Documentation

LS-DYNA

ES-2 50th - Version 8.0.2

ES-2re 50th - Version 8.0.2

User's Manual
Manual Release 0.2 for Model 8.0.2
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Content

1. General information

The development and validation has been performed on different platforms. The following LS-DYNA versions have been used:

LS-DYNA Version	Revision Nr.	SVN-Version
971 R7.1.3 MPP	114888	114888
R9.3 dm	134916	134916
R11	136045	136045

Table 1: LS-DYNA versions.

With the version 8.0.2 of the Euro-SID 2 50th model the following keyword files are delivered:

File name	Content
es2_v8.0.2_mm_ms_kg.key	Dummy model, the file name might vary depending on the system of units
es2_v8.0_nullshells.key	Optional contact shells
es2_v8.0_all_units_load_curves_work.key	Dummy curves for working on the model with a pre-processor
es2_v8.0_all_units_server.asc	Encrypted curve file including the table and curves of the model. This can only be used with valid vendor license
psg_vx.x_DYNAMORE_Dummys	Positioning generator to generate positions by using pre-simulations
Lic_*Dummy_customername_issuedate _expirationdate*	Vendor License file

Table 2: Files delivered.

The numbering scheme of the original model is shown in Table 3. The IDs below refer to the ES-2re model including the optional nulls shells. On demand we deliver renumbered input decks, according to user specifications.

Component	Min ID	Max ID	Total number
Nodes	10000	375946	365139
Solids	11000	457627	446628
Beams	10000	11476	452
Shells	11000	225308	214216
Discrete elements	10500	10517	16
Mass elements	10518	10526	9
Accelerometer	1001	1022	11
Set nodes	1005	1202	9
Set parts	1001	1544	32
Parts	1	740	543
Materials	1001	1201	189

Sections	1001	1740	543
Hourglass	1001	1007	7
Joint stiffness	1001	1018	17
Contacts	1001	1030	26
Local coordinate systems	1001	1045	45
Load curves / tables	1001	1163	163
Time history nodes	10001	10021	11
Time history elements	10000	10016	13

Table 3: Model numbering scheme.

2. Keywords used

The following control and database keywords are used:

*CONTROL_ACCURACY *CONTROL_BULK_VISCOSITY *CONTROL_CONTACT *CONTROL_CPU *CONTROL_ENERGY *CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS	*CONTROL_OUTPUT *CONTROL_SHELL *CONTROL_SOLID *CONTROL_SOLUTION *CONTROL_TERMINATION *CONTROL_TIMESTEP

Table 4: Used Control cards.

The following database cards are defined:

*DATABASE_ABSTAT *DATABASE_BINARY_D3PLOT *DATABASE_DEFORC *DATABASE_ELOUT *DATABASE_EXTENT_BINARY *DATABASE_GLSTAT *DATABASE_JNTFORCE *DATABASE_HISTORY_BEAM_ID	*DATABASE_HISTORY_NODE_ID *DATABASE_MATSUM *DATABASE_NODOUT *DATABASE_RCFORC *DATABASE_SLEOUT

Table 5: Used Database cards.

The following material models are used:

*MAT_DAMPER_NONLINEAR_VISCOUS *MAT_ELASTIC *MAT_FU_CHANG_FOAM *MAT_LINEAR_ELASTIC_DISCRETE_BEAM *MAT_NONLINEAR_ELASTIC_DISCRETE_BEAM *MAT_NULL *MAT_PLASTIC_KINEMATIC *MAT_RIGID *MAT_SIMPLIFIED_RUBBER *MAT_SPRING_NONLINEAR_ELASTIC *MAT_SIMPLIFIED_RUBBER_WITH_DAMAGE	*MAT_SPRING_ELASTIC *MAT_VISCOELASTIC *MAT_SPOTWELD *MAT_FABRIC

Table 6: Used Material models.

The following other keywords are used:

*CONSTRAINED_EXTRA_NODES_SET *CONSTRAINED_JOINT_CYLINDRICAL_ID *CONSTRAINED_JOINT_SPHERICAL_ID *CONSTRAINED_JOINT_STIFFNESS_	*ELEMENT_SEATBELT_ACCELEROMETER *ELEMENT_SHELL *ELEMENT_SOLID *ELEMENT_MASS

GENERALIZED *CONSTRAINED_JOINT_TRANSLATIONAL *CONSTRAINED_RIGID_BODIES *CONTACT_AUTOMATIC_SINGLE_SURFACE *CONTACT_FORCE_TRANSDUCER_PENALTY *CONTACT_TIED_SHELL_EDGE_TO_ SURFACE_ID_OFFSET *DAMPING_PART_STIFFNESS *DEFINE_COORDINATE_NODES *DEFINE_CURVE *DEFINE_TABLE *ELEMENT_BEAM_(ORIENTATION) *ELEMENT_DISCRETE	*NODE *SECTION_BEAM *SECTION_DISCRETE *SECTION_SHELL *SECTION_SOLID *SET_PART_LIST *SET_SHELL_LIST *HOURGLASS *INITIAL_FOAM_REFERENCE_GEOMETRY *PARAMETER *PART_CONTACT

Table 7: Other keywords used in the model.

After the *END keyword the following Primer keywords are defined:

*ASSEMBLY *DUMMY_START *UNITS	*DUMMY_END *H_POINT *POINT_LOCATION

Table 8: Used Primer keywords.

3. Extraction of occupant injury criteria

To extract occupant injury criteria from the model, the following preparations have been made.

3.1 Rib accelerations

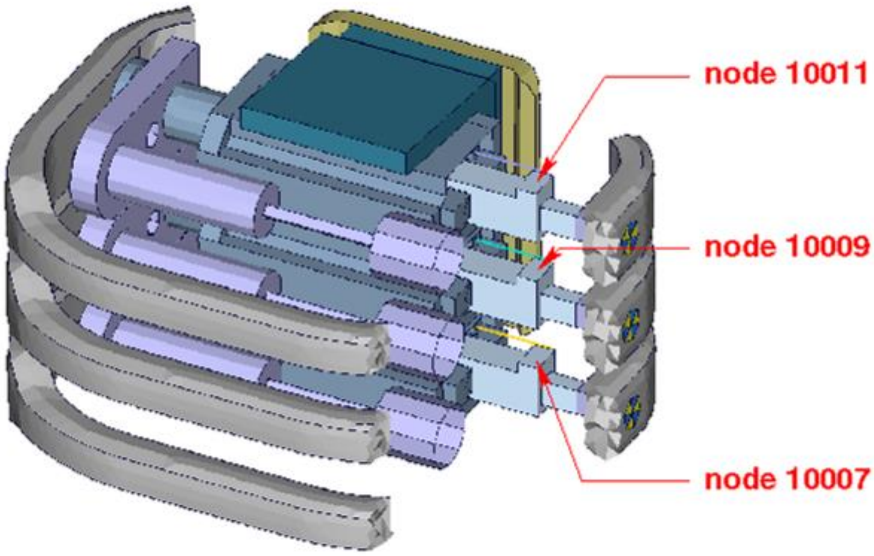


Figure 1: Nodes for extracting rib accelerations

The marked nodes, which are shown in Figure 1, are accelerometer nodes. The description of the accelerometer definitions for the local output is shown in next table.

Item	Node-ID	Label	Component
Upper Rib	10011	RIBSLEUPERAC	Local y-acceleration
Middle Rib	10009	RIBSLEMIERAC	Local y-acceleration
Lower Rib	10007	RIBSLELOERAC	Local y-acceleration

Table 9: Rib acceleration nodes

3.2 Rib intrusion

The rib intrusions can be measured by determining the elongation of springs. The spring elements are listed in the following table and the output is in the deforc file. The springs are located in the piston bearing system.
The measurement of the rib deflection by using the relative displacement of two nodes will not be supported any longer.

Item	Element-ID	Label	Component
Upper Rib intrusion	10500	RIBSLEUPERDSY	Change in length
Middle Rib intrusion	10501	RIBSLEMIERDSY	Change in length
Lower Rib Intrusion	10502	RIBSLELOERDSY	Change in length

Table 10: Rib intrusion elements from deforc

3.3 Spine accelerations

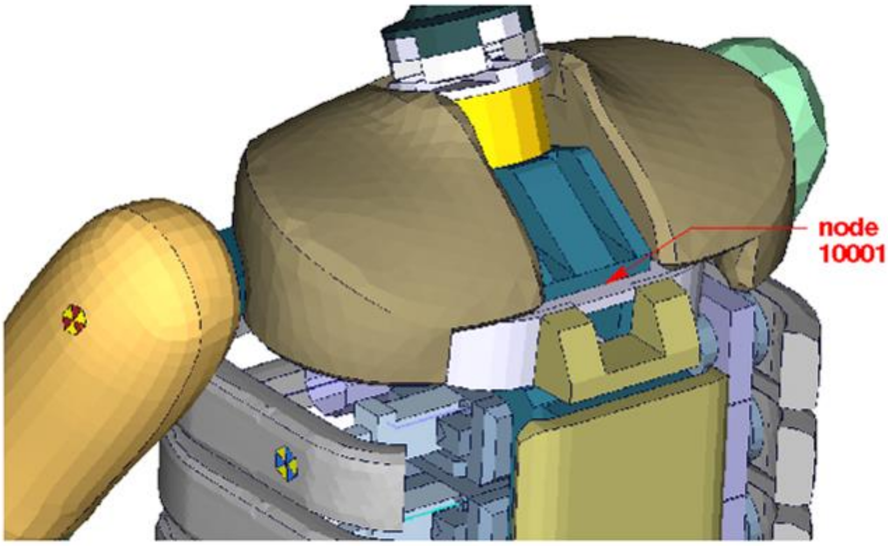


Figure 2: Node for extracting upper spine acceleration

Node 10001, which is marked in Figure 2 is part of the lower plate of neck bracket. An accelerometer is defined.

