SAFER HBM in 9kph sled simulations

selection of torso skin and flesh material properties

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1. Introduction

In the AHBM-projects an active muscle controller has been developed and introduced in the SAFER HBM. When comparing the kinematic predictions of the model (enhanced SAFER v9) to volunteer kinematics in braking and lane change it was found that the model gave a stiffer response than the volunteers [1]. To soften the model, the material of the skin of the torso and buttock, and the solid layer in the torso, here referred to as flesh, was updated. To evaluate which combination of flesh material and skin material is best suited for low-loading simulations, all possible skin/flesh combination were simulated in the SENIORS environment [2] and compared to two 9 kph PMHS tests, performed in the SENIORS project [3].

2. Material update

The SAFER HBM, based on THUMS, was originally created for use in crash simulations [4] which has led to overly stiff behaviour if used in low-acceleration events such as braking and steering events [1]. Therefore, some material properties of the skin and flesh in SAFER HBM was updated to handle both evasive manoeuvres and crash phase. The material in the torso and buttock outer skin was updated to a non-linear orthotropic material model, using the model proposed by [5,6]. In the model, the neck skin used a quasi-isotropic version of the same material model, with the properties from "along" direction in both directions. The skin material properties of the SAFER HBM v9 together with the updated material properties are show in Figure 1. The figure shows that the SAFER HBM v9 skin properties are stiffer than the updated properties for the low-strain range, and the updated material is stiffer in the "along" direction compared to the "across" direction.

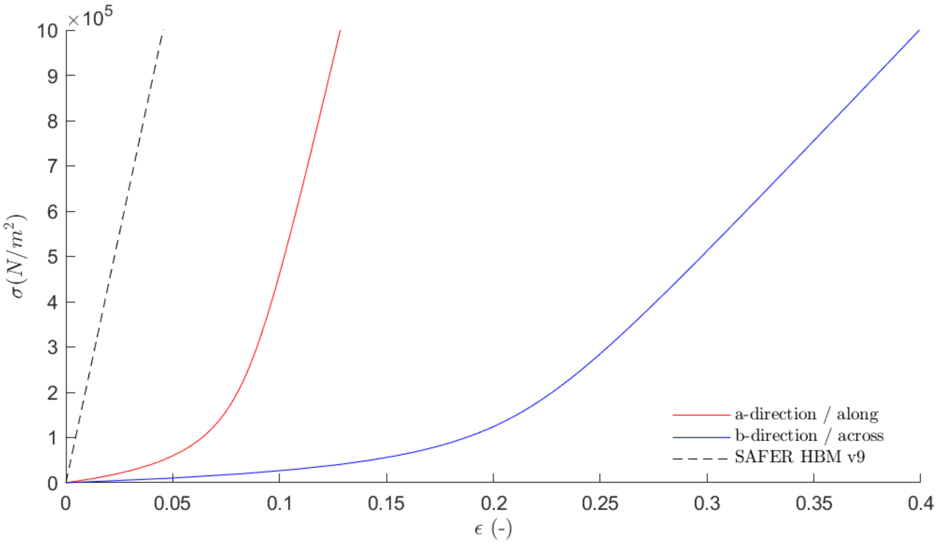

Figure 1. Stress-strain relation of original skin material (dashed black), and the "along" (red) and "across" (blue) directions of the updated material model.

The model describes the material stress-strain relation of human skin in approximate minimum and maximum stiffness directions. In SAFER HBM the model was implemented using *MAT_FABRIC. The skin minimum and maximum stiffness, from "along" and "across" properties in Figure 1, was approximated using the Langer lines [7], and the directions were mapped onto the shell elements of the surface skin of torso and buttock, Figure 2.

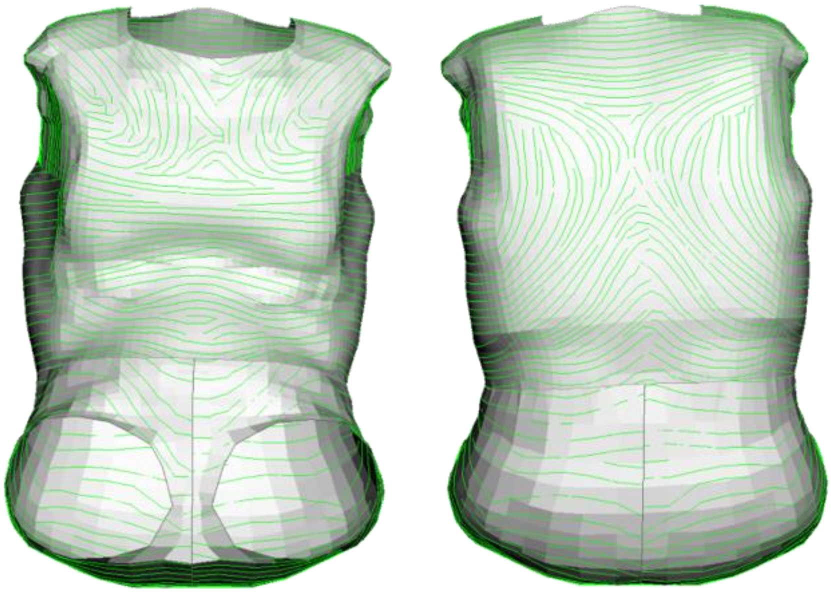

Figure 2. Langer lines on the SAFER HBM torso and buttock.

The flesh of the torso (solid elements) was modelled using two versions of an Ogden rubber material, tuned towards H. Naseri's adipose tissue material model for a specific strain rate [8]. One stiff version (ν= 0.49998), and one average version (ν= 0.49978). The flesh of the buttock was left in the original configuration since the updated material model is tuned for adipose tissue, and there are large muscles in the buttock [9].
To evaluate the effect of changing material properties, the SENIORS 9kph test was run in 12 different combinations, with all available combinations of skin and flesh materials, see Table I.

Table I. Material model simulation matrix.

Skin/flesh material models	Original	Along	Across	Langer lines
Original	X	X	X	X
Naseri - stiff	X	X	X	X
Naseri - average	X	X	X	X

3. Setup

The softened HBM was compared to two PMHS tests from the SENIORS project (1760 and 1762) [3]. The PMHS tests were conducted in a simplified seat (the SAFER seat [2]) with a three-point seat belt pretensioned with 50N. Peak acceleration was approximately 4G.

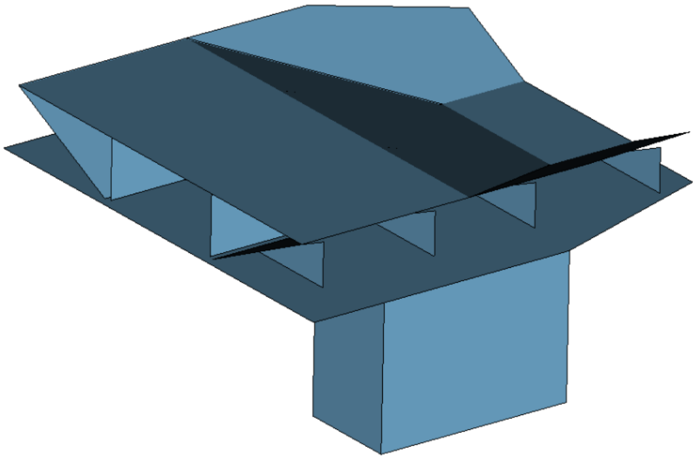

Figure 3. Finite element model of the SAFER seat used in the simulations.

The HBM was positioned in the seat using the average position of the head, T1, T8, L2, and pelvis at t=0 from processed VICON data. The model was pulled into position by pre-tensioned cables – the Marionette method, combined with gravity. The duration of the positioning was 1200 ms, and a global damping was added to prevent oscillations. The position in the SAFER seat was saved in a new include, strains and stresses in buttock and thighs were saved and used as initial strains/stresses in the sled simulations. The HBM position compared to the initial position of PMHS 1762 is shown in Figure 4.

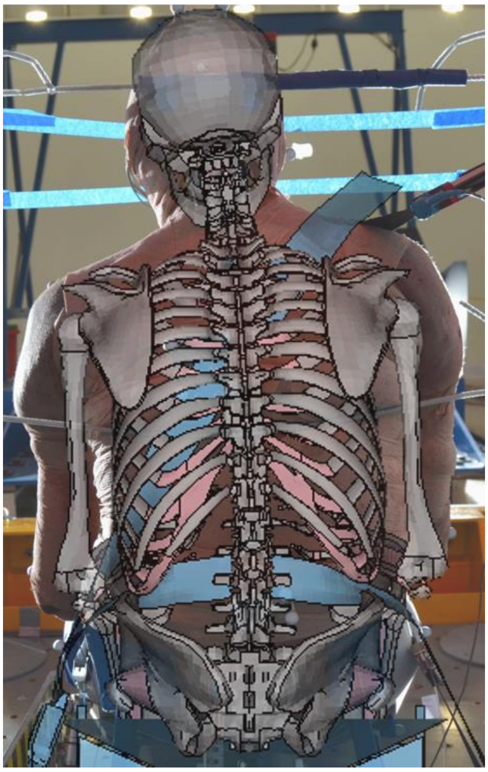

Figure 4. An overlay of initial positions of HBM and PMHS 1762 [3].

The sled simulation was divided into two parts: one pre-simulation (300ms) with belt pre-tensioning of 50N and gravity load, to remove any slack in the belt system. During this phase, T1 was constrained. After this pre-simulation, the T1 constraint was released, the belt system locked, and the average acceleration pulse applied. To simulate the effect of the PMHS head held in place by tape, 4 linear-elastic springs were attached to the HBM head and released after 300+80 ms, to release at approximately the same time as the tape in the PMHS tests. The full duration of the simulation was 600 ms, divided in 300+300 ms.

Sled acceleration raw signals were filtered using a moving average over 2 ms and then sampled every 0.1 ms. After filtering, the two acceleration signals were averaged, Figure 5.

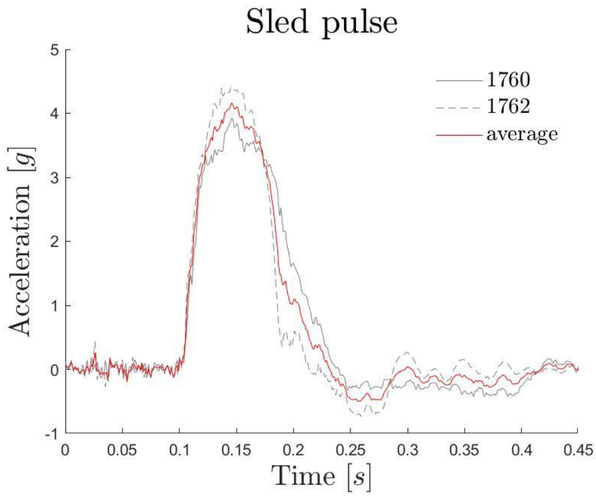

Figure 5. Recorded acceleration pulses from the two PMHS tests (grey) and the calculated average (red) used in the simulations.

