deg
- GS2: belt angle between 25 deg and 28 deg
- GS2.1: belt angle between 23 deg and 30 deg

Measure the distance in y from the acromion lateral border to the outer belt edge where the belt crosses the clavicle .

If the distance is NOT within the given range (depending on the load case), change y_DR accordingly:

Load case depending target distances:

- GS1: distance between 45mm and 63mm
- GS2: distance between 10mm and 55mm
- GS2.1: distance between 28mm and 73mm
    - *y_DR*: y translation of D-ring (positive y value: D-ring moves away from HBM)



STEP 9

Run simulation and check results

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

The knee support should be adjusted to be in contact with the proximal tibia when the HBM is settled.

IF the position of the knee support in the settled model is not satisfying, change the z position

- *z_KS*: distance in z (positive value: knee support moves upwards)

IF the position of the footrest is not satisfying, change x position

- *x_FR*: distance in x (positive value: footrest moves towards HBM)

IF settling phase is not long enough, change duration

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

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

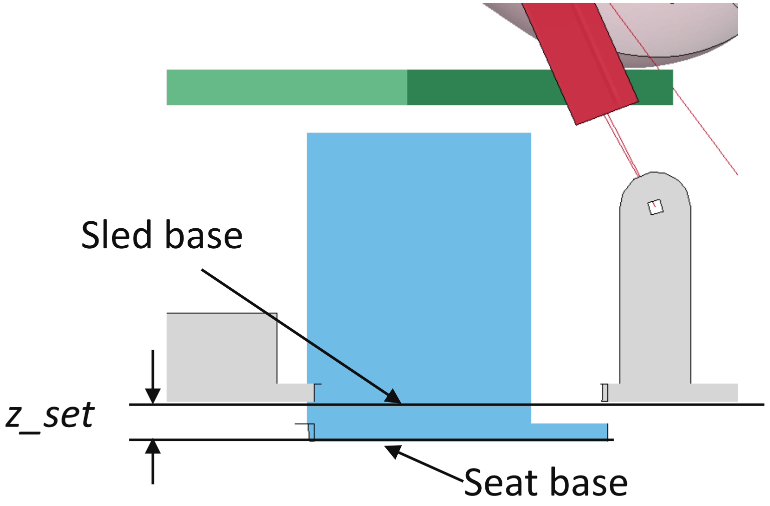
- *FbeamA*: tension force in arm positioning beams. default: 0.1 kN
- *FbeamL*: tension force in leg positioning beams. default: 0.2 kN

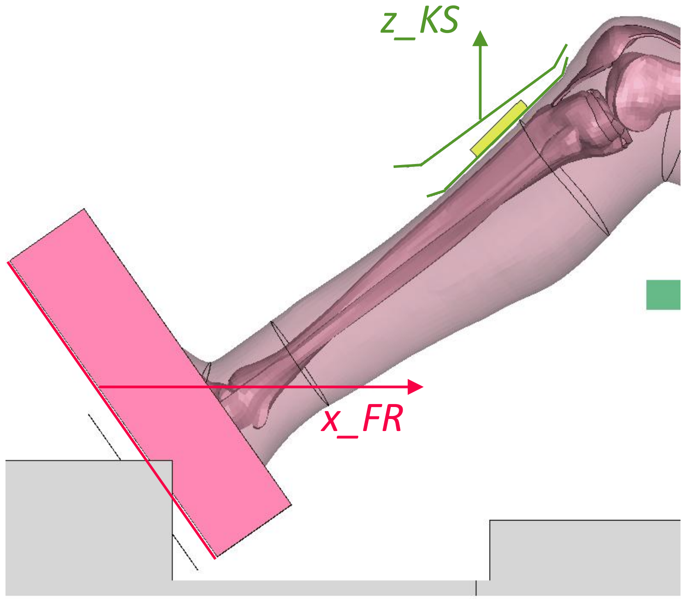
Duration of testbed movement in ms. Change only IF load curve duration changes

- *tload*: duration of loading curve (default 250ms)

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

- *Depth*: default: 23





Final checks

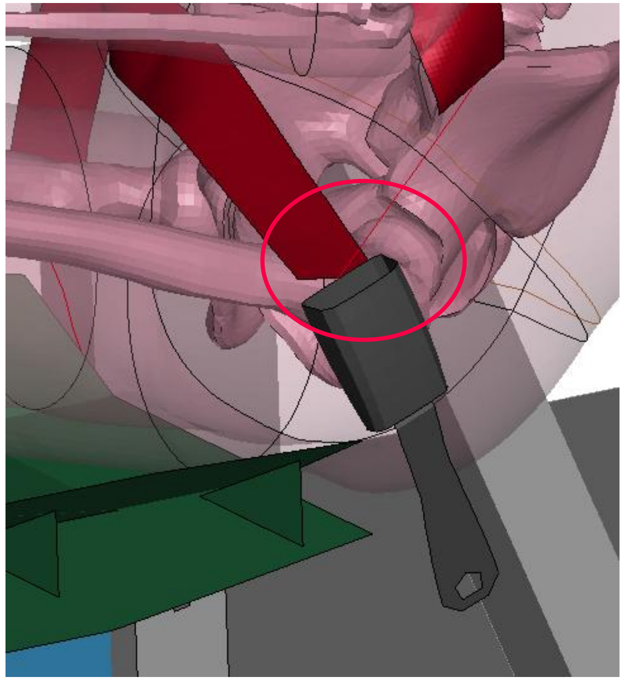
Check following values in the settled model (@ tSetHBM)

	Shoulder belt angle [°]	Distance in y from the outer belt edge to the acromion lateral border [mm]	Distance between seat base and sled base [mm]
Gold standard 1	24 - 29	45 - 63	± 5
Gold standard 2	25 - 28	10 - 55	± 5
Gold standard 2.1	23 - 30	28 - 73	± 5

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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