SCIENCE
PASSION
TECHNOLOGY

HBM4VT – WG 2

KTH simulation setup

Rupp et al. 2008

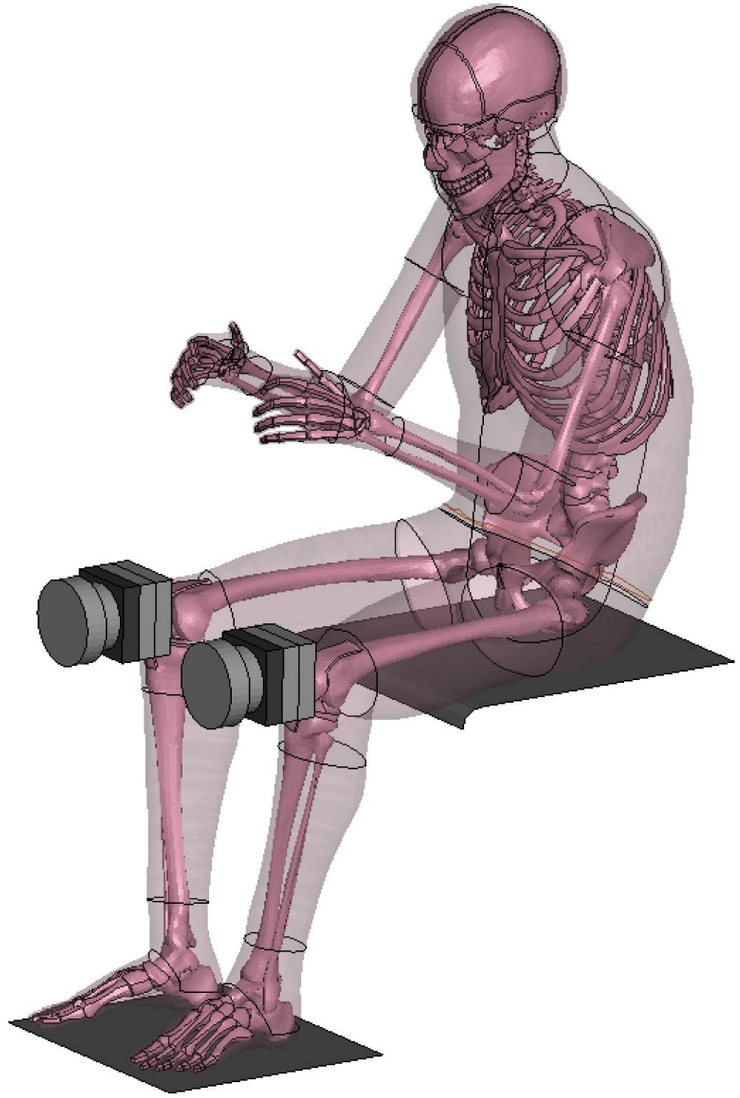
General Overview

Model Setup

KTH tests by Rupp et al., 2008

Key factors to replicate from PMHS tests:

- HBM seated on rigid seat
  - Feet on footrest
- Impactor movement in x direction
- Impactor covered with foam layers as in test
- Contact force between Impactor and knees compared to experimental data



Development notes

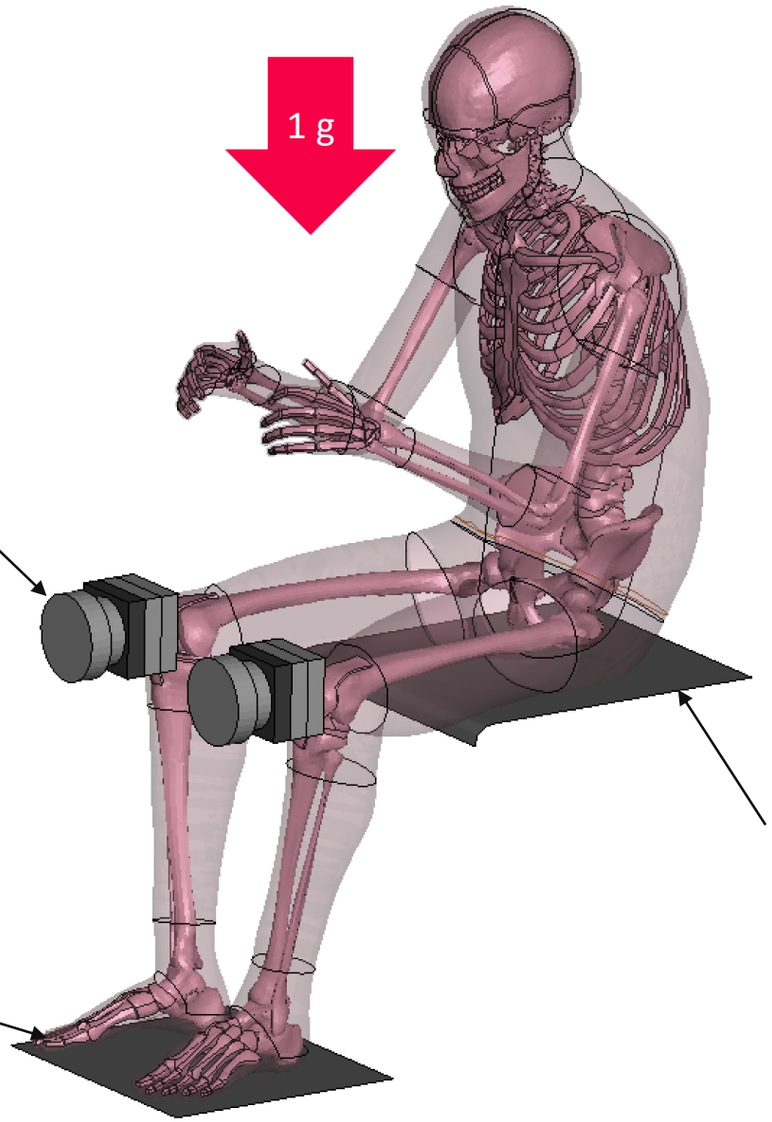
LS-Dyna version used for development:

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

HBMs used in testing:

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

Simulation setup



Impactor
- Initial velocity applied after settling
- Low density foam padding
- Foam adapted to initial velocity (1.2 or 3.5/4.9 m/s)

Footrest
- Moves during settling phase with load of 100 N upwards

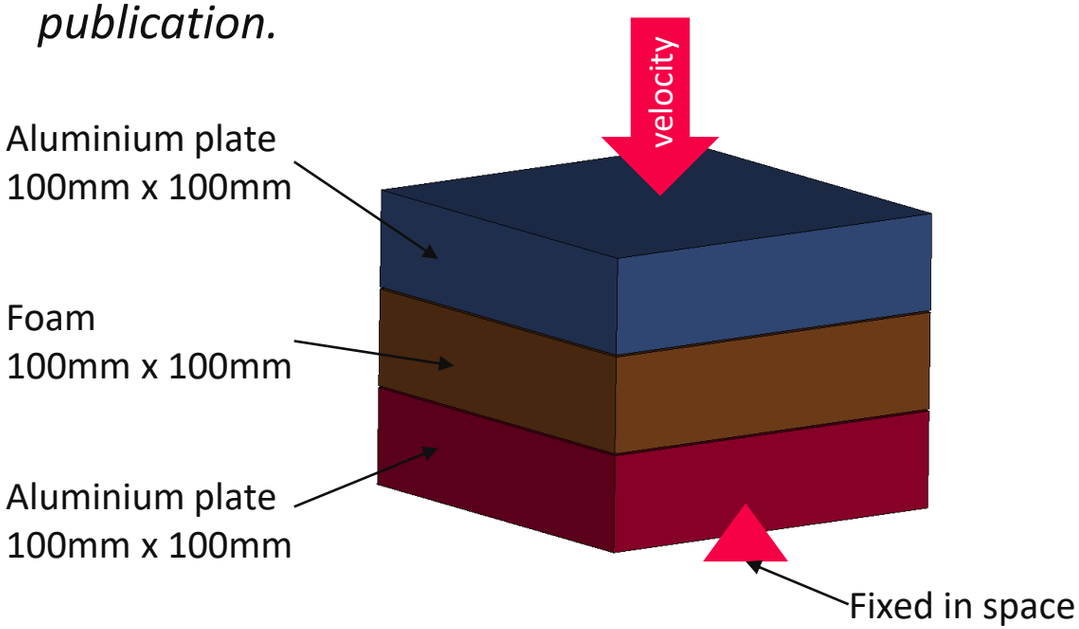
Seat
- Moves to “settle” on HBM

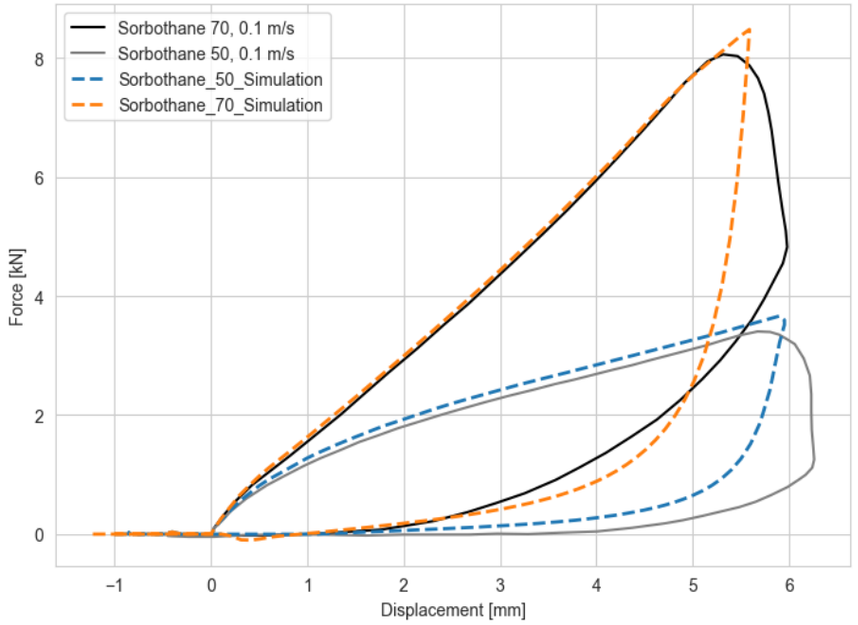
Simulation setup

The foam material was defined based on data from the Sorbothan compression test

Validation of material via simulation:

- Target force deflection curves from paper: *Rupp, J. D., Miller, C. S., Reed, M. P., Madura, N. H., Klinich, K. D., & Schneider, L. W. (2008). Characterization of Knee-Thigh-Hip Response in Frontal Impacts Using Biomechanical Testing and Computational Simulations. Stapp Car Crash Journal, Vol. 52. Advance online publication.*