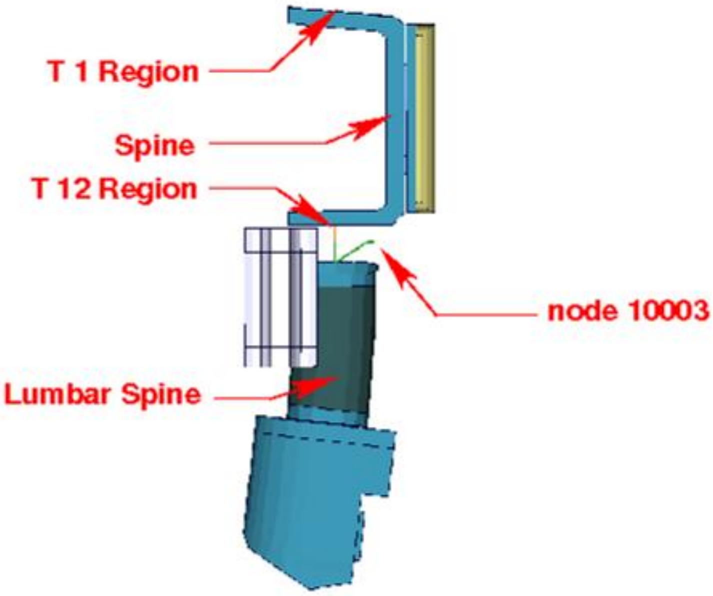


Figure 3: Node for extracting lower spine acceleration

Figure 3 shows parts of the dummy model from y direction. Node 10003 is located between upper spine and lumbar spine. An accelerometer is defined.

Item	Node-ID	Label	Component
Upper spine	10001	SPIN0100ERAC	y-acceleration
Lower Spine	10003	SPIN1200ERAC	y-acceleration

Table11: Spine acceleration nodes

3.4 Pelvis acceleration

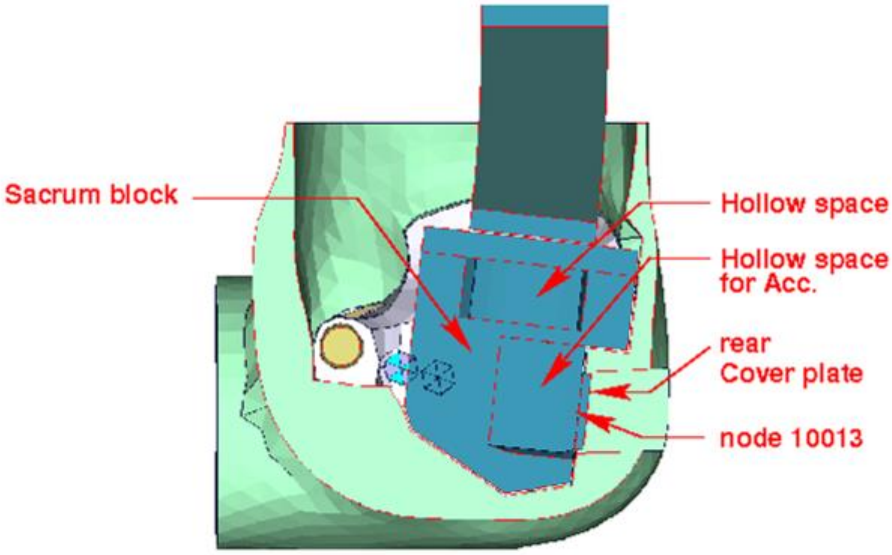


Figure 4: Node for extracting pelvis acceleration

Figure 4 shows a plane cut along the z-x-plane. The accelerometer is mounted in the marked hollow space. Node 10013 is located on the rear cover plate of sacrum block. An accelerometer is defined.

Item	Node-ID	Label	Available components
Pelvis	10013	PELV0000ERAC	Local y-acceleration

Table 12: Pelvis accelerometer node.

3.5 Head acceleration

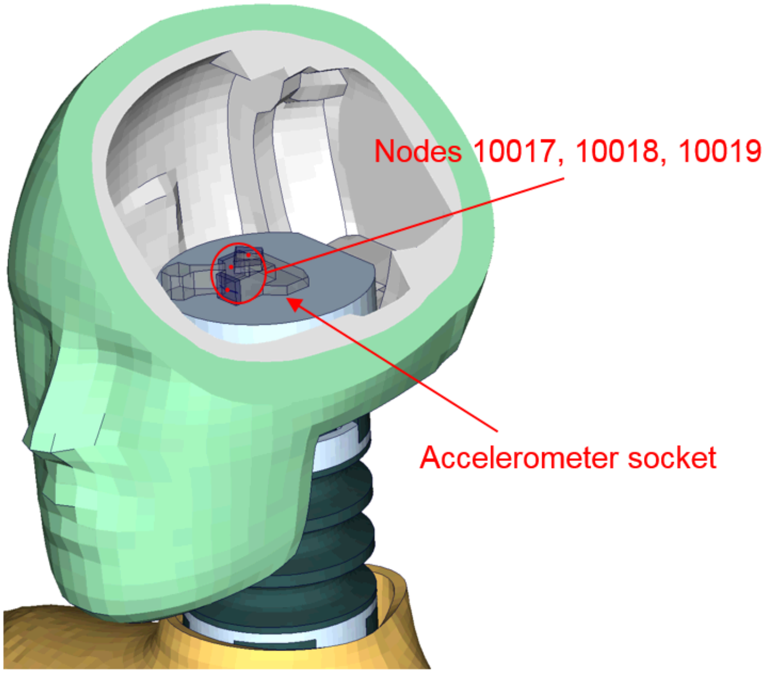


Figure 5: Nodes for extracting head acceleration

Figure 5 shows the head model. Nodes 10017, 10018 and 10019 are located on the accelerometer socket. There is a separate accelerometer at each node.

Item	Node-ID	Label	Available components
Head	10017	HEAD0000ERACX	local x-acceleration
Head	10018	HEAD0000ERACY	local y-acceleration
Head	10019	HEAD0000ERACZ	local z-acceleration

Table 13: Head accelerometer nodes

3.6 Pubic Symphysis force

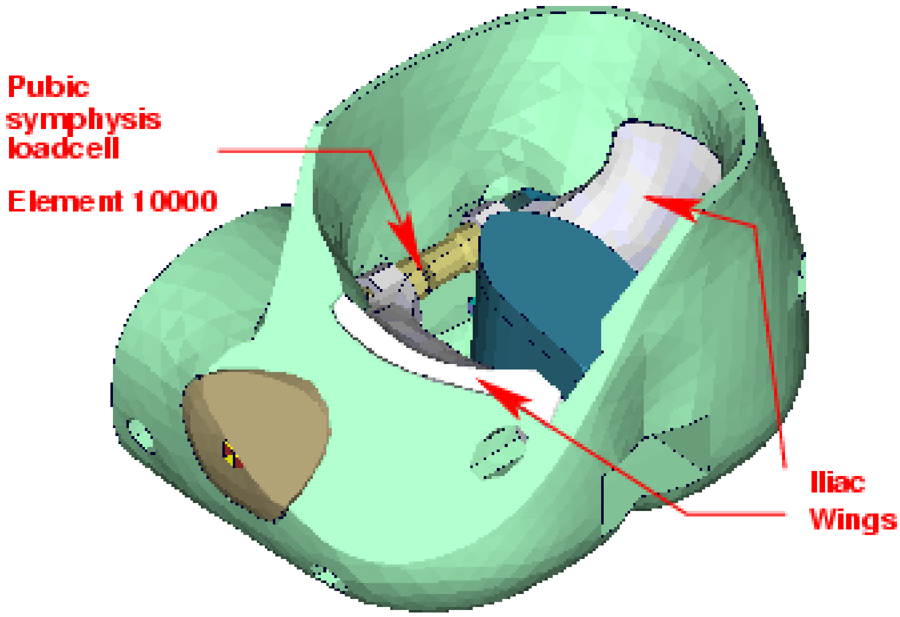


Figure 6: location for extracting signals of pubic symphysis load cell

Figure 6 shows the pubic symphysis load cell. The left iliac wing is connected to the first part of the load cell. The right iliac wing is connected to the second part. Both load cell parts generate under load the force in the connecting element 10000. The pubic symphysis force is the shear-S force of beam element 10000.