A simulation model of seat and restraints for the 35 kph tests was provided by Autoliv [2]. Some variables were changed to get better correlation to the 9 kph tests, changes to parameters are shown in Table II. Belt load curve factors were changed to remove any rebounding caused by belt elasticity. Friction between HBM and belt was increased to prevent the softer models to slip out of the shoulder belt. All 12 HBM configurations were run with the 9 kph parameters, and 2 models (original and a soft model) were used in a boundary condition sensitivity study, described in detail in paragraph A. Boundary condition sensitivity study.

Table II. Table of simulation parameters changed between 35 kph and 9 kph simulations.

Parameter	35 kph	9 kph
Contact, HBM to seat, friction (FS,FD)	0.3	0.8
Contact, HBM to belt, friction (FS,FD)	0.4	1.5
Retractor: LLC, SFO	1	100
Retractor: ULC, SFO	0.4	10000

Seat belt mat (MAT_FABRIC), ULC, SFO	1.773E-5	1.773E-3
Seat belt mat (1d belt), ULC, SFO	1	100
Retractor pre-tensioning force (50N)	LLC	Pretensioner

A. Boundary condition sensitivity study.

To study the sensitivity of the boundary condition parameters changed from 35 kph to 9 kph, two HBM configurations, original and with both skin and flesh changed) was run with each of the parameters changed (seat belt hysteresis was treated as one parameter, friction between HBM and seat was run with two values), in a total of 8 simulations.

Parameter	Baseline	Changed
Contact, HBM to seat, friction (FS,FD)	0.8	0.3 (low)/0.5 (medium)
Contact, HBM to belt, friction (FS,FD)	1.5	0.5
Retractor: LLC, SFO	100	1
Retractor: ULC, SFO	10000	100
Seat belt mat (MAT_FABRIC), ULC, SFO	1.773E-3	1.773E-5

4. Evaluation

To evaluate the performance of the models, kinematic traces of the head, T1, T8, L2 and pelvis were compared to PMHS data, as well as forces in the seat, foot pan and seat belt system. Seat and foot pan forces were inertia compensated by removing results from experiment/simulation with empty sled. Both loading (first ~150 ms) and unloading/rebounding (last ~150 ms) phases were compared as the intended model usage covers both phases.

Seat belt forces at four positions were measured and compared to PMHS tests. The cross sections used for belt force predictions in the simulations are highlighted in red in Figure 6.

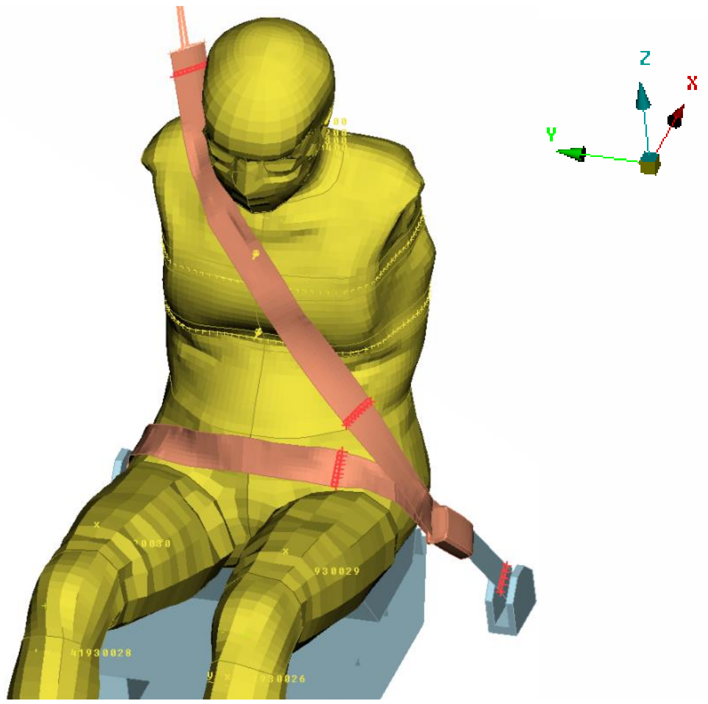

Figure 6. HBM positioned in the SAFER seat, upper extremities removed. Cross sections used to measure seat belt forces are highlighted in red. Lap belt and lower shoulder belt points are located above the left thigh (right in figure), upper shoulder belt above the right shoulder and buckle cross section below the buckle to the left of the HBM (right in the figure). The global coordinate system is shown in the top right corner.

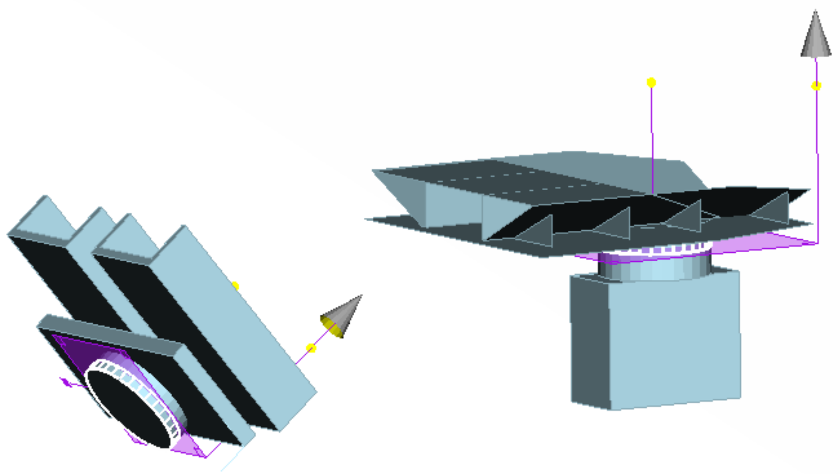

Figure 7. Seat and feet support, with cross sections used to measure feet and seat forces shown in purple. The two arrows indicate measured local z-direction of the two cross-sections.

Seat belt and buckle forces from simulations were filtered using a SAE180 filter, and seat and feet forces from simulation were filtered using a SAE60 filter.

5. Results

In Figure 8, the kinematic traces of head, T1, T8, L2 and pelvis, in the xz (approximately sagittal) plane is shown, with positive x-displacements in the forward direction and positive z-displacements are in the upward direction. The points on the lines indicates points in time, and between each point is 50 ms. The excursions grow when going from pelvis towards the head, with the largest magnitude in the head excursions. The traces for the different HBM configurations are similar for the pelvis and deviate towards the head. The largest difference is seen for the head, and mainly in the rebounding phase where the original model rebounds back further than starting position, while the softer models stay in a forward position at the end of the simulation.

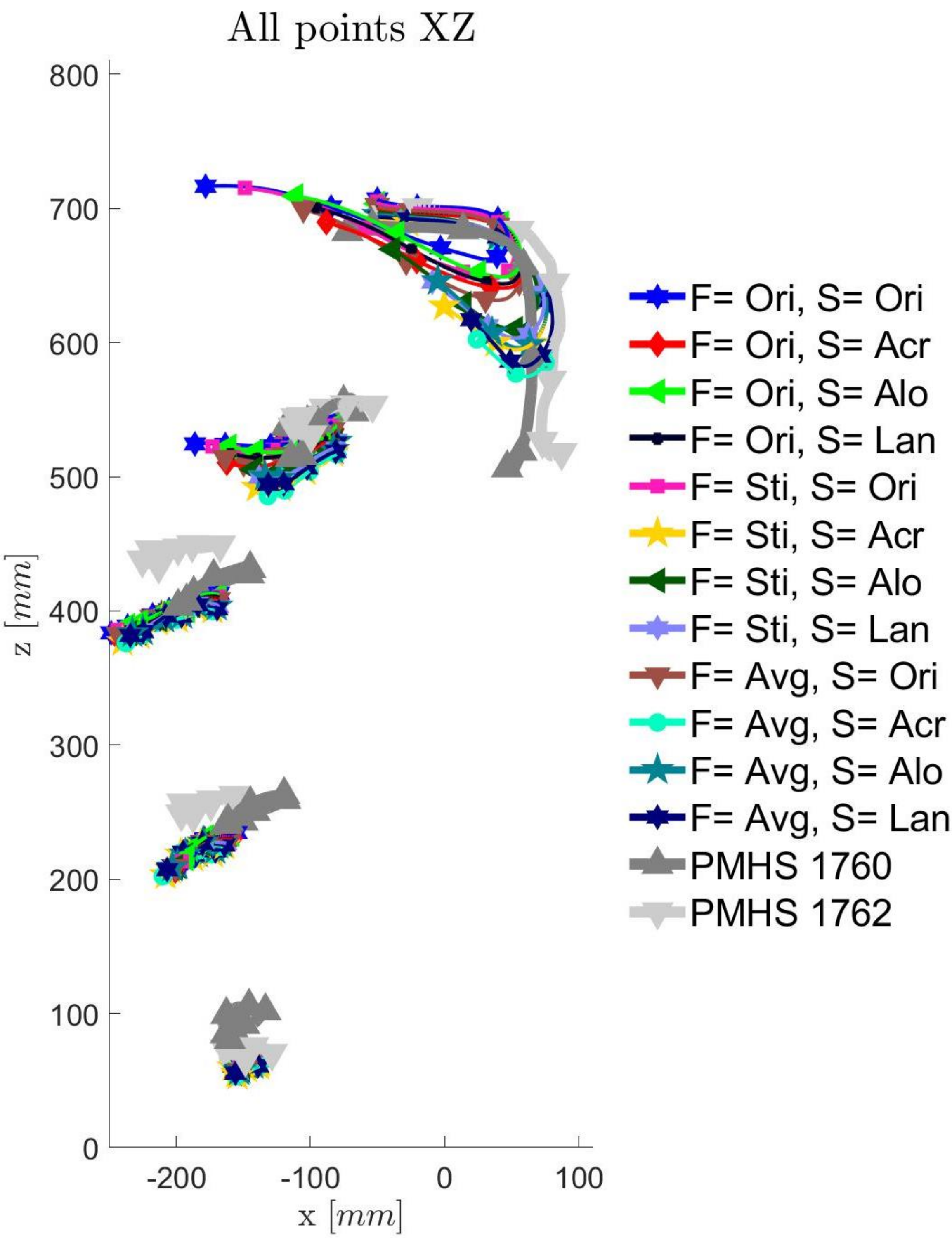

Figure 8. Position and kinematic trace, in relation to seat, of 12 simulation models and two PMHS tests. Shown are pelvis, L2, T8, T1 and head traces, from bottom and up. The points on the lines indicate points in time, the points are plotted every 50 ms. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction.