Simulation phases

Initial model

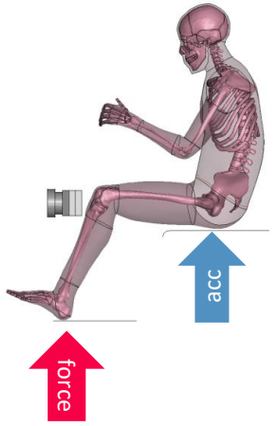
HBM positioned in target position

- Rotated to achieve 90° sternum angle

Settling phase

HBM settling

- HBM pelvis and spine constraint
- No gravity



Seat

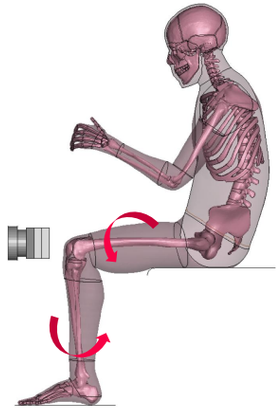
- Seat is accelerated upwards with 1 g

Footrest

- Footrest is moved upwards with constant force

Leg positioning

- HBM pelvis and spine constraint
- No gravity



Upper legs

- Rotated to horizontal

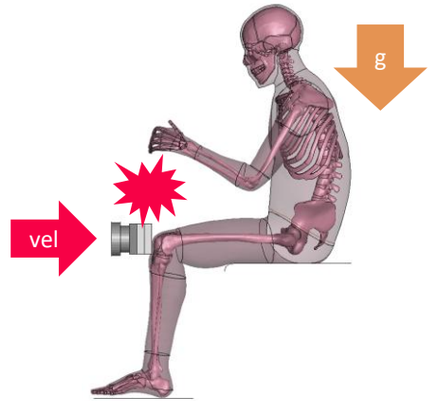
Lower legs

- Rotated to vertical

Loading phase

Load application

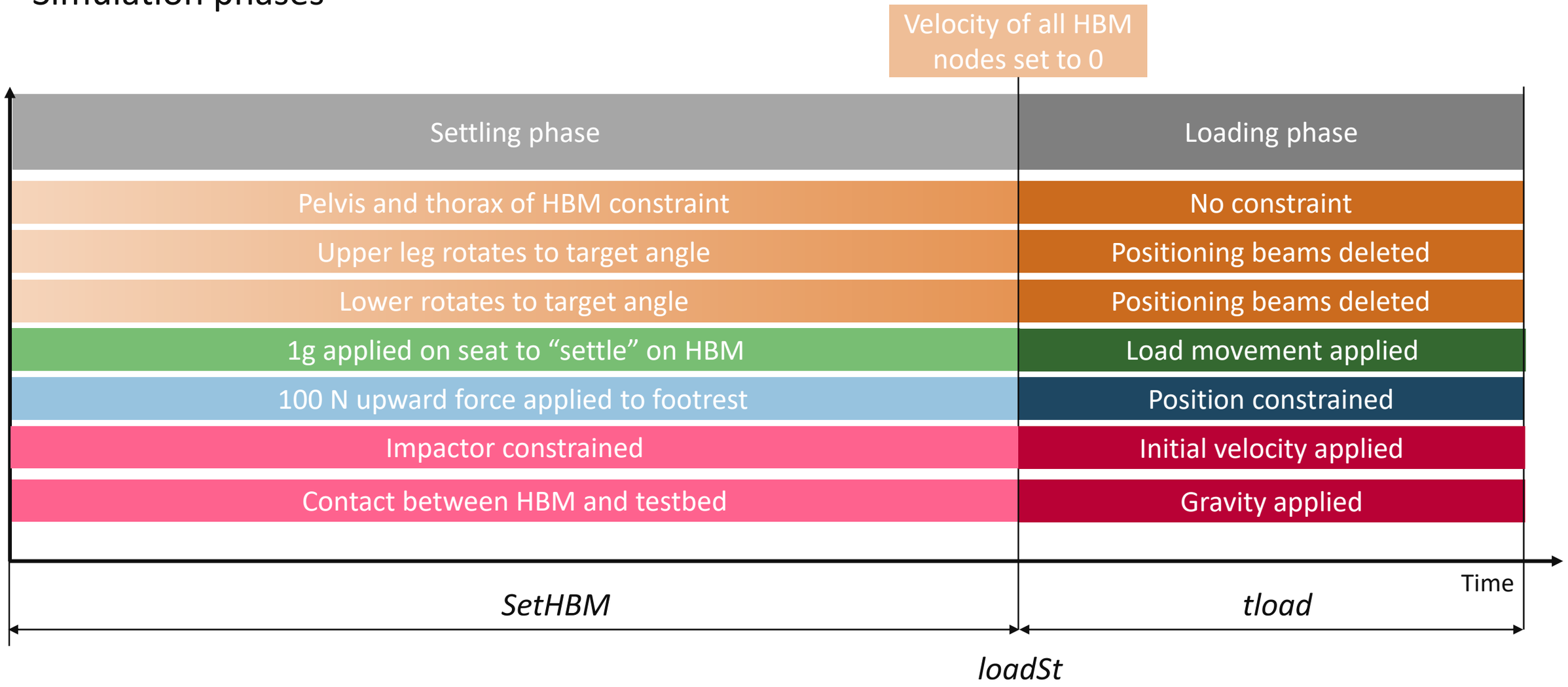
- HBM constraints released
- Gravity applied
- Impactor velocity applied