Item	Beam-ID	Label	Component
Pubic symphysis force	10000	PUBC0000ER	Shear-S force

Table14: Pubic force beam

3.7 Shoulder force

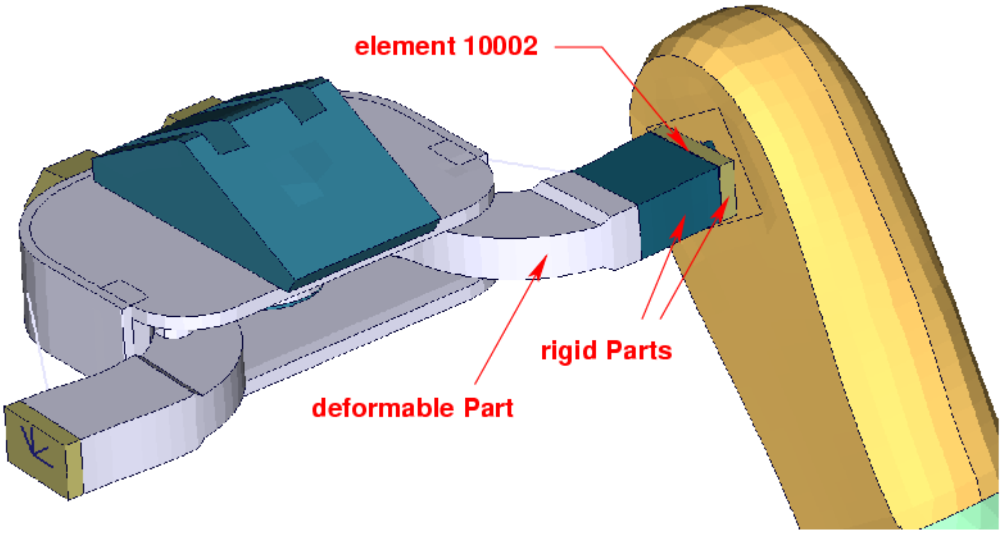


Figure 7: clavicle box with adapted clavicle to measure shoulder forces

Element 10002 which is marked in Figure 7 is a discrete beam with coincident nodes. The clavicle is equipped with load cell. The load cell is represented by a rigid box. The discrete beam is located between the rigid box and the arm adaptor plate. For local determination a local coordinate system is provided. The components are shown in table below.

Item	Beam-ID	Label	Component
Shoulder force x-direction y-direction	10002	SHLDLE00ER	force axial shear-S

Table 15: Shoulder force beam

3.8 Back plate load cell

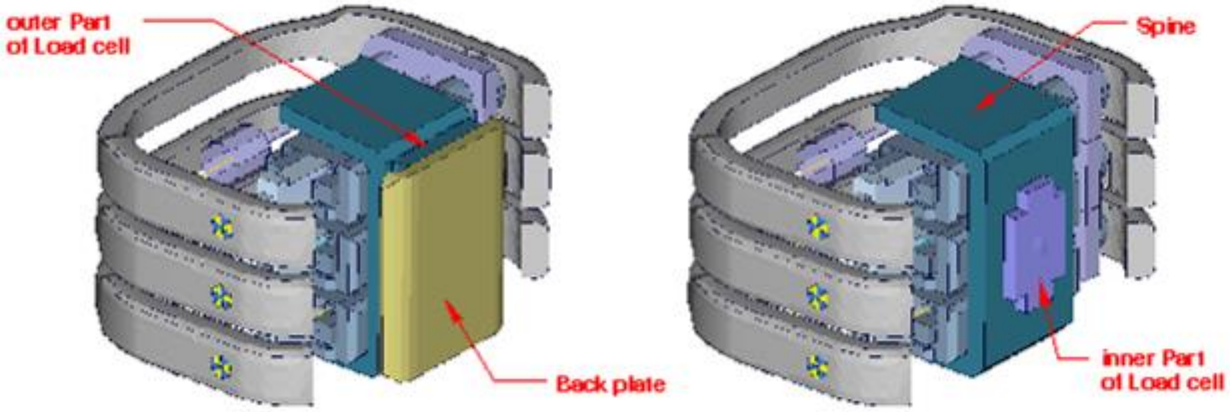


Figure 8: spine box with back plate

Figure 8 shows the spine box from back. The inner part of back plate load cell is connected to spine. The outer part is the adapter to the back plate. A discrete beam between both parts measures the forces and moments.

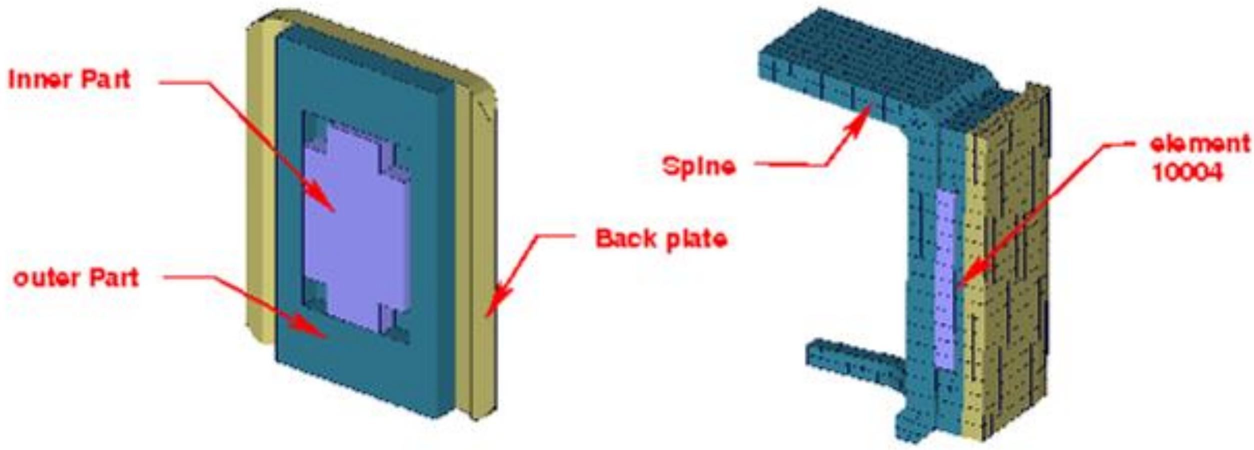


Figure 9: model of back plate load cell

Figure 9 shows the back plate assembly and a plane cut in y-direction. The discrete beam is located between the inner and outer parts of load cell. The local components to determine the forces and moments are shown in table below.

Item	Beam-ID	Label	Component
Back plate forces	10004	BAPL0000ER	force
x-direction			axial
y-direction			shear-S
Back plate moment	10004	BAPL0000ER	moment
About z-direction			moment-T

Table 16: Back plate forces and moment beam

3.9 Neck load cells

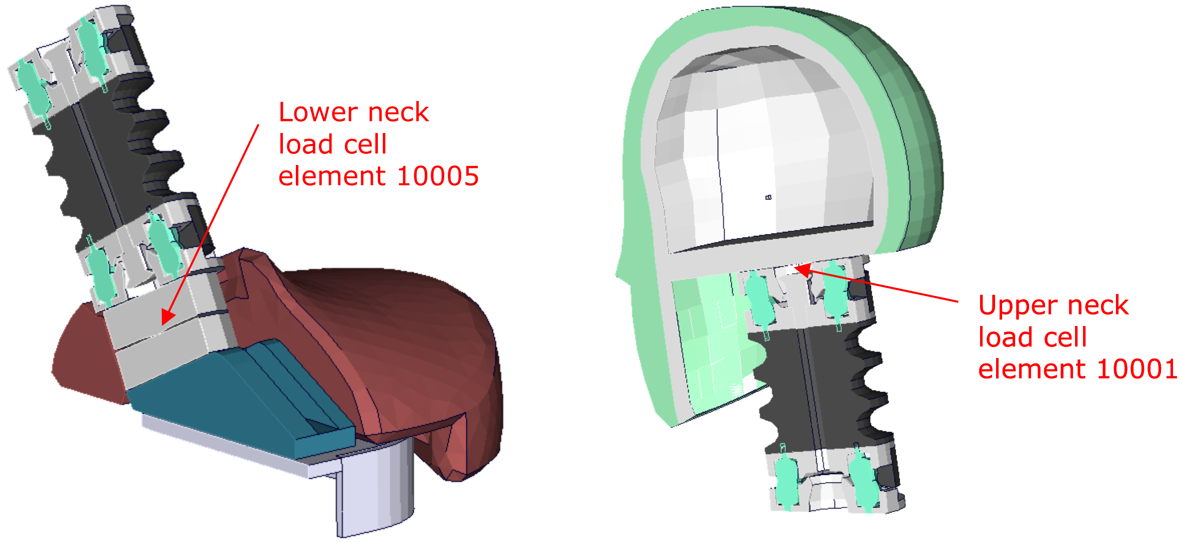


Figure 10: models of lower and upper neck load cell

Figure 10 shows the location of upper and lower neck load cell. Both are discretized as discrete beams. The table below gives details on the extraction of the loads.

Item	Beam-ID	Label	Component
Upper neck force y-direction	10001	NECKUP00ER	force shear-S
Upper neck moment About x-direction	10001	NECKUP00ER	moment torsion
Lower neck force y-direction	10005	NECKLO00ER	force shear-S
lower neck moment About x-direction	10005	NECKLO00ER	moment torsion

Table17: Neck force and moment beams

3.10 T12 load cell (lumbar spine)

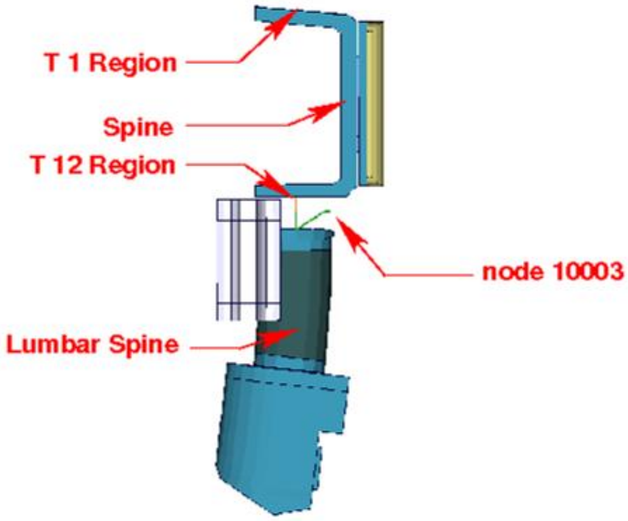


Figure 11: overview spine to sacrum with T12 load cell

Figure 11 shows the T12 area. The upper rigid beam is merged to spine and the lower rigid beam is merged to the upper lumbar spine adapter plate. Between the rigid beams a discrete beam is located to determine the T12- forces and moments. The local directions are shown in table below.