The head excursions in Figure 9 are larger for the softer models compared to the stiffer models, and the softer models also show less rebound. The stiffest model is the original, with peak displacements of around 90mm in x and -50mm in z. The softest model, with average flesh and "across" skin has peak displacements of around 125mm in x and -110mm in z. The head excursions can be divided into three groups. The two models with average flesh and "across" and "Langer" skins are similar in excursion. The other 4 models with both updated flesh and updated skin show more similarities between them. The 6 models with original skin or/and flesh give the smallest excursions and are similar. However, none of the simulation models show the same behaviour as the two PMHSs, which show no head rebound.

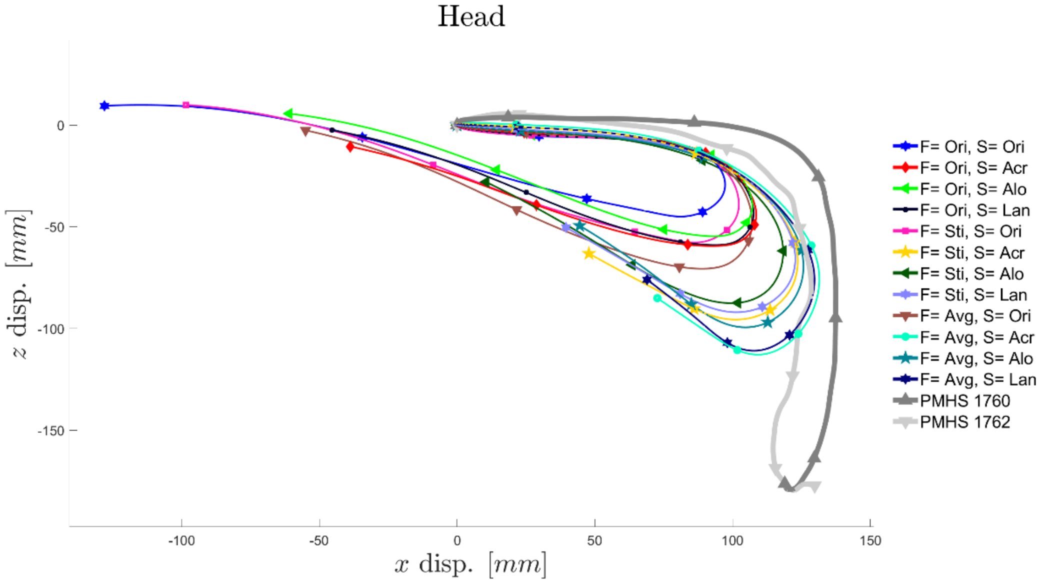

Figure 9. Head kinematics for the PMHS tests and the 12 different HBMs, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

Just as for the head excursions, the T1 excursions show decreased rebound with softer models. All six models with both changed skin and flesh move upwards (positive z) the last 50 ms of the simulation, as does PMHS 1762.

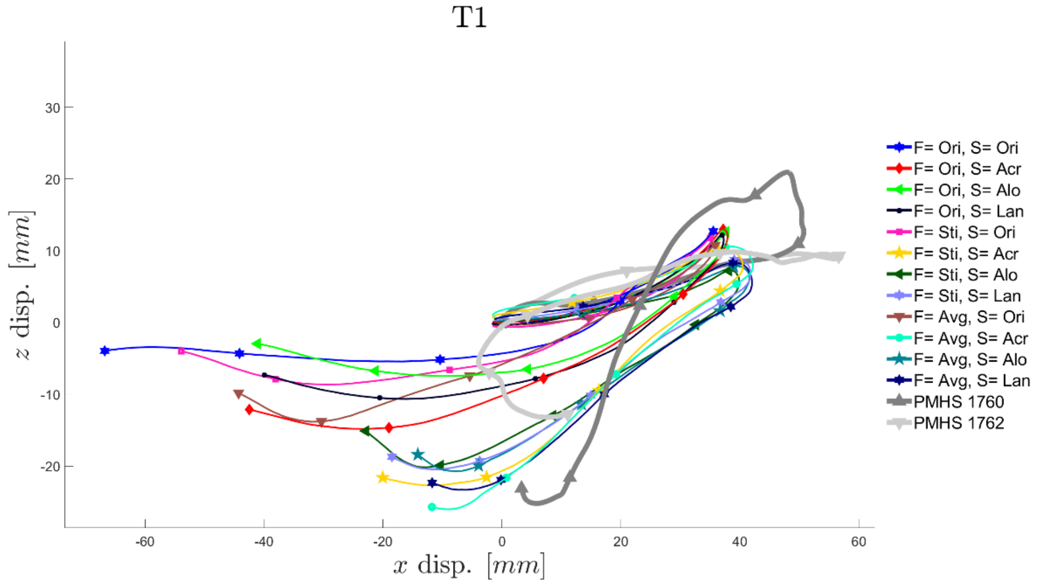

Figure 10. T1 kinematics for the PMHS tests and the 12 different HBMs, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

T8 excursions, Figure 11, are similar for all simulation models. Peak forward excursion (x direction) is around 40mm for all models, and end position in x direction ranges from around -20 to -40 mm for the simulation models.

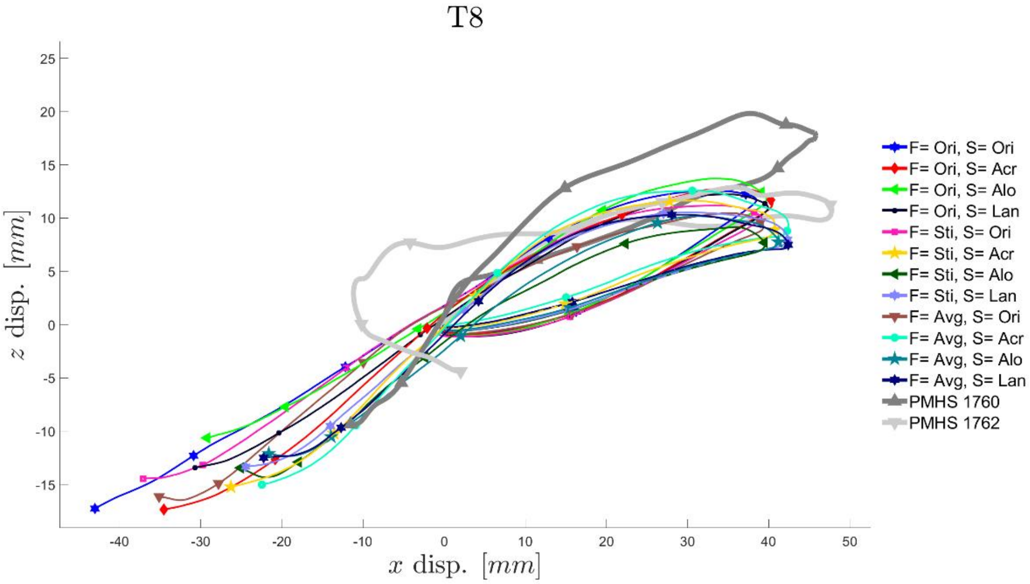

Figure 11. T8 kinematics for the PMHS tests and the 12 different HBMs, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

L2 peak forward excursions, Figure 12, range from around 15-25mm for the models, and around 30mm for the PMHSs.

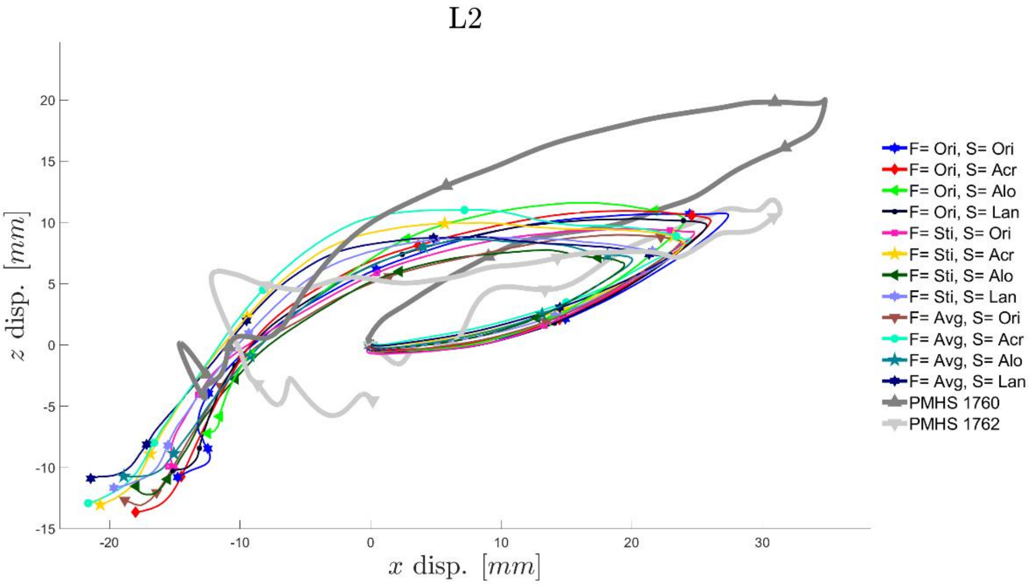

Figure 12. L2 kinematics for the PMHS tests and the 12 different HBMs, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

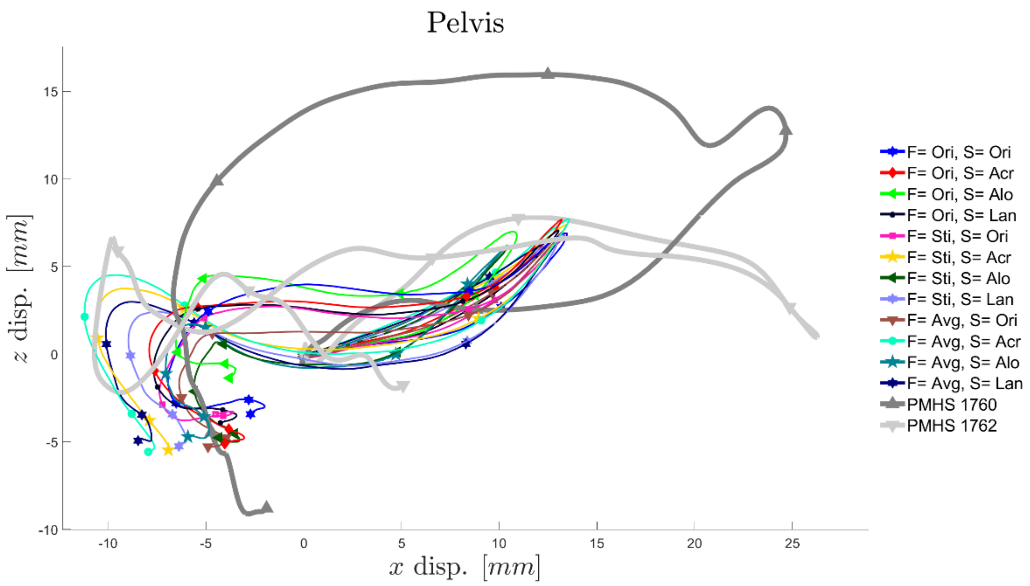

Figure 13. Pelvis kinematics for the PMHS tests and the 12 different HBMs, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

The measured forces in the buckle cross section, shown in Figure 14, have a peak magnitude of around 1.4 to 1.8 kN, and show a similar trend as for PMHS 1762.