Load

- Initial velocity impactors
- Gravity applied

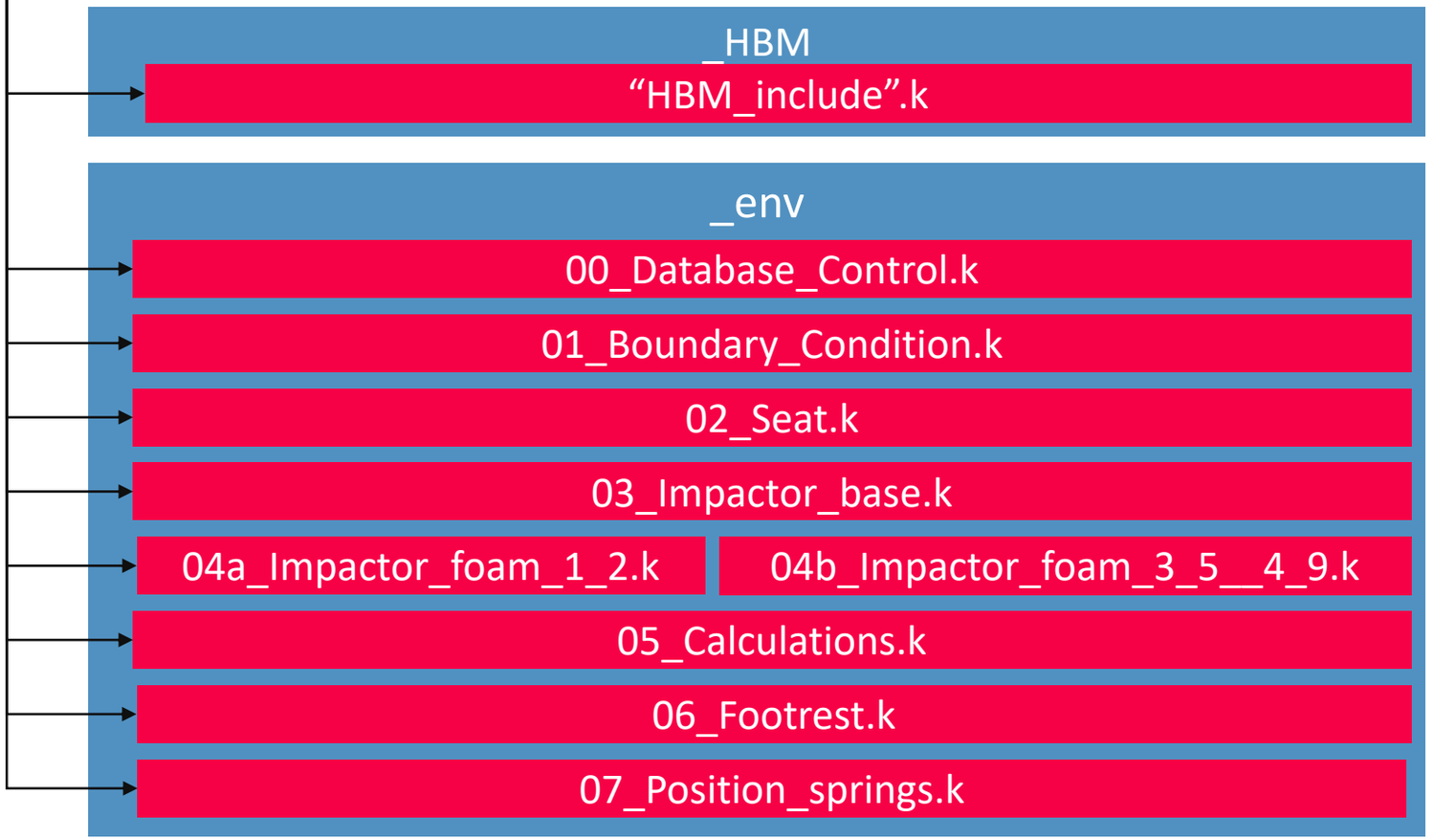
Simulation phases



Overview – KTH load case

00_Master_KTH.k

→ Single file to be changed
Follow the descripted procedure



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

→ Select include file for foam depending on initial impactor velocity (1.2, 3.5, 4.9 m/s)

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_KTH.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

Instrumentation requirements

Equip your HBM with the required output

- Strains in cortical bones of pelvis and femur

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
- 1kHz for strain output

Update all NODE and OBJECT IDs in the HBM ID-file in “…\data\metadata” accordingly (see THUMS file for example)

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) Measure angles and distances
6) Define attachment nodes for positioning beams
7) Check for intersections
8) Measure initial lower leg angles
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) Measure angles and distances

Goal:

- Define sensible HBM contact set
- Measure sternum angle and distances

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) Measure angles and distances
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) Measure angles and distances
6) Define attachment nodes for positioning beams

7) 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
4) Set ID for contact sets and constraints
5) Measure angles and distances
6) Define attachment nodes for positioning beams
7) Check for intersections

8) Measure initial lower leg angles

Goal:

- Measure the femur and tibia 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
4) Set ID for contact sets and constraints
5) Measure angles and distances
6) Define attachment nodes for positioning beams
7) Check for intersections
8) Measure initial lower leg angles
9) **Run simulation and check results**

Goal: Adapt settling or load time if necessary

S T E P 1
Definition of the load case

Define the load case to be simulated

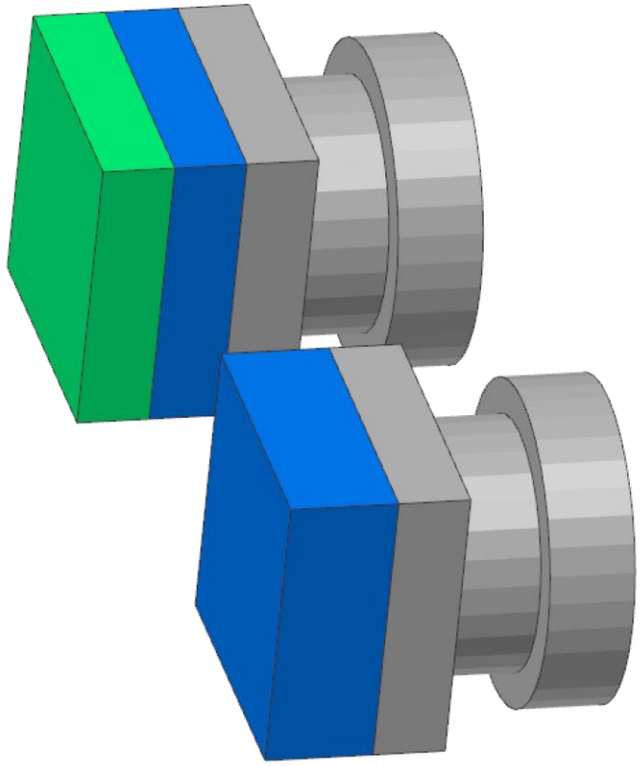
Set one flag to 1:

- LS = 1: Low speed 1.2 m/s
- MS =1: Medium speed 3.5 m/s
- HS = 1: High speed 4.9 m/s

Select foam include in master file according to defined load case

- LS = 1: include “04a_Impactor_foam_1_2.k” twice in the I N C L U D E S section of the file “00_Master_KTH.k”
- MS/HS = 1: include “04b_Impactor_foam_3_5__4_9.k” twice in the I N C L U D E S section of the file “00_Master_KTH.k”