Item	Beam-ID	Label	Component
T12 force y-direction	10006	SPIN1200ER	force shear-S
T12 moment About x-direction	10006	SPIN1200ER	torsion
T12 moment About z-direction	10006	SPIN1200ER	moment-t

Table18: T12 force and moment beam

3.11 Lower lumbar load cell

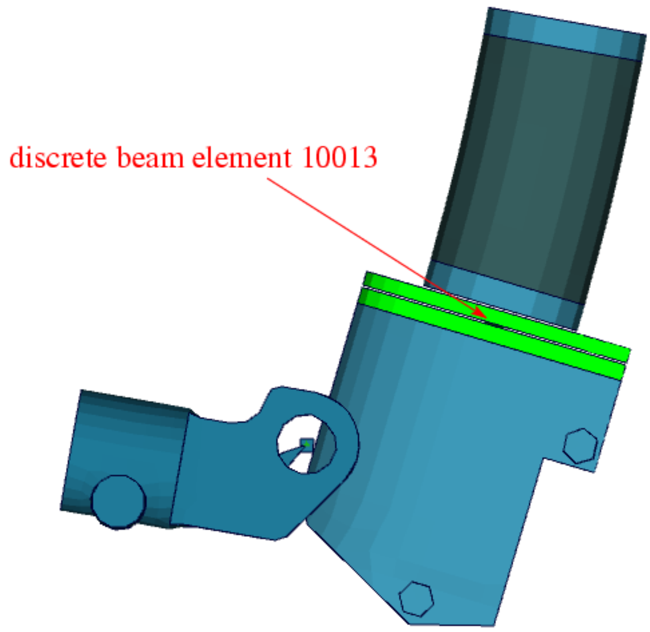


Figure 12: lower lumbar load cell

Figure 12 shows the lower lumbar area. Discrete beam element 10013 located in the lower lumbar spine area can be used to measure forces and moments. The local directions are shown in table below.

Item	Beam-ID	Label	Component
Lower lumbar force y-direction	10013	LUSP0000ER	force shear-S
Lower lumbar moment About x-direction	10013	LUSP0000ER	torsion
Lower lumbar moment About z-direction	10013	LUSP0000ER	moment-t

Table19: Lower lumbar force and moment beam

3.12 Abdominal forces

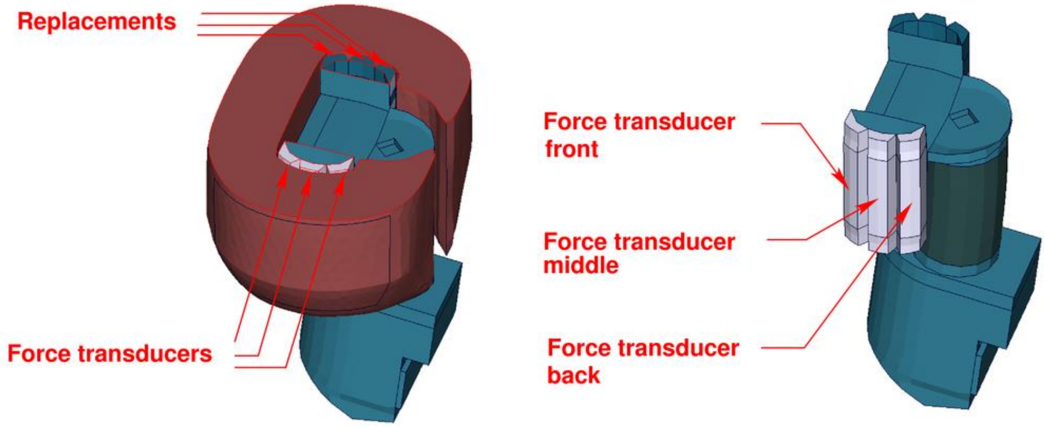


Figure 13: models of abdominal force transducers and replacements

The abdominal forces are determined by three load cells. Figure 13 shows the abdomen region. On the impact side the abdominal carrier is equipped with force transducers. On the other side replacements are located.

Three *CONTACT FORCE TRANSDUCER definitions are used in the model to represent the load cells. The title option is applied to find the interface number in the rcforc. The 3rd contact definition is the front force transducer. The 4th and 5th definition are measuring for the middle and back force. The sum of the three forces is the abdominal resultant force. This is the old way to evaluate the abdomen forces. It is still in the model included to compare the results to older ES-2 Versions.

Remark: A renumbering or adding further contact definitions in the run may change the numbering and has to be considered in Post processing.

Item	Interface-ID	Label	Component
Abdominal force front	Interface 3	ABDOMINAL FORCE – FRONT	magnitude
Abdominal force middle	Interface 4	ABDOMINAL FORCE – MIDDLE	magnitude
Abdominal force back	Interface 5	ABDOMINAL FORCE - BACK	magnitude
Abdominal resultant force	Interfaces 3+4+5		magnitude

Table20: Abdomen interface forces

Since ES-2 version 5.0 there are discrete beam elements for the evaluation of the abdominal forces available. Thus, it is possible to model an uniaxial load cell. This method is recommended to evaluate abdomen force.

Item	Beam-ID	Label	Component
Abdominal force front	10014	ABDOLEFRER	shear-S
Abdominal force middle	10015	ABDOLEMIER	shear-S
Abdominal force back	10016	ABDOLEREER	shear-S

Table21: Abdomen forces beams

3.13 Femur load cells

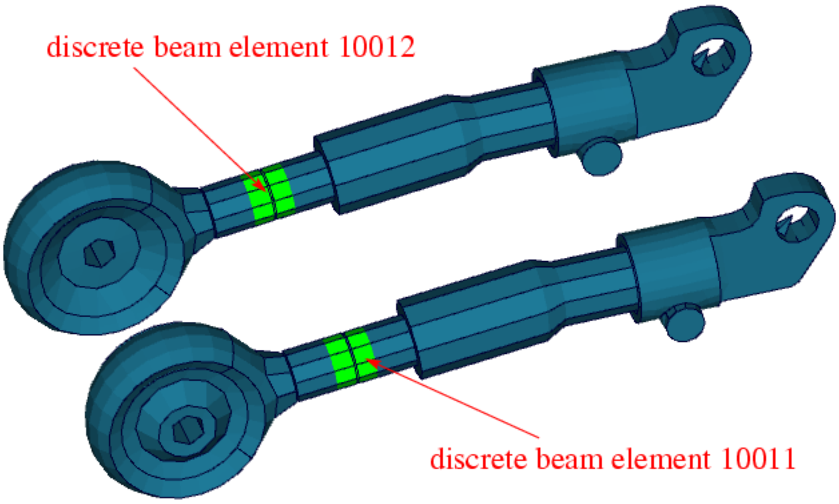


Figure 14: femur load cells

Figure 14 shows the femur area. Discrete beam elements 10011 & 10012 are located in the femur to determine forces and moments. The local directions are shown in table below.

Item	Beam-ID	Label	Component
Femur force left y-direction	10011	FEMRLE00ER	force shear-S
Femur moment left about x-direction	10011	FEMRLE00ER	moment torsion
Femur force right y-direction	10012	FEMRRI00ER	force shear-S
Femur moment right about x-direction	10012	FEMRRI00ER	moment torsion

Table22: Femur forces and moment beams

3.14 Additional force transducer contacts

To understand the kinematics and the load distribution on the dummy in a better way, for some parts additional evaluation contacts are defined. The title option is applied to find the interface number in the rcforc.

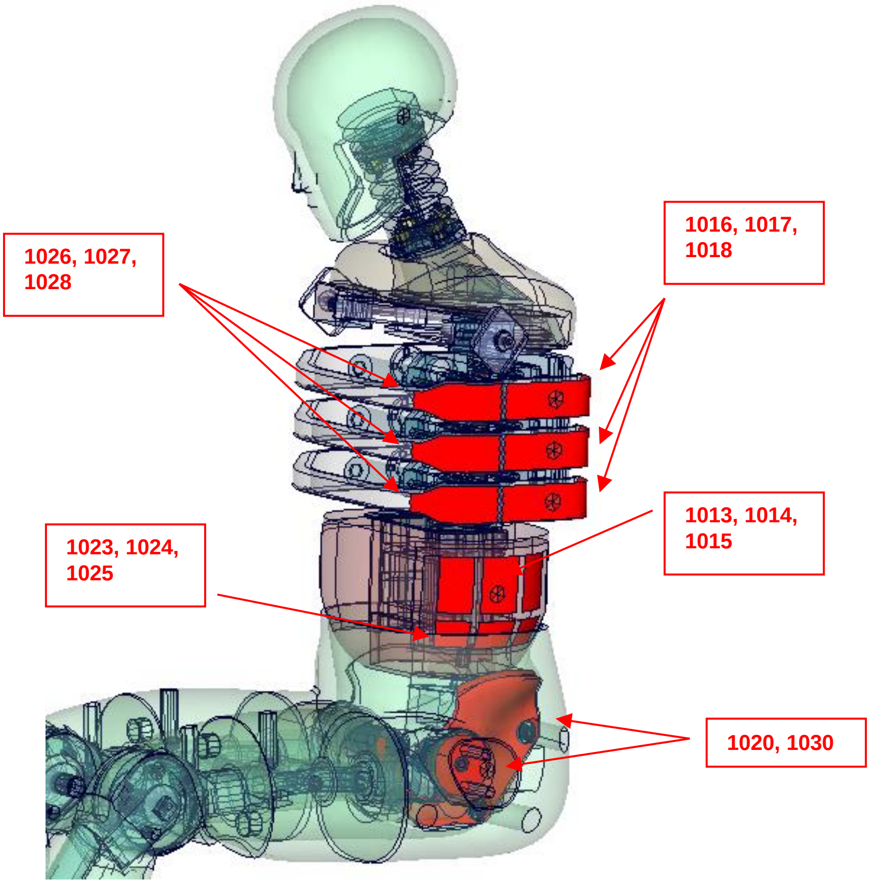


Figure 15: force transducer contacts

Figure 15 shows the area where additional force transducer contacts are defined.