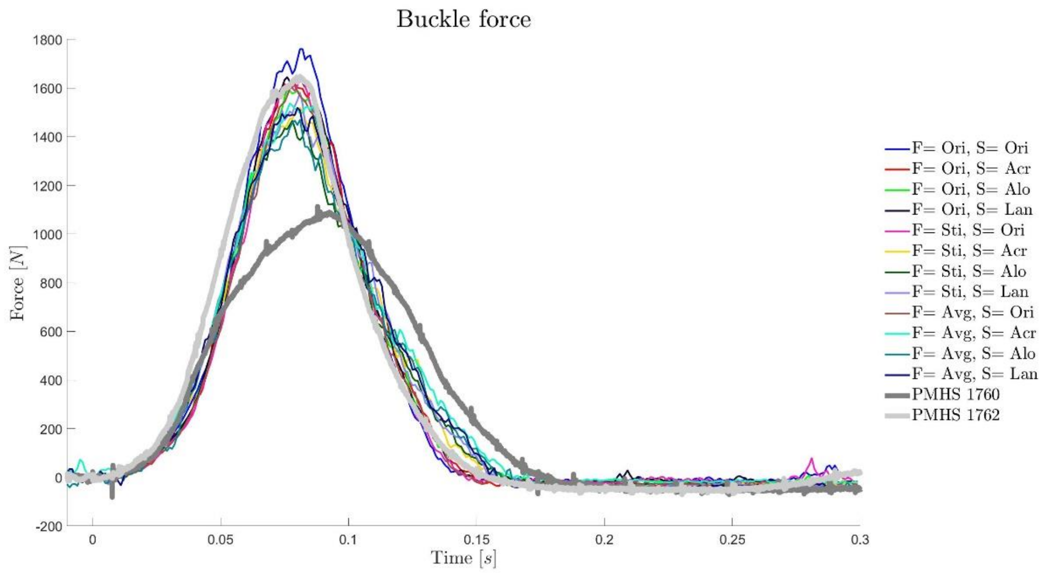

Figure 14. Buckle force for 12 simulation models and the two PMHS tests. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

Forces measured in the lap belt are shown in Figure 15. All models show a lower peak magnitude compared to PMHS 1762. Three models, the three configurations with "along" skin material, have a similar peak magnitude (around 400 N) as PMHS 1760. The remaining 9 models have a peak magnitude of roughly the average peak of both PMHSs (500 N).

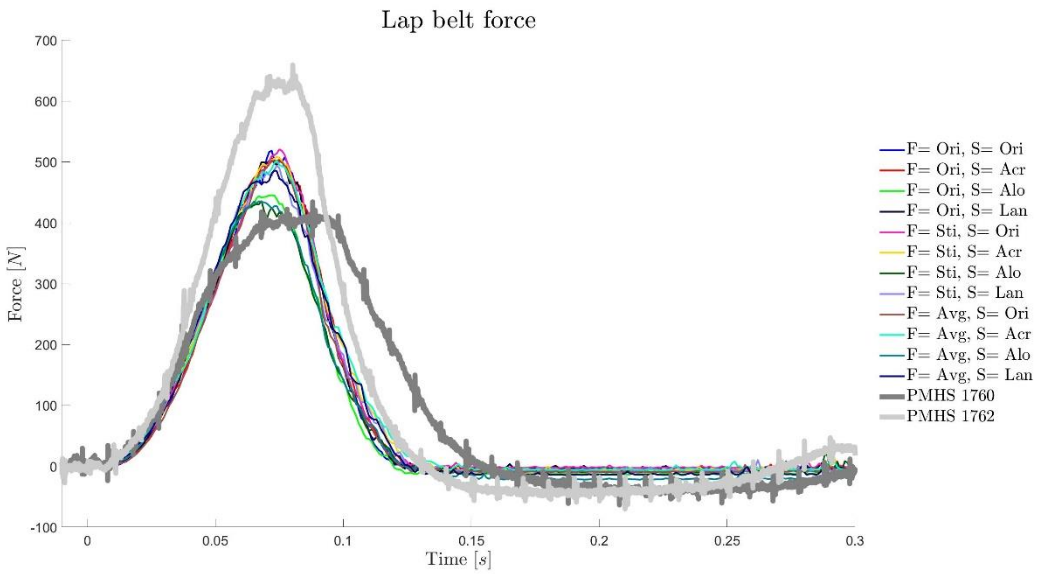

Figure 15. Lap belt force for 12 simulation models and the two PMHS tests. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

For the two measured shoulder belt forces, the largest force is measured in the original HBM configuration. All models show similarities with PMHS 1762. For all models and both PMHS tests, the largest force is measured in the upper point. There is an overlap between the upper and lower peak magnitudes, where the upper (larger) force of the models with modified flesh are similar to the lower (lower) forces of the models with original flesh, Figure 16, Figure 17.

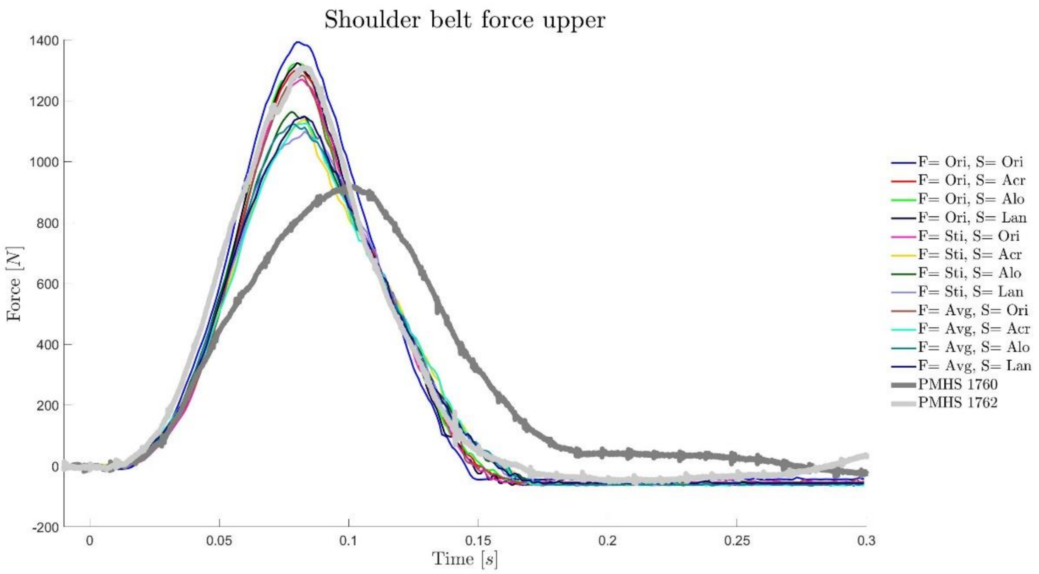

Figure 16. Upper shoulder belt force. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

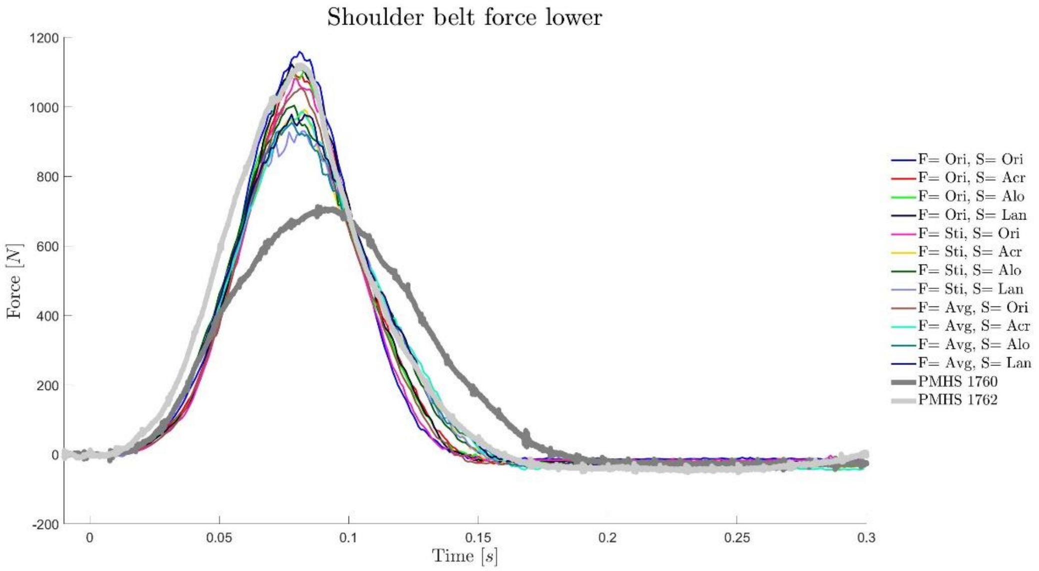

Figure 17. Lower shoulder belt force. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

The measured seat forces are similar between the simulation models, and similar to forces measured in PMHS tests, Figure 18, Figure 19.