04b_impactor_foam_3_5__4_9.k



04a_impactor_foam_1_2.k

S T E P 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

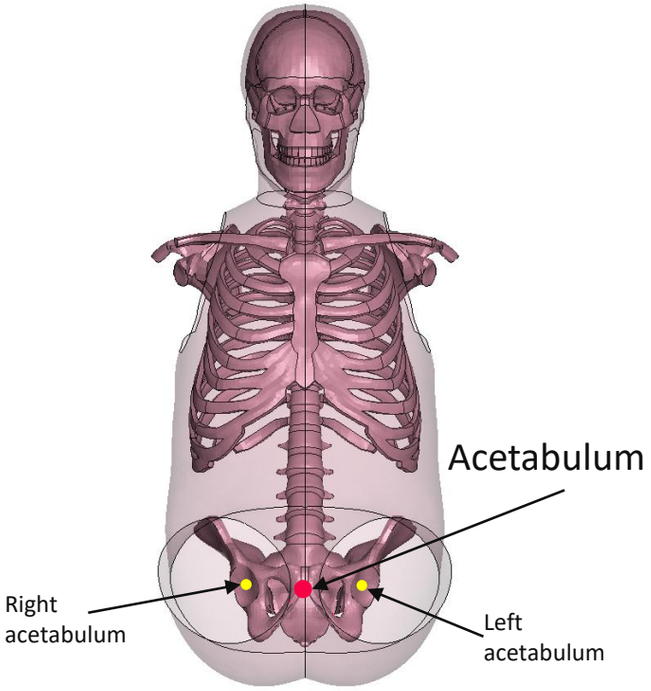
→ Footrest is positioned +10mm in z direction if HBM doesn‘t wear shoes (represents thickness of sole)

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



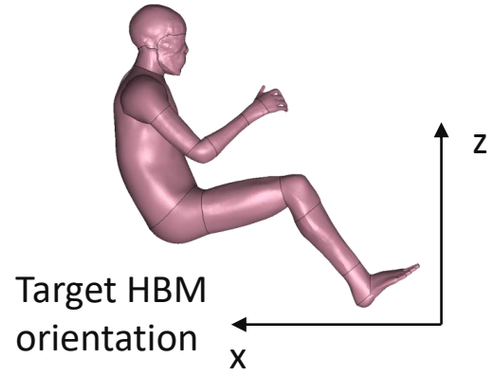
Default HBM position

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 achieve the desired target orientation



Target HBM orientation

S T E P 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 seat, footrest and impactor

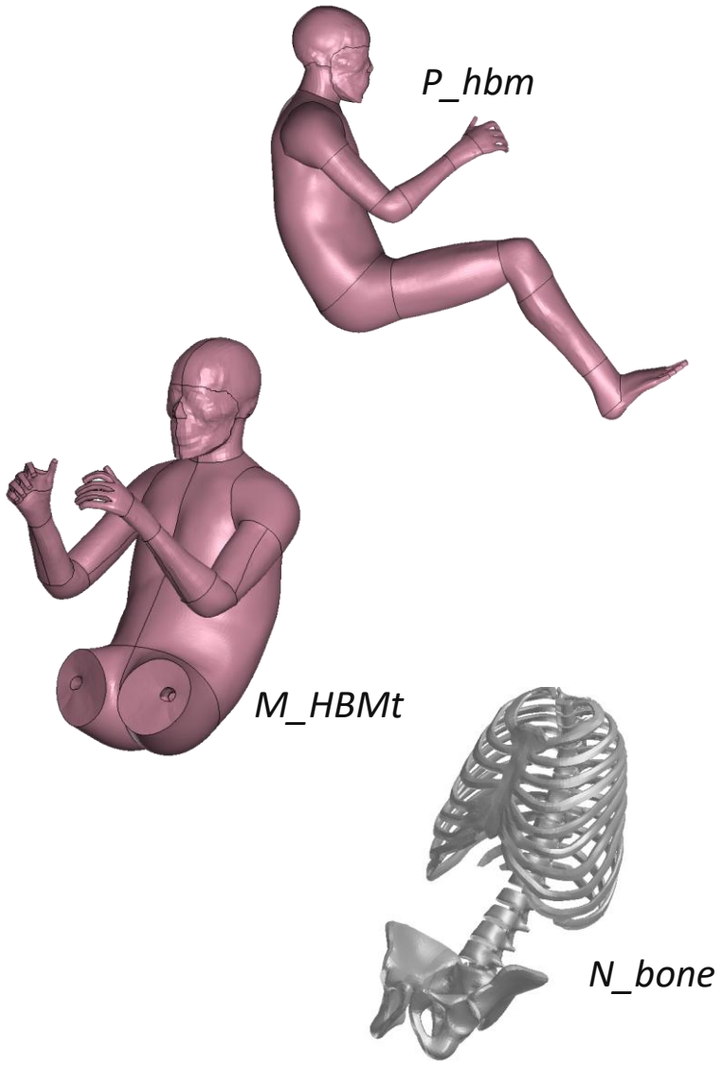
Define the mass of the HBM without legs
- *M_HBMt*: Mass of the HBM without legs in [kg]

→ 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)

IF the testbed shares node IDs with the HBM, set an ID offset for the HBM
- IDoff: default: 0.



STEP 5

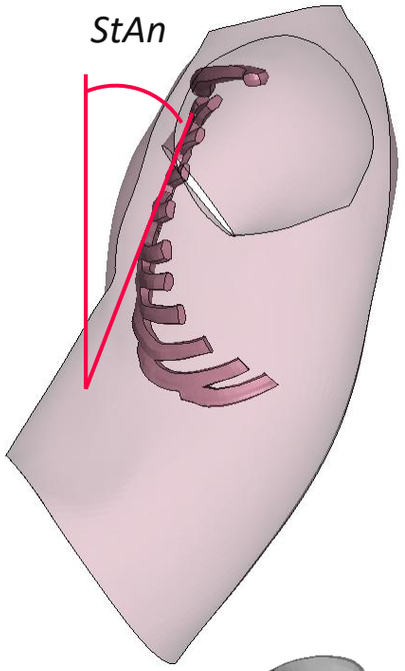
Define sternum angle and ID offset

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 achieve a sternum angle of 90° to the horizontal plane

→ A sensitivity study showed a negligible influence of the pelvic angle on the HBM response. Therefore the position of the HBM is based on the sternum angle.