Item	Interface-ID	Label	Component
Upper rib force	1016	RIB FORCE – UPPER RIB	magnitude
Middle rib force	1017	RIB FORCE – MIDDLE RIB	magnitude
Lower rib force	1018	RIB FORCE – LOWER RIB	magnitude
Upper rib front force	1026	RIB FRONT FORCE – UPPER RIB	magnitude

Middle rib front force	1027	RIB FRONT FORCE – UPPER RIB	magnitude
Lower rib front force	1028	RIB FRONT FORCE – UPPER RIB	magnitude
Abdomen to surrounding force front	1013	SURROUNDINGS-TO-ABDOMEN FORCE - FRONT	magnitude
Abdomen to surrounding force middle	1014	SURROUNDINGS-TO-ABDOMEN FORCE - MIDDLE	magnitude
Abdomen to surrounding force back	1015	SURROUNDINGS-TO-ABDOMEN FORCE - BACK	magnitude
Abdomen to pelvis force front	1023	PELVIS-TO-ABDOMEN FORCE - FRONT	magnitude
Abdomen to pelvis force middle	1024	PELVIS-TO-ABDOMEN FORCE - MIDDLE	magnitude
Abdomen to pelvis force back	1025	PELVIS-TO-ABDOMEN FORCE - BACK	magnitude
Pelvis back plate to surrounding force	1020	SURROUNDINGS-TO-PELVIS FORCE	magnitude
Iliac wing to pelvis force	1030	PELVIS-TO-ILIAC-WING LEFT	magnitude

Table23: Additional force transducer contacts

3.15 ES-2re extension forces

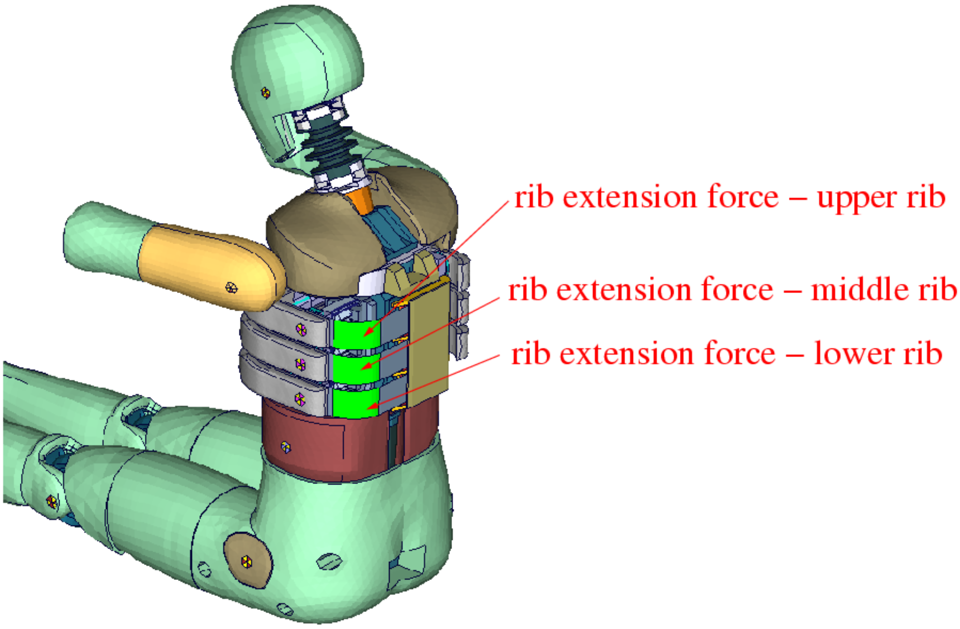


Figure 16: force transducer contacts of rib extension

Three *CONTACT FORCE TRANSDUCER definitions are used in the model to measure impact forces on the rib extensions of ES-2re model. The title option is applied to find the interface number in the rcforc.

Remark: A renumbering or adding further contact definitions in the run may change the numbering and has to be considered in post-processing.

Item	Interface-ID	Label	Component
Extension force upper rib	Interface 6	RIB EXTENSION FORCE - UPPER RIB	magnitude
Extension force middle rib	Interface 7	RIB EXTENSION FORCE - MIDDLE RIB	magnitude
Extension force lower rib	Interface 8	RIB EXTENSION FORCE - LOWER RIB	magnitude
Extension resultant force	Interfaces 6+7+8		magnitude

Table24: rib extension interface forces

4. Accelerometers

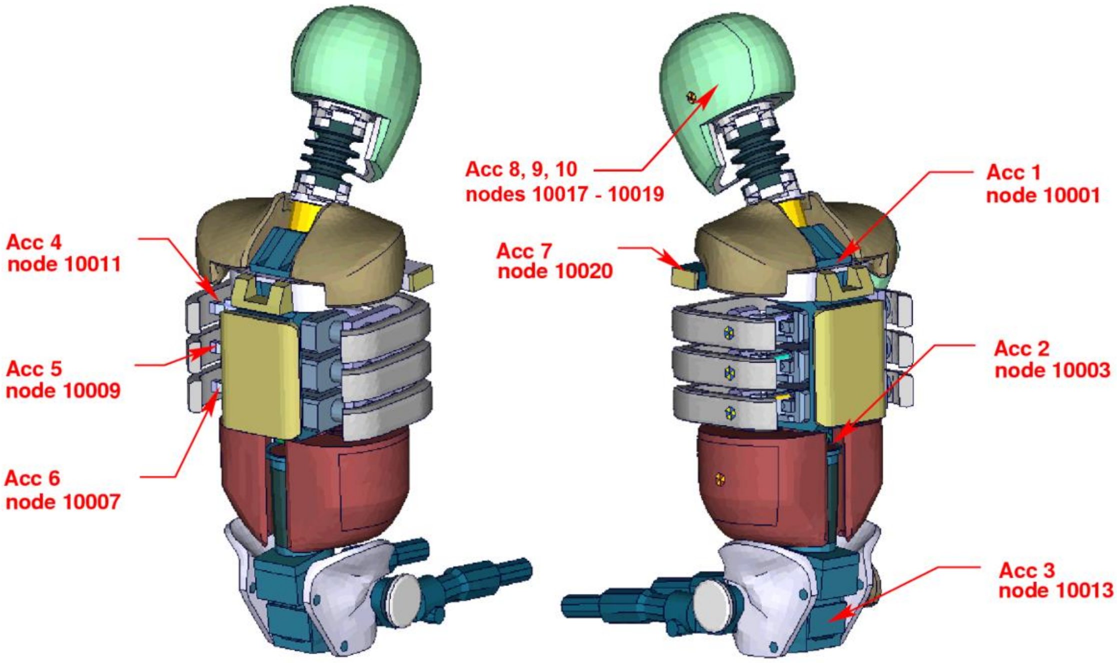


Figure 17: location of the accelerometers

Figure 17 shows the model from several views. The accelerometer and time history nodes are marked.

The accelerometer seven is an additional measurement used for validation. The following table shows the definition of the nodes.

Location	Acc-ID	1st node	Accelerometer Label
Upper spine	1	10001	SPIN0100ERAC
Lower spine	2	10003	SPIN1200ERAC
Pelvis	3	10013	PELV0000ERAC
Upper rib	4	10011	RIBSLEUPERAC
Middle rib	5	10009	RIBSLEMIERAC
Lower rib	6	10007	RIBSLELOERAC
Left arm joint	7	10020	SHLDLE00ERAC
Head	8	10017	HEAD0000ERACX
Head	9	10018	HEAD0000ERACY
Head	10	10019	HEAD0000ERACZ