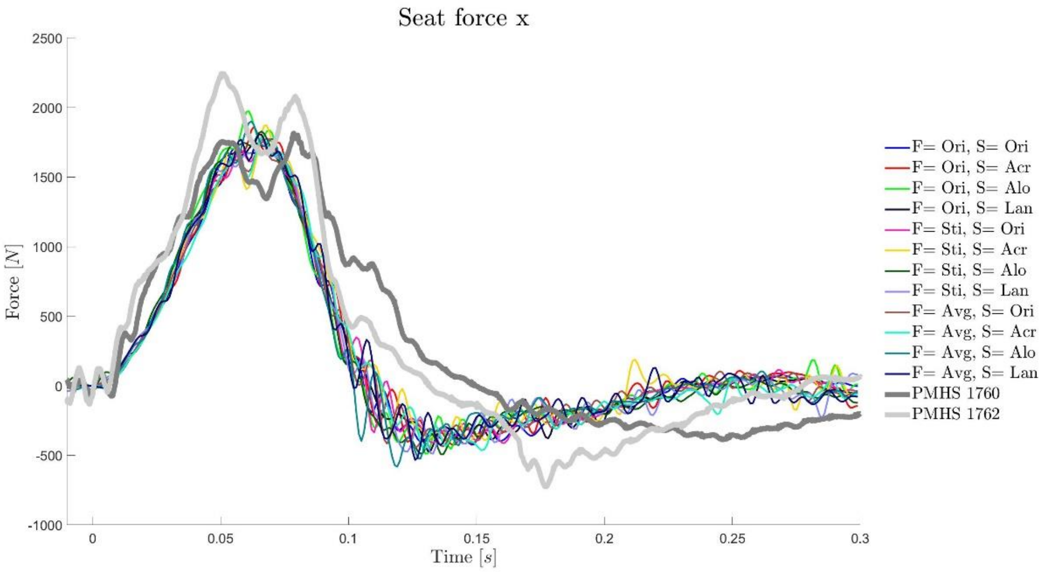

Figure 18. Seat force in local x (forward) direction, inertia compensated, for 12 simulation models and the two PMHS tests. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

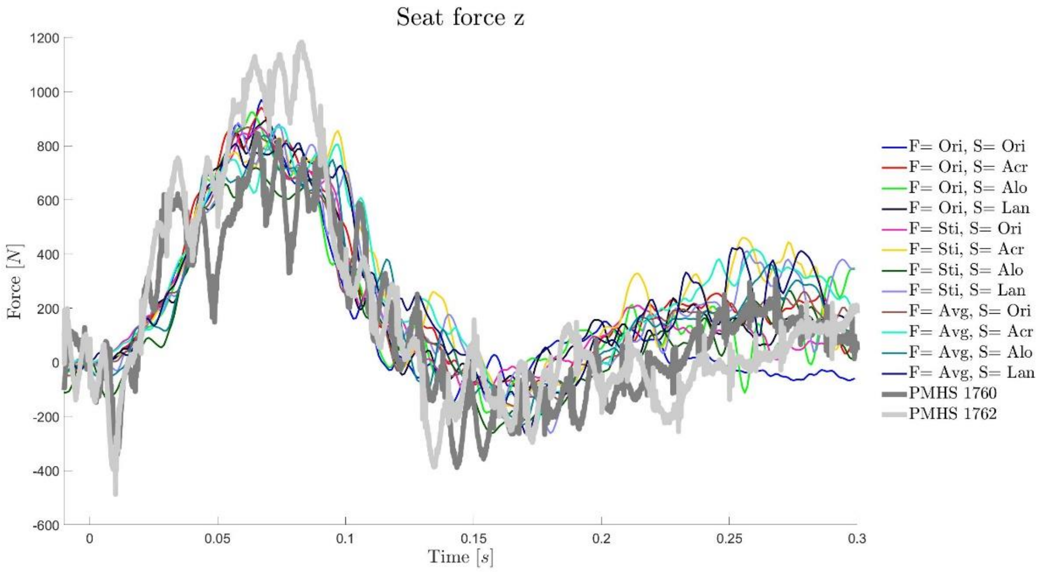

Figure 19. Seat force in local negative z (downward) direction, inertia compensated, for 12 simulation models and the two PMHS tests. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

Feet forces are similar between the simulations, and are lower compared to both PMHS tests, in both x and z directions, Figure 20, Figure 21.

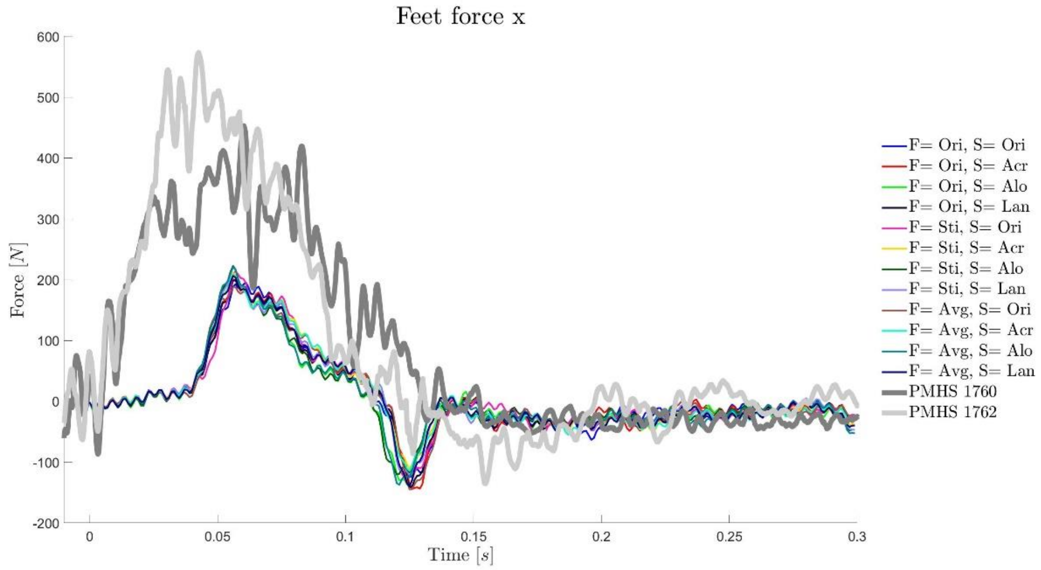

Figure 20. Feet force in local negative x (downward/rearward) direction, inertia compensated, for 12 simulation models and the two PMHS tests. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

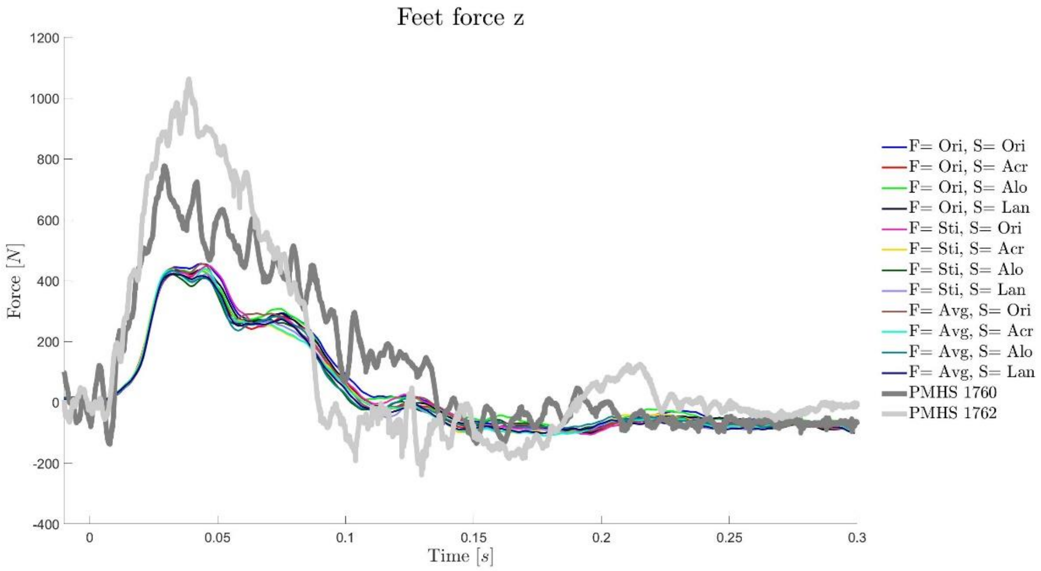

Figure 21. Feet force in local negative z (upward/forward) direction, inertia compensated, for 12 simulation models and the two PMHS tests. The "F" in the legend stands for flesh model, and "S" for skin model, "Ori" original (skin/flesh), "Acr" across, "Alo" along, "Lan" Langer lines, "Sti" stiff and "Avg" average.

A. Boundary condition sensitivity study

Positions and kinematic traces for the 5 measured points are shown in Figure 22. For the head, there is a clear difference between results for the original (red) and updated (blue) HBM configurations, where all updated models give less rebound compared to the original configuration. The same trend is visible for T1, but here the trend is less clear. Detailed traces, normalized to initial position for each measured point, is presented in the appendix.