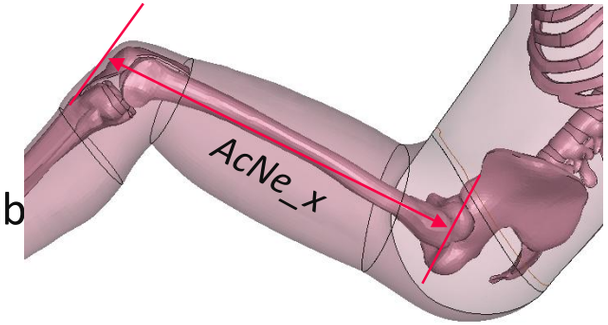


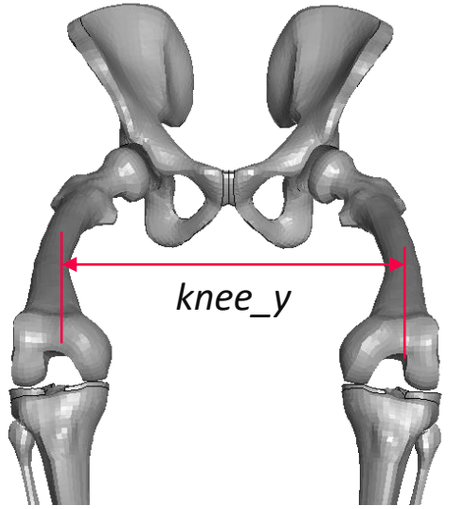
Measure the distance between the midpoints of the knees

- *knee_y* : y-distance between knee midpoints

Measure the distance in x-direction between the center of acetab and the foremost point of knee

- *AcNe_x*: x-distance AC and foremost point of knee





STEP 6
Define attachment nodes for positioning beams

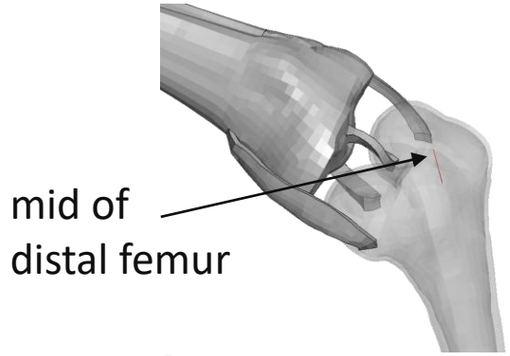
Save the file “00_Master_Sled.k” and open it in a pre-processor

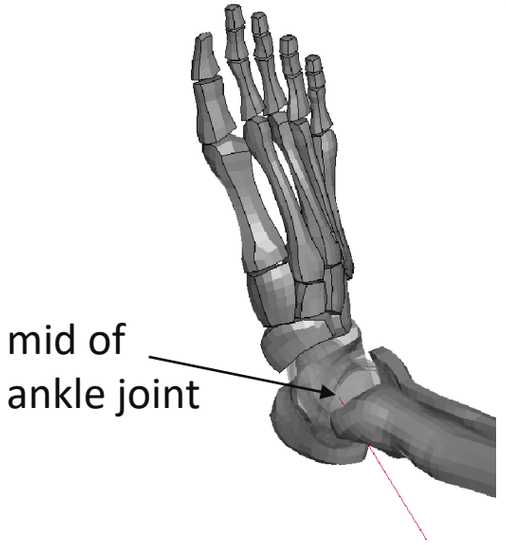
Node IDs for the landmarks to be positioned (ri = right, le = left)

- *N_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

IF the impactor has intersections to the legs, move the impactor in x

- *Imp_x*: moving distance of impactor in x (positive value = impactor moves away from HBM)

Note: Keep a clearance between hub and HBM of at least 25mm in the settled model to facilitate filtering of the force signal in the assessment notebook

IF the height of the impactor relative to the legs is not satisfying, move the impactor in z

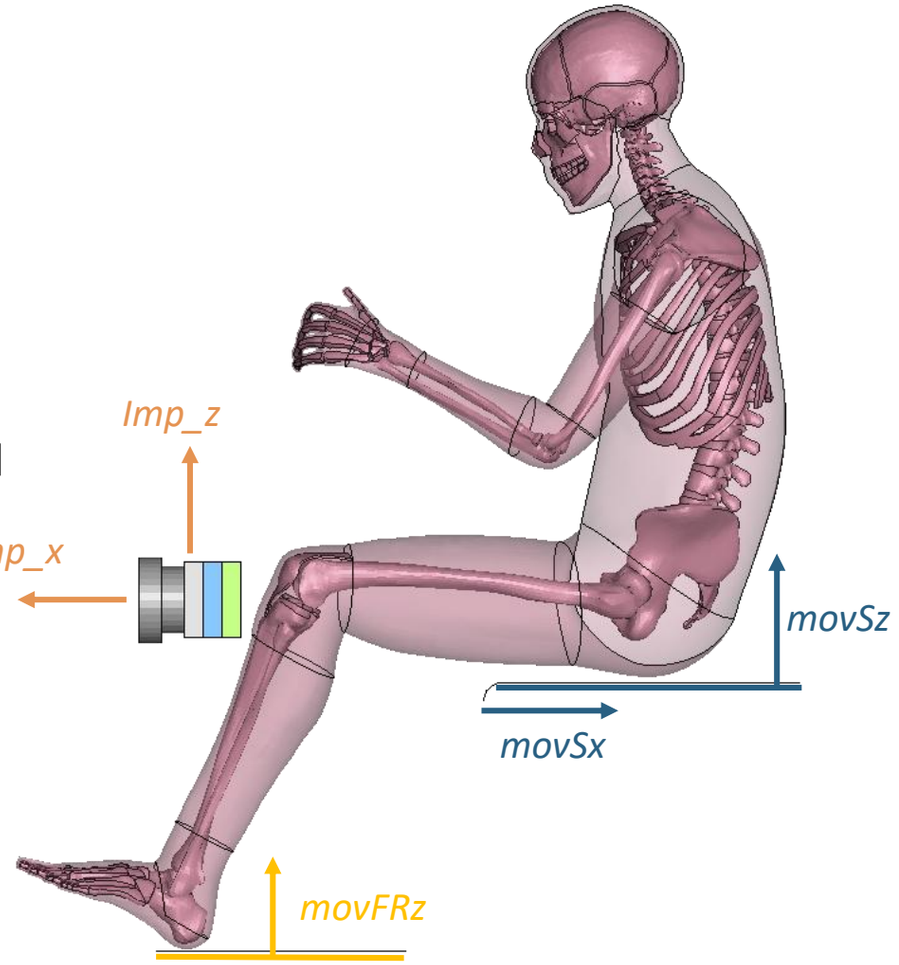
- *Imp_z*: moving distance of impactor in z (positive value = impactor moves upwards)