Table25: ES-2 accelerometers

5. Local coordinate systems

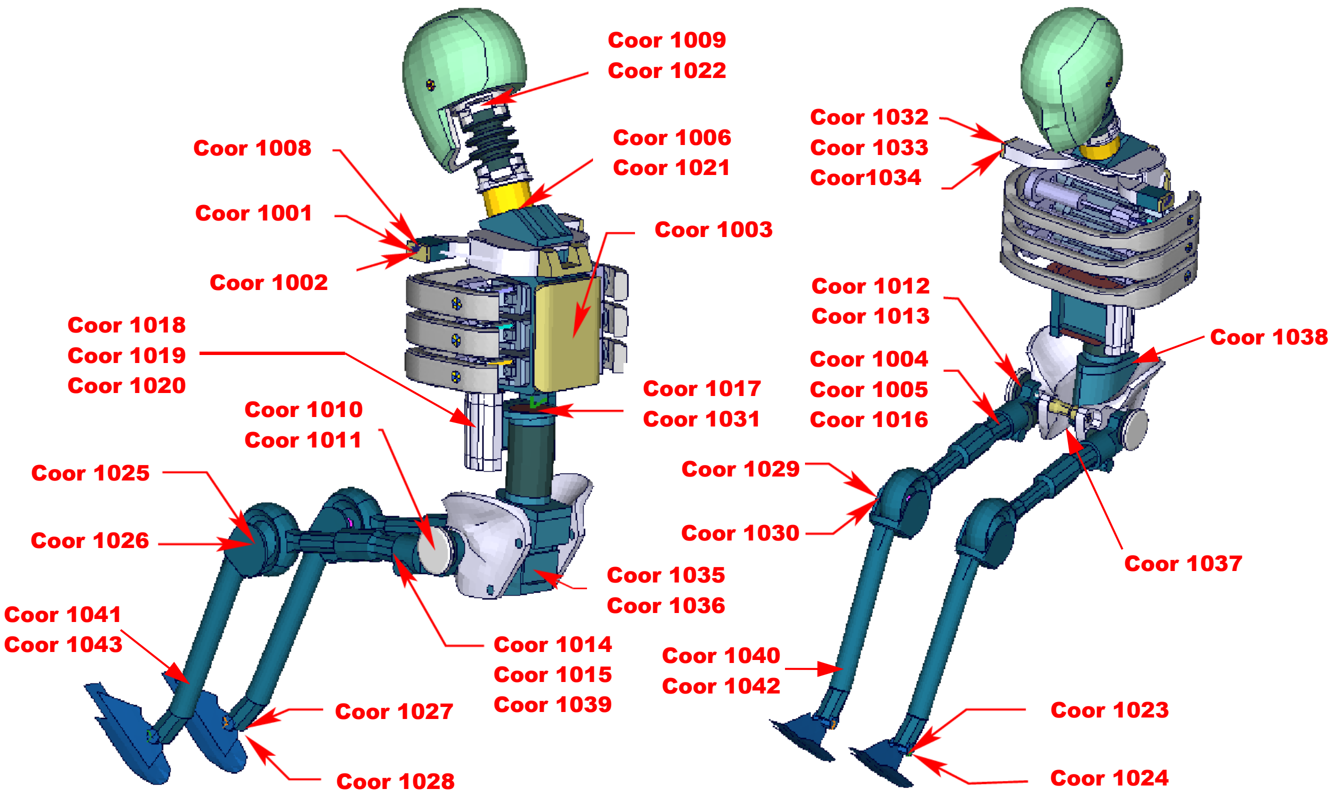


Figure 18: ES-2 skeleton with local coordinate systems

The model uses the local coordinate systems, which are shown in Figure 18, for definitions of joints or output of quantities in local systems.

6. License file

The ES-2 is distributed with an encrypted curve file which needs valid vendor license. The license file is sent to the user with the whole dummy package.

In the encrypted curve file, all load curves are included. There are parameters defined which can be used to offset the numbering of the load curves. The load curves can be scaled by using parameters which are encrypted in the normal ES-2 input. The names of the parameters refer to the table or load curve ID of each material. So if the values of the table ID 1002 are to be scaled then the parameter s1002 must be used.

The principle structure is as follows:

Input data of the ES-2 file:

```
*PARAMETER
$ Load Curve offset
I lcoff          0

$ Load Curve scale values
R sTABID        1.0
             .
             .
             .
```

Input of the encrypted curve file:

```
*PARAMETER_EXPRESSION
I lcTABID    TABID + &lcoff
R eTABID     1.0 * &sTABID


*DEFINE_CURVE
&lcTABID          0       1.0&eTABID            0.0         0.0
          <Values_x>          <Values_y>
             .
             .
             .
```

The encrypted curve file has to be included **in the dummy model main file AFTER the parameter block**.

For the work in a pre-processor, an additional file is delivered:

es2_v8.0_all_units_load_curves_work.key

This work file includes the same input as the encrypted curve file. The only difference is the scaling of the load curves in the work file. The load curves are scaled randomly in a wrong range and they are much too soft to be used for a LS-DYNA simulation. But the file can be used to observe the quality and shape of the material curves.

A LS-DYNA simulation in use of the work file will give wrong results and is very unstable.

For more information about our licensing scheme please read also our flyer **Dummy_Model_licensing_faq_x.x.pdf** which is delivered with the needed vendor license.

7. Incorporating the dummy in vehicle models

7.1 Positioning, tree file

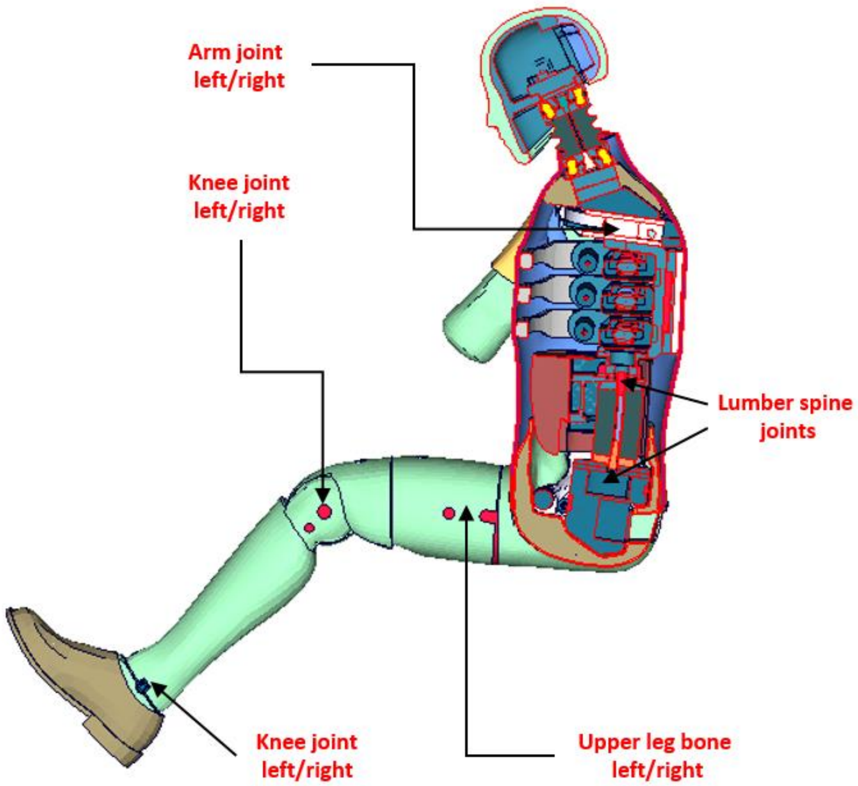


Figure 19: cut through the model with joints

The ES-2 model is delivered with a tree file for the Primer and LS-Prepost pre-processors (may work also for HyperMesh and ANSA, not verified by DYNAmore). This allows the user to position the dummy and adjust the parts according to their degree of freedom. Figure 19 shows the connections of movable parts via tree file.
The accompanying local coordinate systems are shown in Figure 18. All revolute joints are visualized by beams.

Movable parts and revolute joints are:

- Foot, left and right about their ankle joints, in x-, z-axis
  (stop angle x-axis: -30.0 and +30.0 degree)
  (stop angle z-axis: -20.0 and +20.0 degree)
- Lower leg, left and right about their knee joints
  (stop angle y-axis : -25.0 and -90.0 degree)
- Upper leg bone, left and right about x-axis
  (stop angle: -40.0 and +40.0 degree)
- Upper leg bone, left and right about hip joints in y-,z-axis
  (stop angle y-axis: no stop angle)

(stop angle z-axis: -72 and 72 degree)
- Pelvis about its joint, in y-axis
  (stop angle y-axis: no stop angle)
- Lumbar spine about its joint, in y-axis
  (stop angle y-axis: no stop angle)
- Torso about fake joint, in y-axis
  (stop angle y-axis: no stop angle)
- Arm left and right about their arm joints
  (stop angle y-axis: no stop angle)

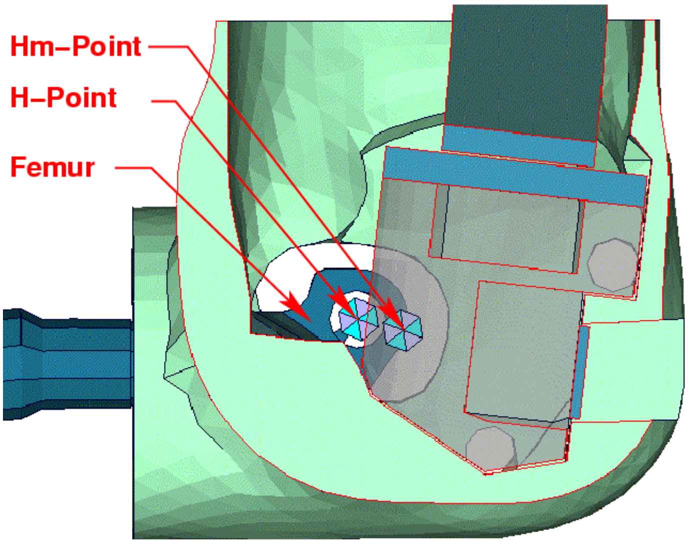


Figure 20: location of H- and Hm-point

Figure 20 shows the location of H- and Hm-Point. More details are given in the "User Manual ES-2; 2002, FTSS Inc.".

Following nodes are used:

- The node 10100 is located at the H-Point.
- The Hm-Point, determined by the HIII Manikin, is located at node 10000.