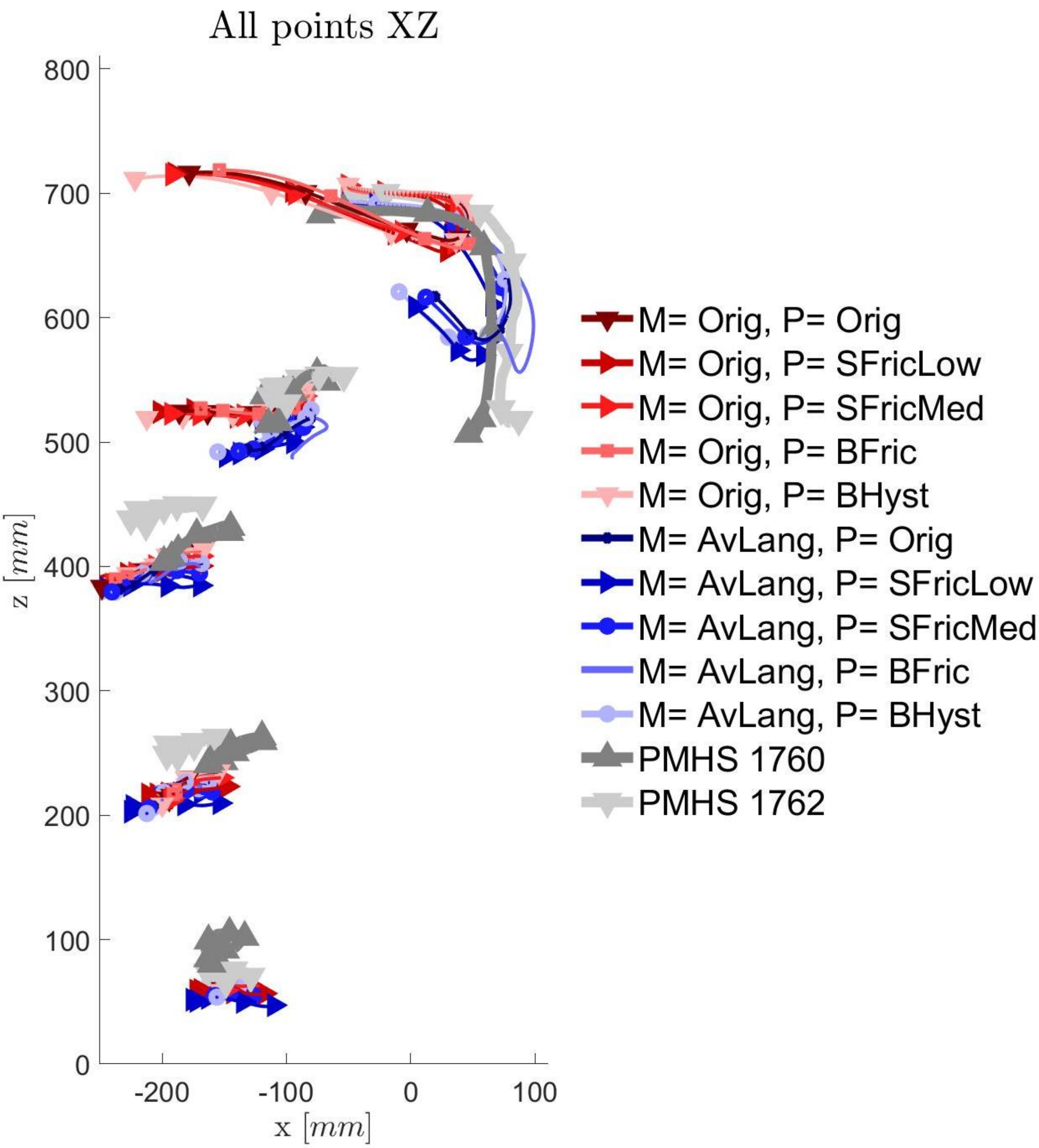

Figure 22. Position and kinematic trace, in relation to seat, of 2 HBM models (original - blue and average flesh with Langer lines skin - red) for 5 simulation setups, and two PMHS tests. Shown are pelvis, L2, T8, T1 and head traces, from bottom and up. The points on the lines indicate points in time, the points are plotted every 50 ms. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction.

The measured forces in the buckle cross section, shown in Figure 23, vary with both HBM configuration and simulation parameters, with lower seat-HBM friction giving higher buckle forces, and softer model giving higher buckle forces.

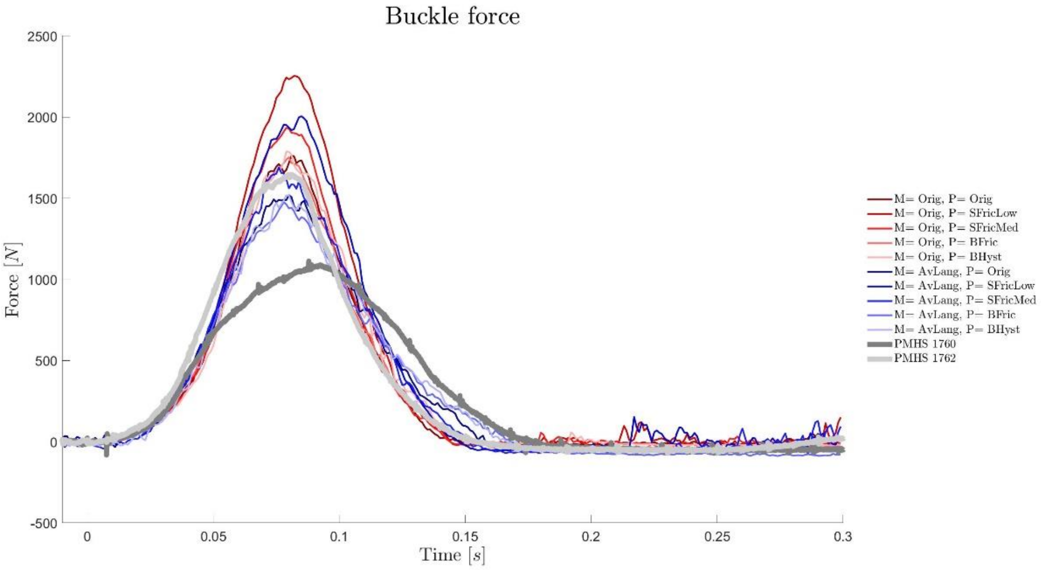

Figure 23. Buckle force for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

The lap belt force was mainly dependent on the friction between HBM and seat, with lower friction giving higher lap belt force; Figure 24.

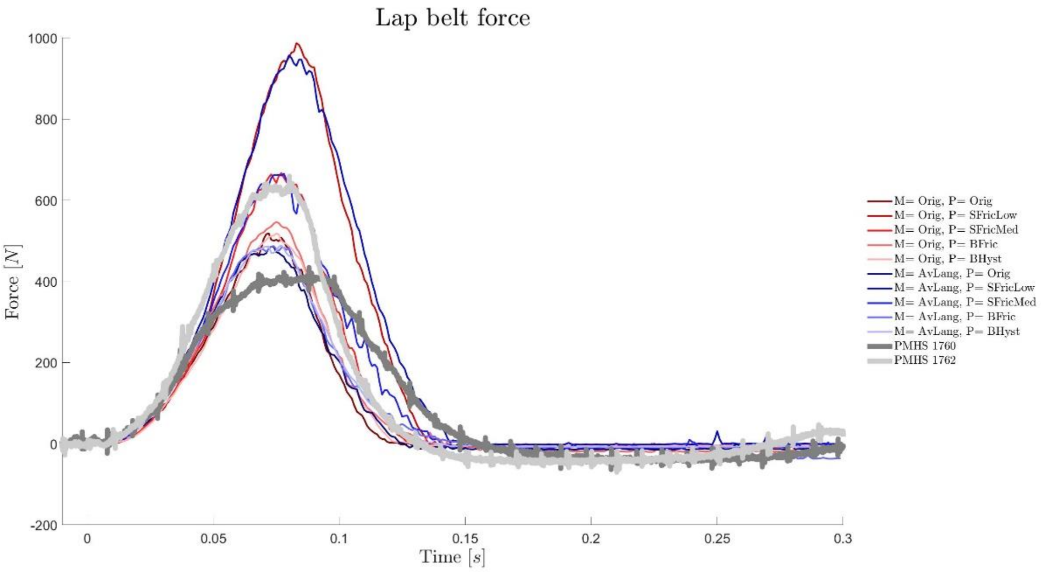

Figure 24. Lap belt force for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

The shoulder belt force is sensitive to both HBM configuration and parameter, where lower seat-HBM friction gives higher shoulder belt force and lower belt friction gives lower shoulder belt force, Figure 25, Figure 26.

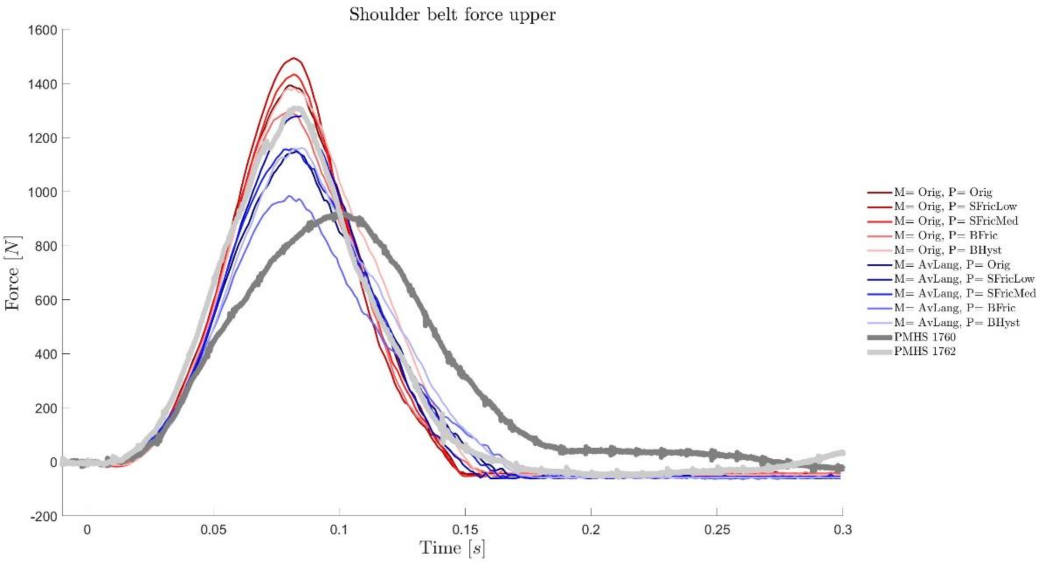

Figure 25. Upper shoulder belt force, for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

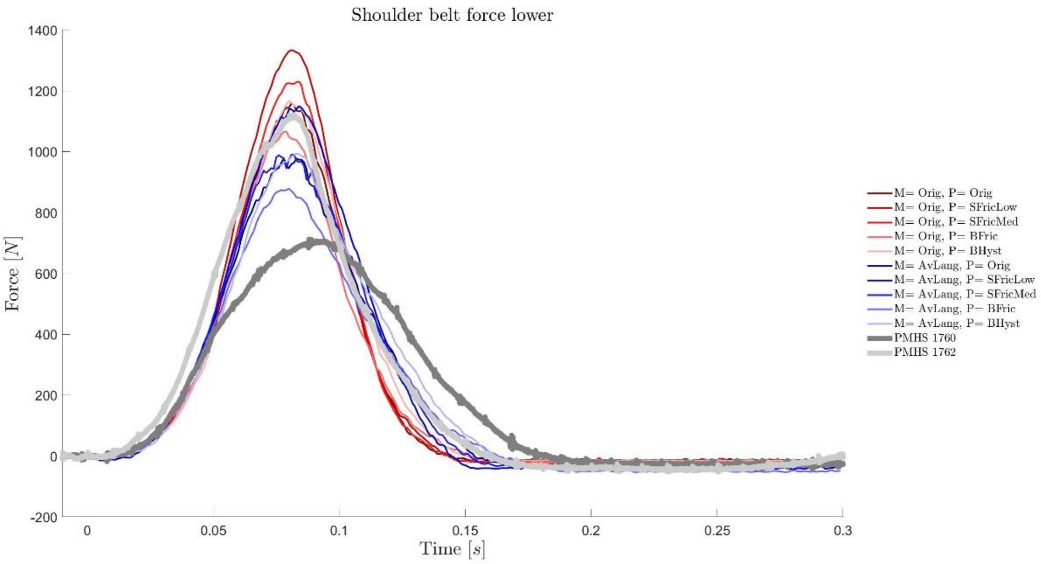

Figure 26. Lower shoulder belt force, for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

The seat forces in seat x and z directions vary with the seat-HBM friction parameter, but not much with HBM configuration or seat belt parameters Figure 27, Figure 28.