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 HBM has intersections to the seat, move seat in z and CHECK distance of seat edge to lower legs

- *movSz*: moving distance of seat in z (positive value = upwards)
- *movSx*: moving distance of seat in x (positive value = backwards, target approx. 200 mm to backside of lower legs)

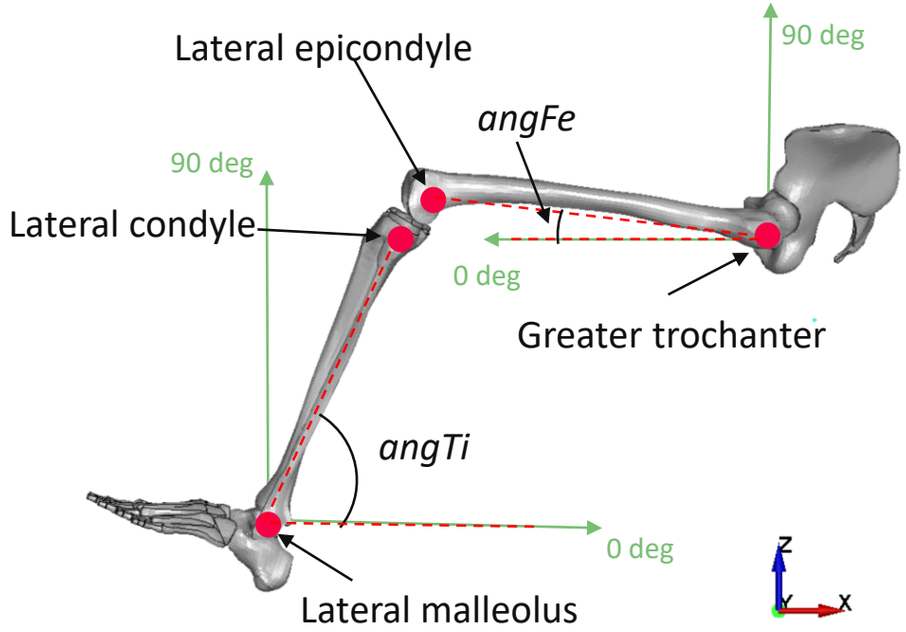


STEP 8
Define HBM position

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

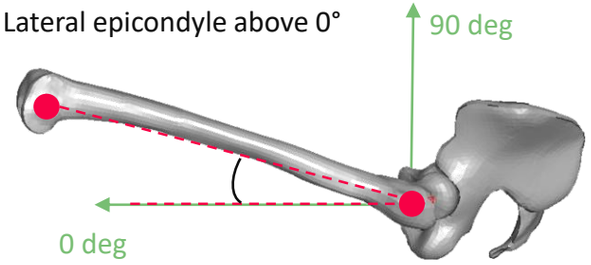
- *angFe*: femur angle defined as a positive value*
- *angTi*: tibia angle defined as a positive value

→ The target position of the knee and the ankle will we defined to achieve a femur angle of 0° and a tibia angle of 90° to the horizontal axis in the x-z plane



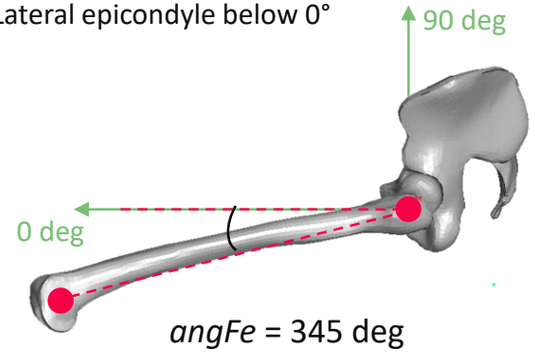
Example scenarios for different femur angles

Lateral epicondyle above 0°



angFe = 15 deg

Lateral epicondyle below 0°



angFe = 345 deg

*If the lateral epicondyle lies below 0°, enter *angFe* with respect to 360°

STEP 9
Run simulation and check results

Check the d3plot and adapt the parameter if needed:

IF settling phase is not long enough, change duration

- *SetHBM*: duration of settling phase (default: 300 ms)

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

- *Fbeam*: default: 0.2 kN

Maximum duration of testbed movement in ms.
Simulation is also terminated upon contact between lower legs and seat.