The coordinates of the H-Point and Hm-Point by pelvis angle 0° are:

Location	x-coor	y-coor	z-coor
H-Point	-21	0	5
Hm-Point	0	0	0

Table 106: H-Point coordinates

In the H-Point of the dummy model two coordinate systems are modeled. These coordinate systems are connected to each other by a spherical joint. One coordinate system is connected to global directions, e.g. only translations are possible, rotations are disabled. The other one is connected to the dummy, so it is possible to measure quickly and easily the pelvis angle of the ES-2 during the positioning simulation. These coordinate systems are also used to determine the initial pelvis angle with Primer.

7.2 Positioning by pre-simulation

Due to the modeling of the dummy jacket with solids elements, in order to avoid penetrations, the rotation of the arm has to be done by a pre-simulation. Also, if the upper legs are rotated at the hip joints, initial penetrations could occur. For this reason, it is recommended to position the upper legs by a pre-simulation.

DYNAmore developed a new positioning script for the pre-simulation of the ES2(re) which is very easy to use. There are only a few steps necessary to achieve a correctly positioned dummy model. In order to run the pre-simulation, the positioning script <psg_vx.x_DYNAMORE_Dummys> is delivered together with the dummy model.

The first step is the positioning of the ES2(re) model by using a preprocessor of your choice. Don’t worry about the penetrations and highly distorted elements.
The second step is to save this positioned ES2(re) as a new model. Include your license file into the new model.
In the next step, use the delivered positioning script to generate a pre-simulation input for LS-DYNA. The script needs both the original and the target position of the dummy.

Run

psg_vx.x_DYNAMORE_Dummys –d dummy_pos_origin.key –t dummy_pos_target.key

The last step is to run the generated input in LS-DYNA and use the results.

7.3 Measuring of pelvis and torso angle

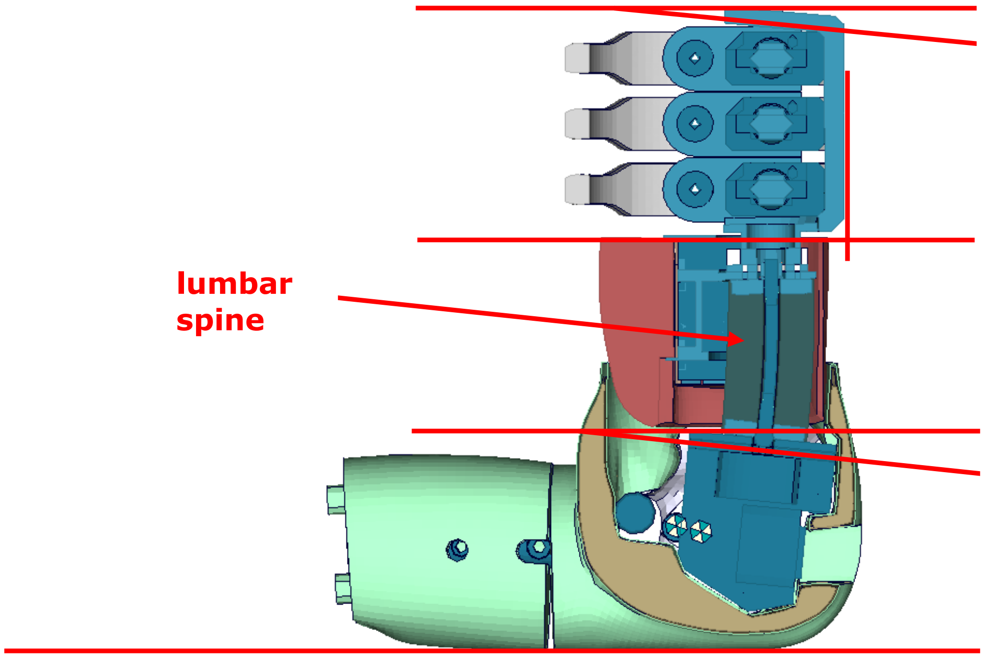


Figure 21: angles of important edges of the ES-2 dummy

Figure 21 shows the model in an upright position. The sacrum block and the spine box are rotated according to a 3D measurement of the fully assembled model.
There are different ways to measure the pelvis- and torso angle in the hardware model.

Angle	Device	Angle in upright position
Pelvis angle	Tilt sensor	6.5°
	H-Point device	0.0°
Torso angle	Tilt sensor	5.0°
	Measure at back plate	0.0°

Table 27: dummy angles

In the software model following parts should be used to identify pelvis- and torso angle.

Angle	Parts	Angle in upright position
Pelvis angle	Between PID 413 & 415	0.0°
Torso angle	Measure at back plate PID 106	0.0°

Table 28: dummy model angles

7.4 Numbering

- Nodes in the range of 10.000 to 11.000 are used for joints, accelerometers, etc. definitions.
- Nodes with node IDs above 11.000 are used only in *NODE and *ELEMENT cards.
- Elements in the range of 10.000 to 11.000 are used for history, discrete elements, etc. definitions.
- Elements with IDs above 11.000 are used only in *ELEMENT cards.

7.5 Contact definition

Dummy to Vehicle and Seat:

For the contact of the dummy model to the vehicle and the seat an automatic surface to surface contact is proposed. For this contact definition a property set (*SET PART, id: 1500) has been prepared in the dummy input-file. This property set includes all properties of the ES-2(re) model which are necessary for the dummy to environment contact definition.
The usage of a single surface contact is not recommended. This might interfere with the contact definitions of the dummy model itself. To remove the dummy model from used automatic single surface contact a second property set (*SET PART, id: 1501) has been prepared. This property set includes all properties of the dummy model, so it can be added easily to a used exclude list of the automatic single surface contact for whole vehicle.

The following figure depicts properties used in property sets 1500 & 1501:

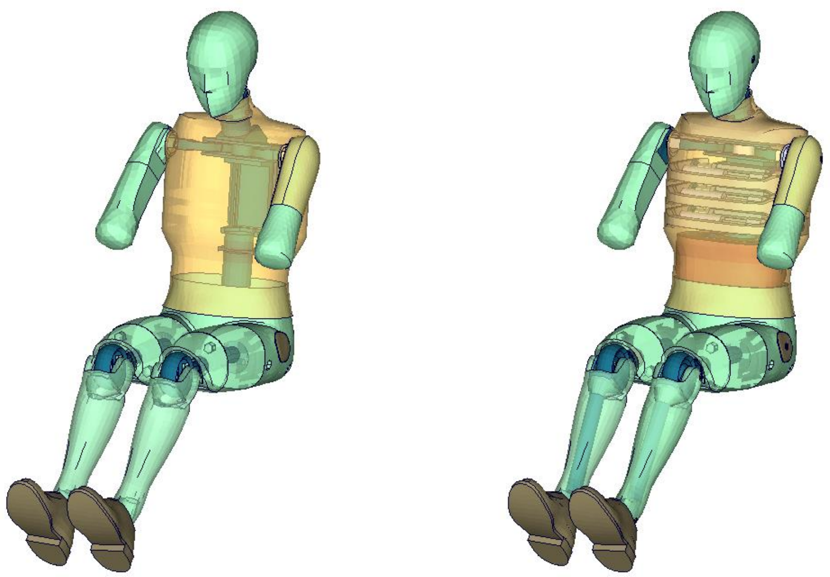


Figure 22: parts used in contact definition

Optional Contact Shells:

A separate property (PID 740) has been defined. This property is used for nullshell elements closing physical gaps of the dummy model (for example between pelvis and jacket). DYNAmore prepared a separate include file. This include file is called es2_v8.0_nullshells.inc, it includes nullshell elements of property 740. These nullshells can be helpful for some contact problems of dummy to environment contact. The usage of this contact shells is optional and will not change the results of the ES-2 barrier tests.

7.6 Additional remarks

- The modification of the *CONTROL cards of the dummy file may have an influence on the performance and robustness of the model. Therefore the *CONTROL cards of the dummy models are proposed for integrated simulations as well. Important flags on LS-DYNA control cards:
    - CONTROL ACCURACY flag INN=2
    - CONTROL BULK VISCOSITY flag TYPE=-1
    - CONTROL SHELL flag ESORT=1
    - CONTROL SOLID flag ESORT=1
    - CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS
- If the CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS is erased from the model the simulation time in large models can be two or three times longer. It is strongly recommended to use this control card in MPP simulations.
- The model should only be used with a time step size of 0.9 microseconds or less!
- If a model for right side impact is needed, please contact DYNAmore. RHD models in both systems of units are available.
- All nodes are connected to an element, except the third beam nodes of the beam elements.
- No mass less nodes are present in the input file of the dummy except the third beam nodes of the beam elements.
- The model is free of initial penetrations.

8. Release notes from v7.0 to v8.0.2

The following major modifications are made:

8.1 Modifications from v8.0.1 to v8.0.2

- fixed velocity node output in database history

8.2 Modifications from v8.0 to v8.0.1

- fixed head back cover position for ES2
- removed initial penetrations

8.3 Modifications from v7.0 to v8.0

The modifications are separated in geometrical, non-geometrical and additional modifications.