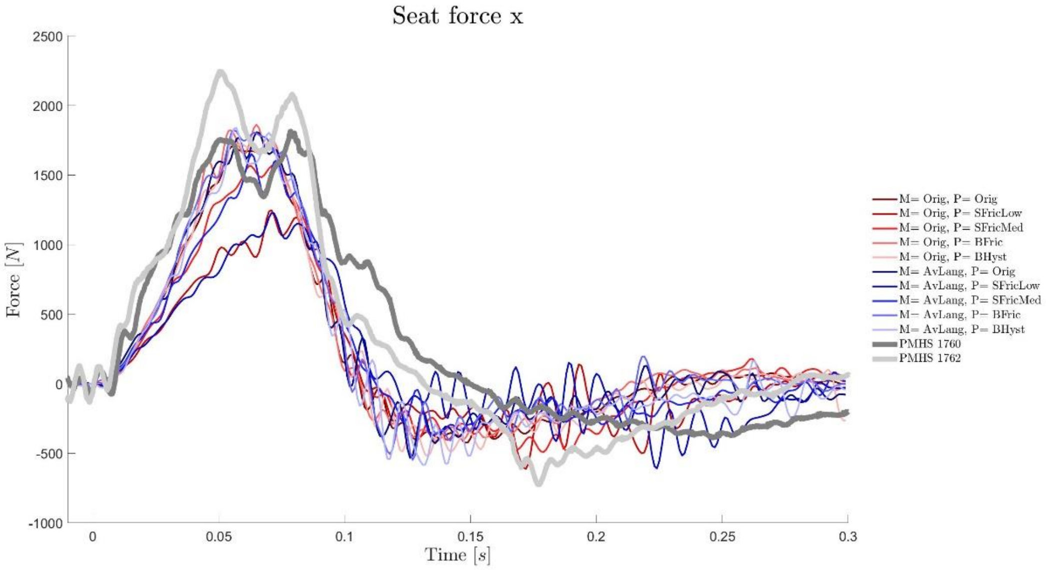

Figure 27. Seat force in local x (forward) direction, inertia compensated, for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

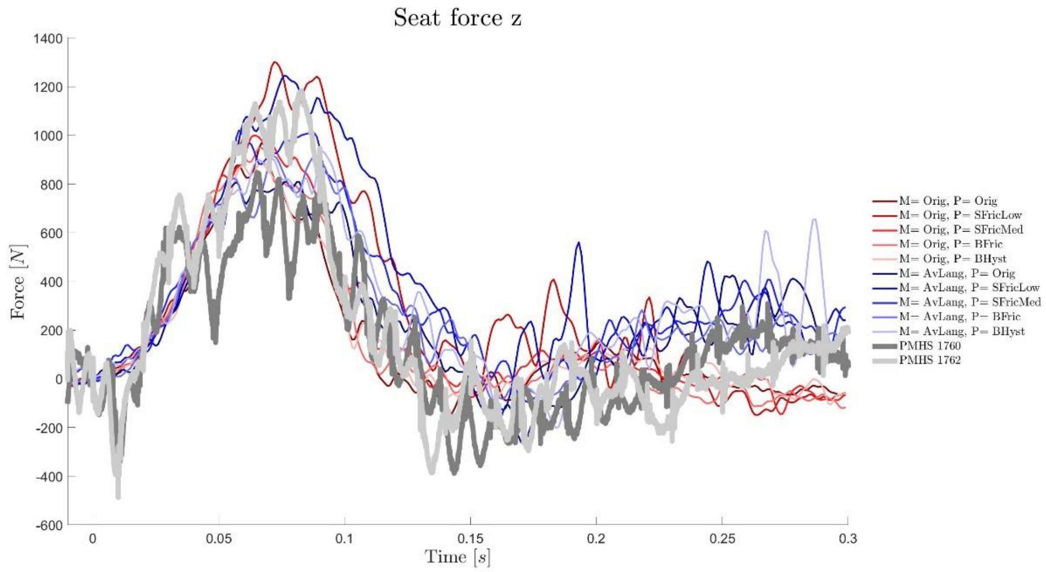

Figure 28. Seat force in local negative z (downward) direction, inertia compensated, for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

The feet force does not vary much with HBM configuration or simulation parameter, Figure 29, Figure 30.

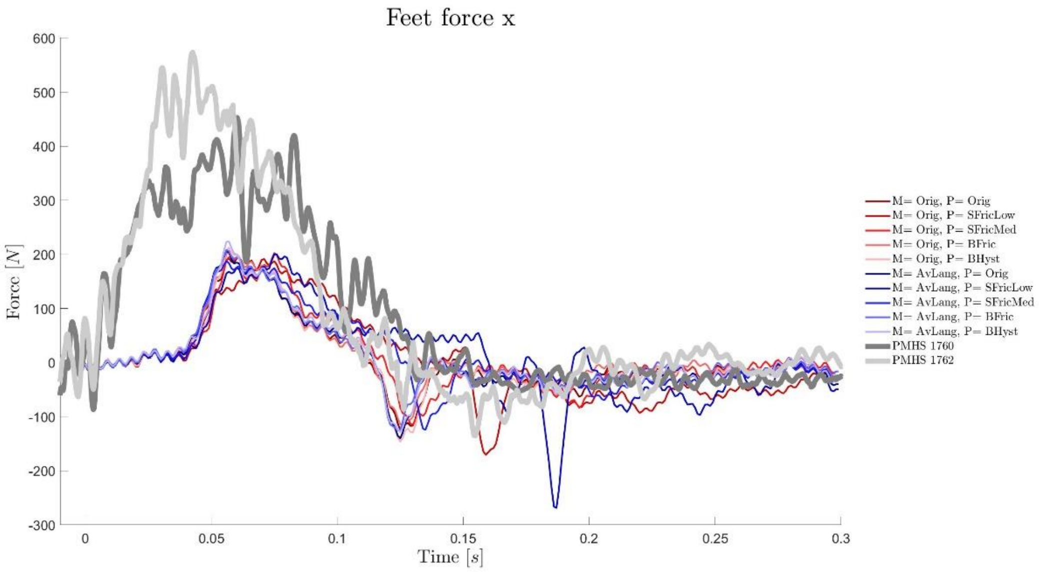

Figure 29. Feet force in local negative x (downward/rearward) direction, inertia compensated, for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

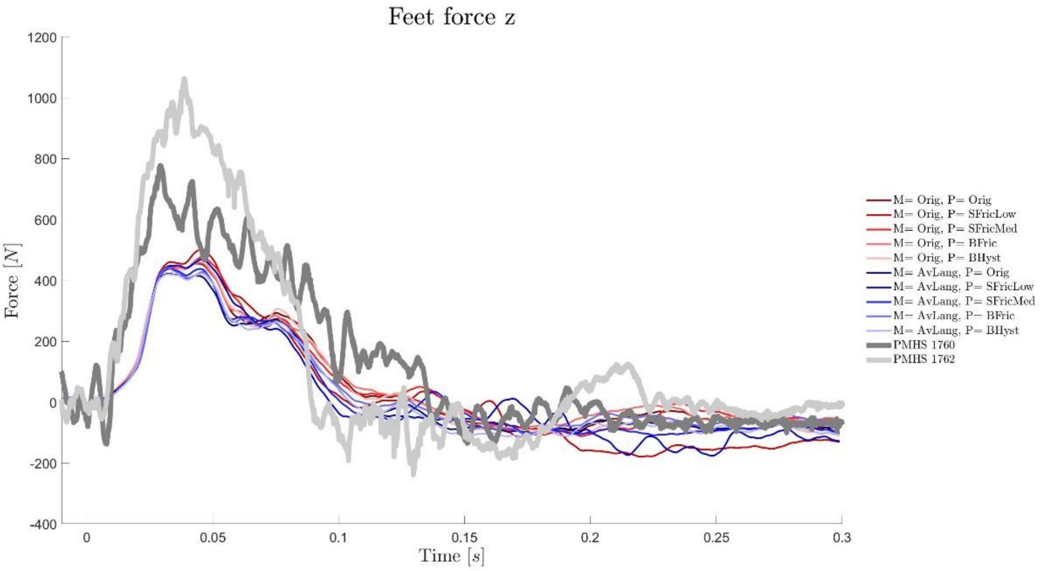

Figure 30. Feet force in local negative z (upward/forward) direction, inertia compensated, for 10 simulation models and the two PMHS tests. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

6. Discussion

Since the setup was highly sensitive to all any and all parameter changes introduced in this study the load case may not be the most suitable for validation of HBMs in low speed impacts. However, when considering the boundary condition sensitivity study the difference between the HBM configurations remain, and thus the results can be used to guide the selection of skin/flesh material models.

When comparing all 12 model configurations, it was seen that the major differences between the models were in the rebound phase and not the loading phase. The least rebounding models, and as such also closest to the PMHS results, were the models with the HBM flesh modelled with average fat properties combined with the HBM skin modelled using either Langer lines or "across" properties in both material directions. Since the loading of the back skin is mainly across the Langer lines when bending forward, Figure 2, it is expected that the "across" and Langer lines models give similar results. The results with "along" skin differ from results with Langer and "across" skins, showing that the material direction has an influence on the results. Therefore, the orthotropic material model, Langer lines, is judged to be the most suitable skin material model.

A high friction between seat belt and HBM (1.5) was introduced to prevent the shoulder belt from slipping off in the softer models. When running with lower frictions there was a difference in shoulder belt behaviour between the different HBM configurations, where the shoulder belt slipped off the shoulder for some models but not for others. In order to keep the on the shoulder for all models, the friction was increased until the belt remained on the shoulder for all models. This should be seen as a proxy for an unknown parameter in the PMHS setup and not as a true friction value, as it is increased beyond what is typically used.

7. Conclusions

Based on the simulation results it can be concluded that the most suitable flesh model is the average fat model, and that this load case can be used to guide in the selection of material model but not to validate the model. The most human-like skin modelling was judged to be the orthotropic "Langer lines"-model.