- *tload*: duration of loading curve (default: 200 ms)

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

- *Depth*: default: 25

Final checks

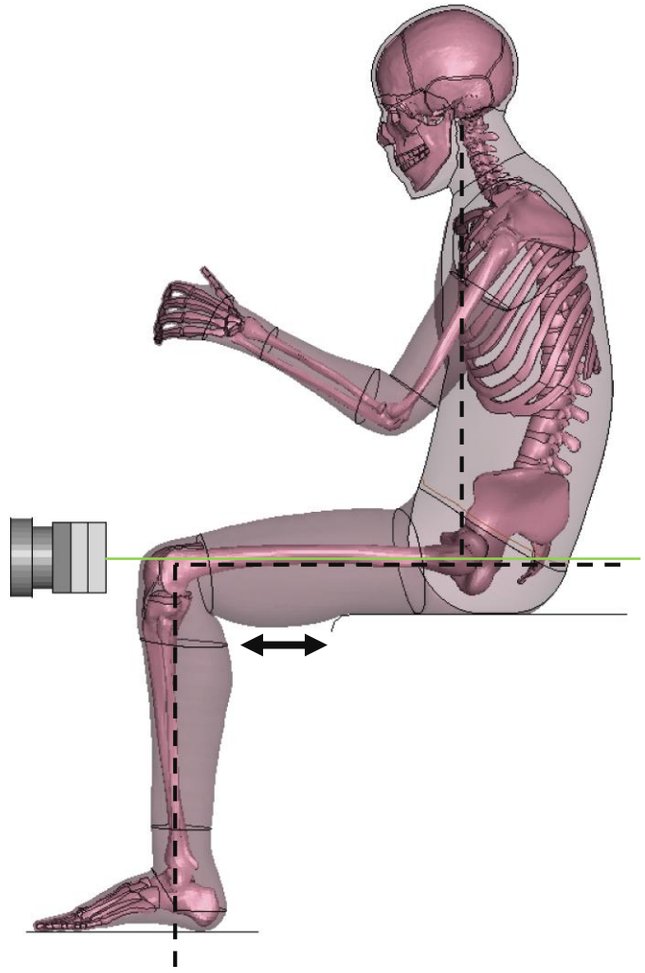
Posture after positioning/settling

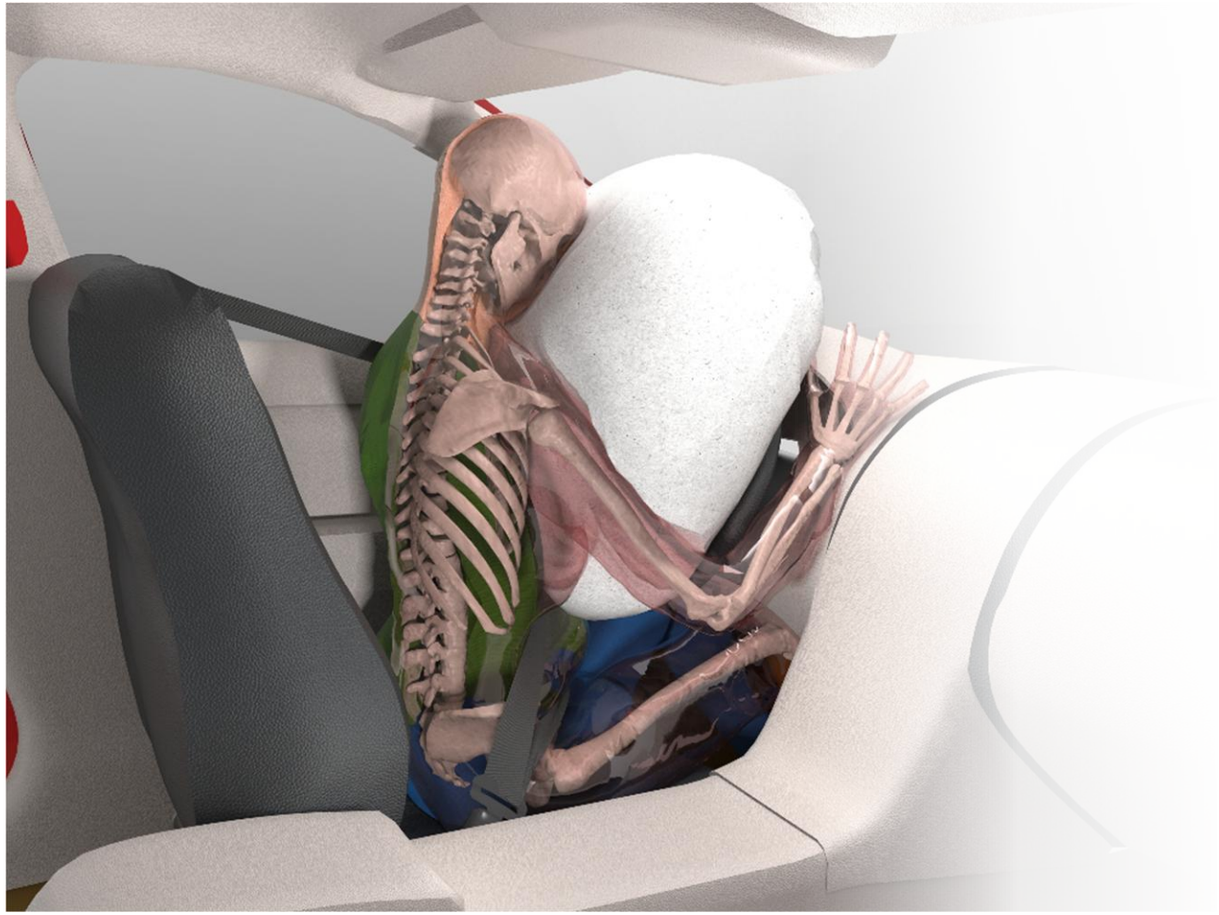
- Sternum approx. vertical
- Femur/tibia axis approx. horizontal/vertical
- Distance between seat edge and lower leg approx. 200 mm

Impactor position after positioning/settling

- Impactor beam axis should pass through the knee joint centre or the condyles

Plausibility of impactor movement and response during loading





Vehicle Safety Institute

Graz University of Technology

Inffeldgasse 23/1
8010 Graz Austria
www.vsi.tugraz.at

Desiree Kofler
desiree.kofler@tugraz.at
+43 316 873 30350

Felix Ressi
felix.ressi@tugraz.at
+43 316 873 30363

Corina Klug
corina.klug@tugraz.at
+43 316 873 30329