8. References

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9. Appendix

A. Boundary condition sensitivity study - kinematics

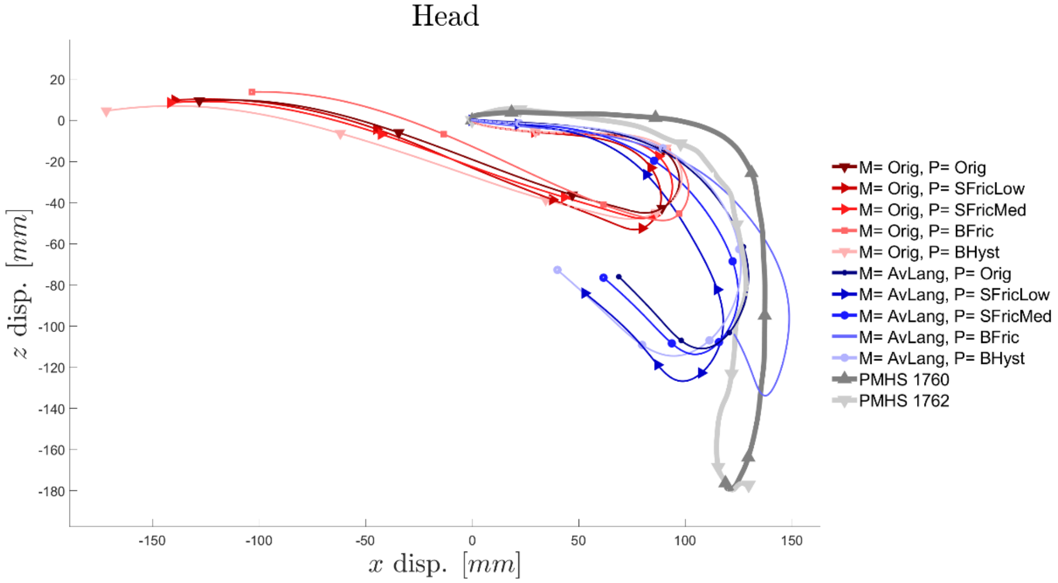

Figure 31. Head kinematics for the PMHS tests and the 10 simulations, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. “M” stands for HBM model, “P” for parameter, “Orig” for original (model and parameter), “AvLang” for average flesh with Langer skin, “SFricLow” the lower seat-HBM friction, “SFricMid” the middle seat-HBM friction, “BFric” belt-HBM friction, “BHyst” belt hysteresis.

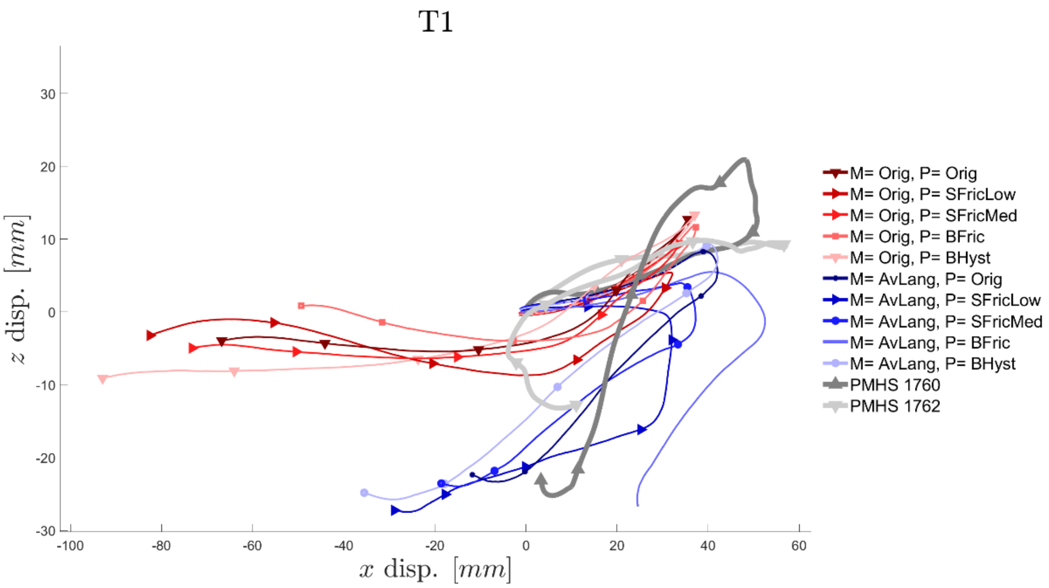

Figure 32. T1 kinematics for the PMHS tests and the 10 simulations, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. “M” stands for HBM model, “P” for parameter, “Orig” for original (model and parameter), “AvLang” for average flesh with Langer skin, “SFricLow” the lower seat-HBM friction, “SFricMid” the middle seat-HBM friction, “BFric” belt-HBM friction, “BHyst” belt hysteresis.

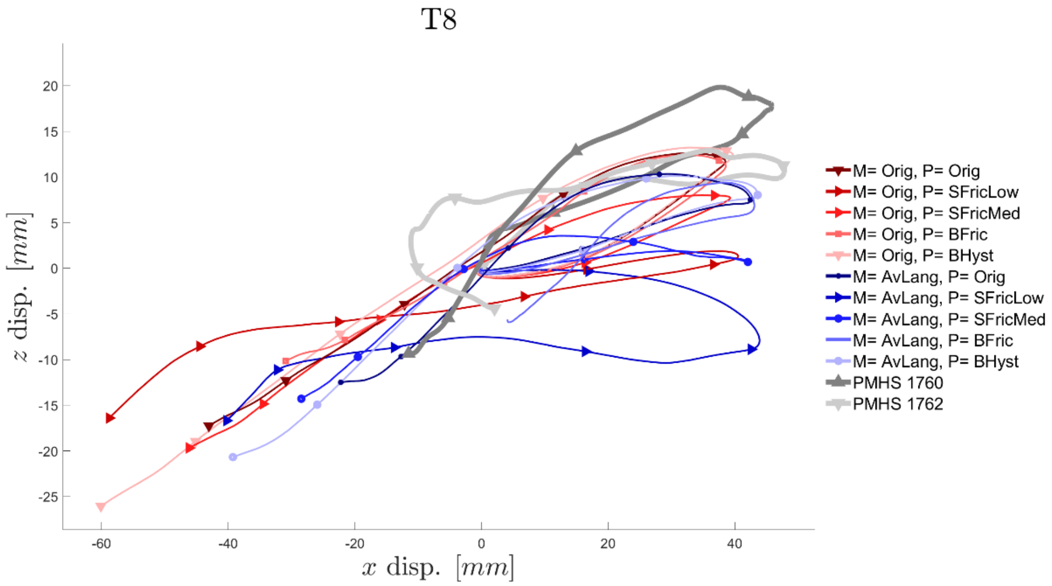

Figure 33. T8 kinematics for the PMHS tests and the 10 simulations, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

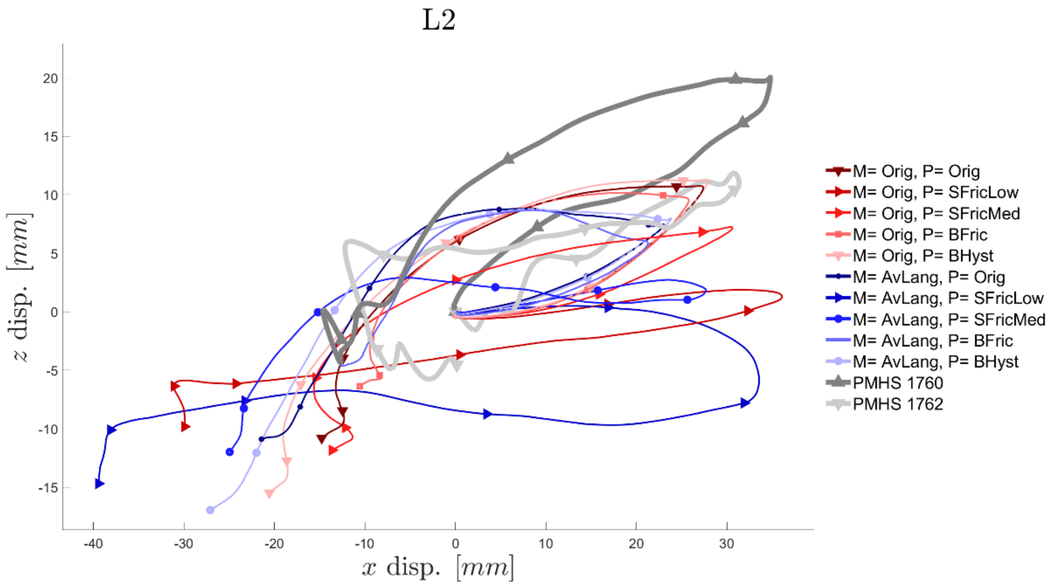

Figure 34. L2 kinematics for the PMHS tests and the 10 simulations, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.

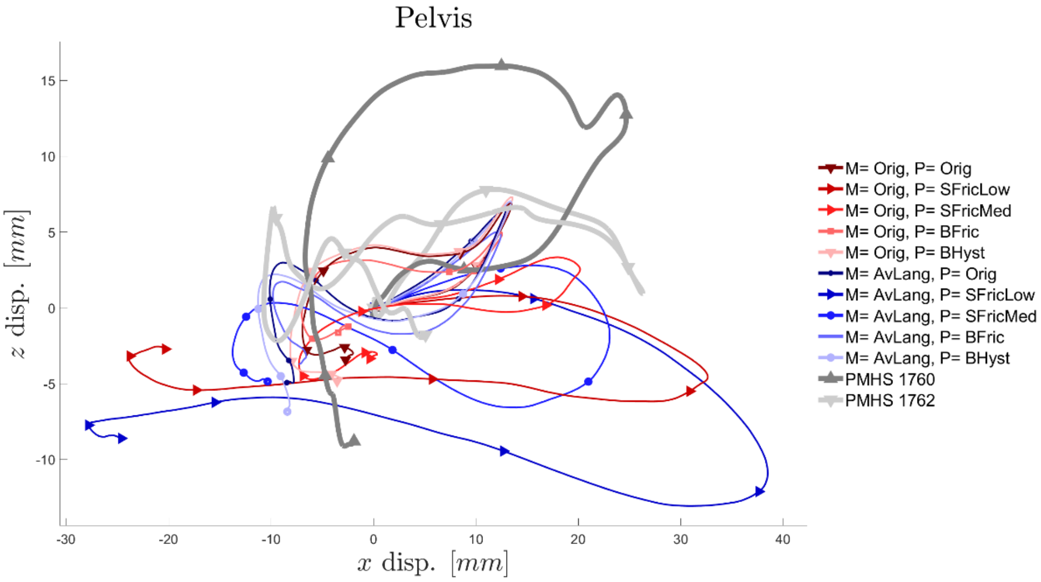

Figure 35. Pelvis kinematics for the PMHS tests and the 10 simulations, in xz plane. Positive x displacements are in the HBM forward direction and positive z displacements in upward direction. The points on the lines indicate points in time, the points are plotted every 50 ms. "M" stands for HBM model, "P" for parameter, "Orig" for original (model and parameter), "AvLang" for average flesh with Langer skin, "SFricLow" the lower seat-HBM friction, "SFricMid" the middle seat-HBM friction, "BFric" belt-HBM friction, "BHyst" belt hysteresis.