8.3.1 Geometrical modifications

- New mesh for dummy neck and buffers to increase bending behavior of the neck

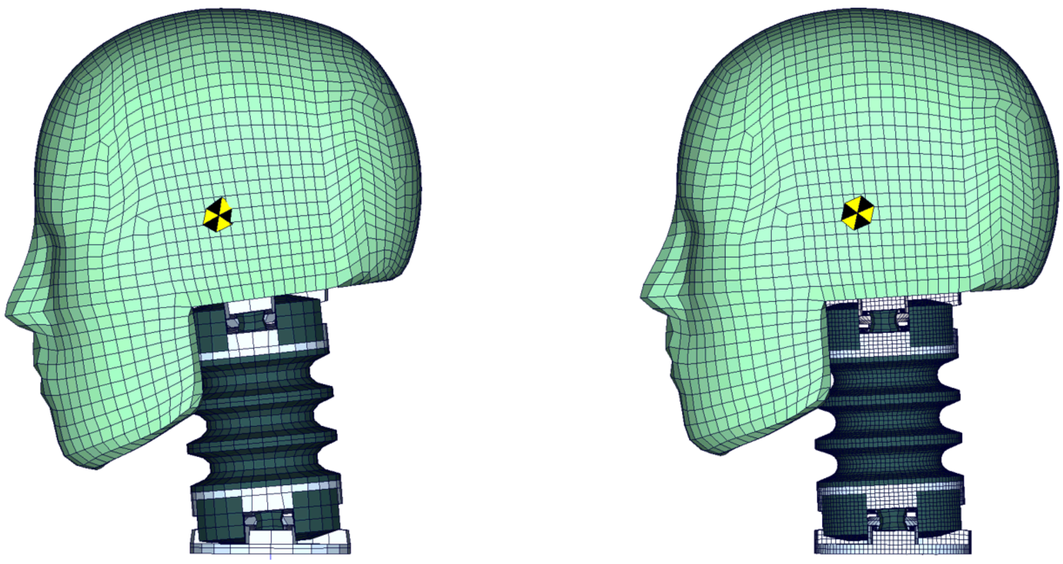


Figure 23: Dummy head and neck ES-2 v7.0 (left) and v8.0 (right)

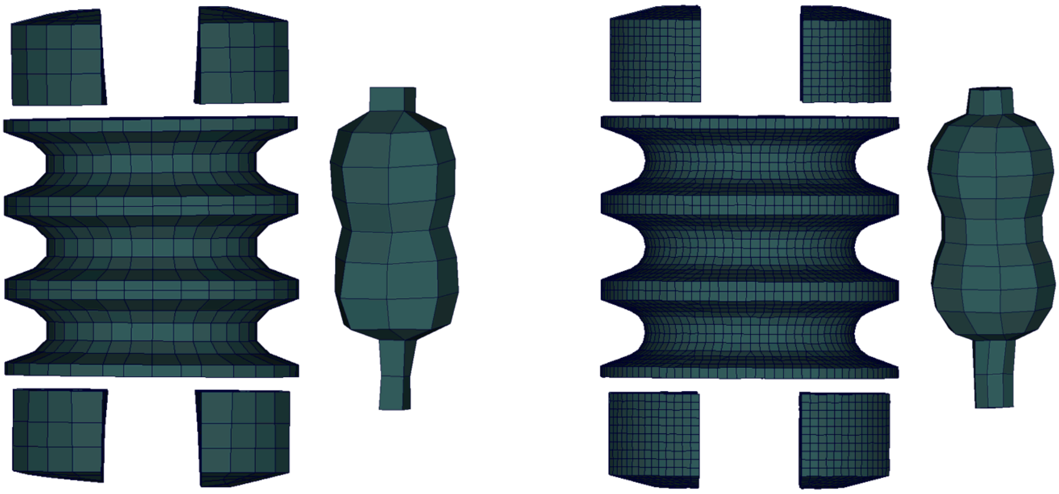


Figure 24: Dummy neck mesh ES-2 v7.0 (left) and v8.0 (right) detail

- New mesh for dummy iliac

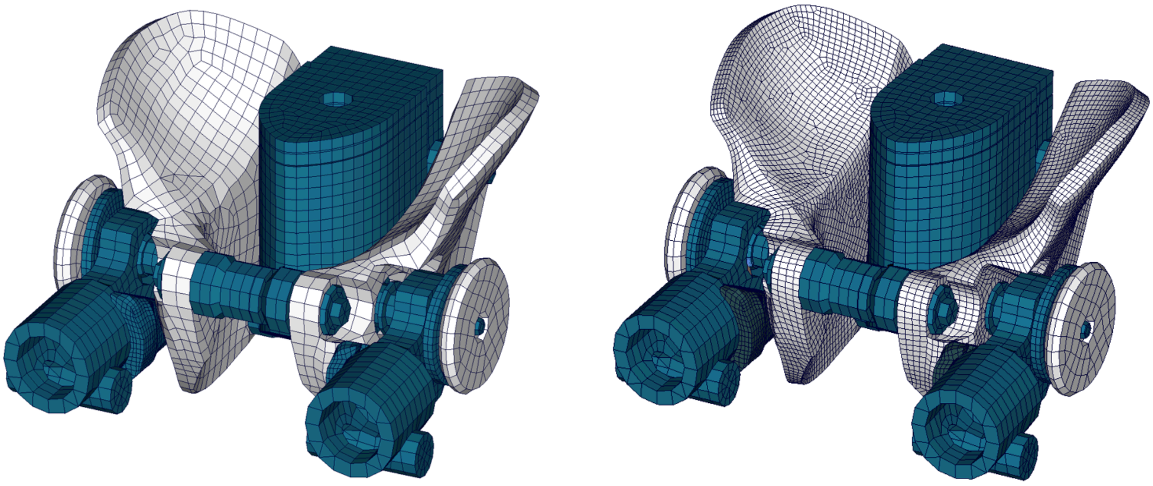


Figure 25: Iliac overview ES-2 v7.0 (left) and v8.0 (right)

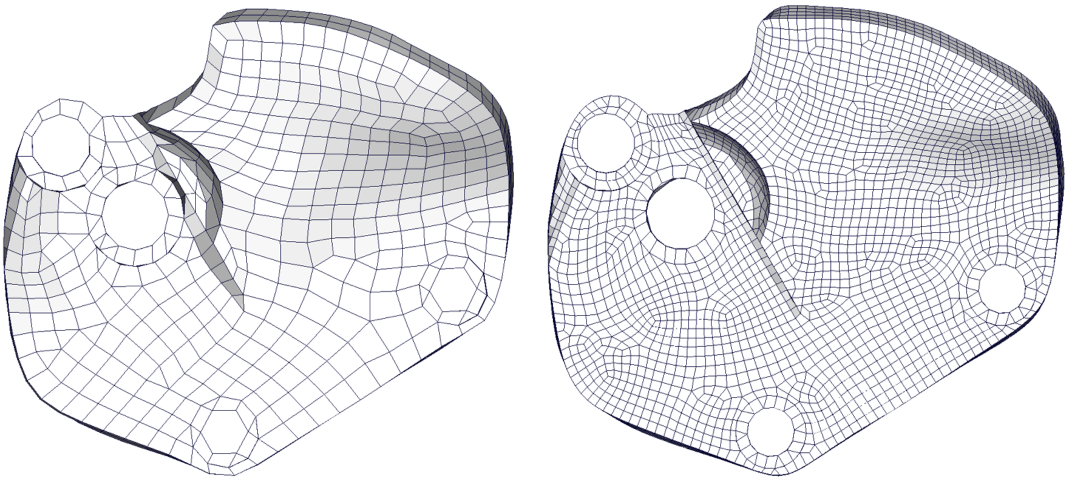


Figure 26: Iliac mesh ES-2 v7.0 (left) and v8.0 (right) detail

8.4 Non-geometric dummy model modifications

- Separate positions for head-accelerometers for more realistic head-accelerations

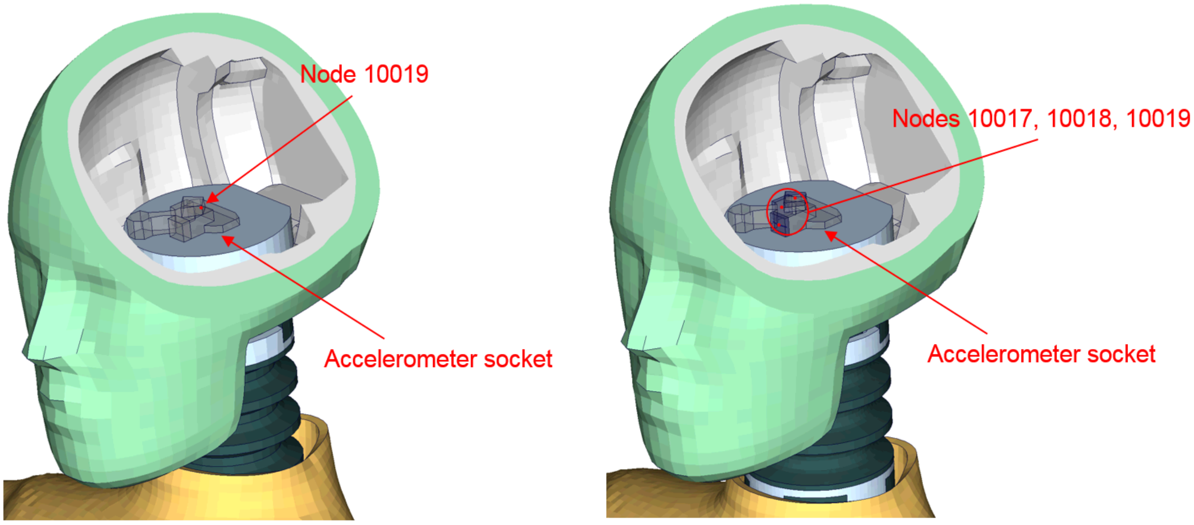


Figure 27: Head accelerometer positions ES-2 v7.0 (left) and v8.0 (right)

- Upper leg bone, left and right about hip: stop angle of z-axis increased to -72/72 degrees

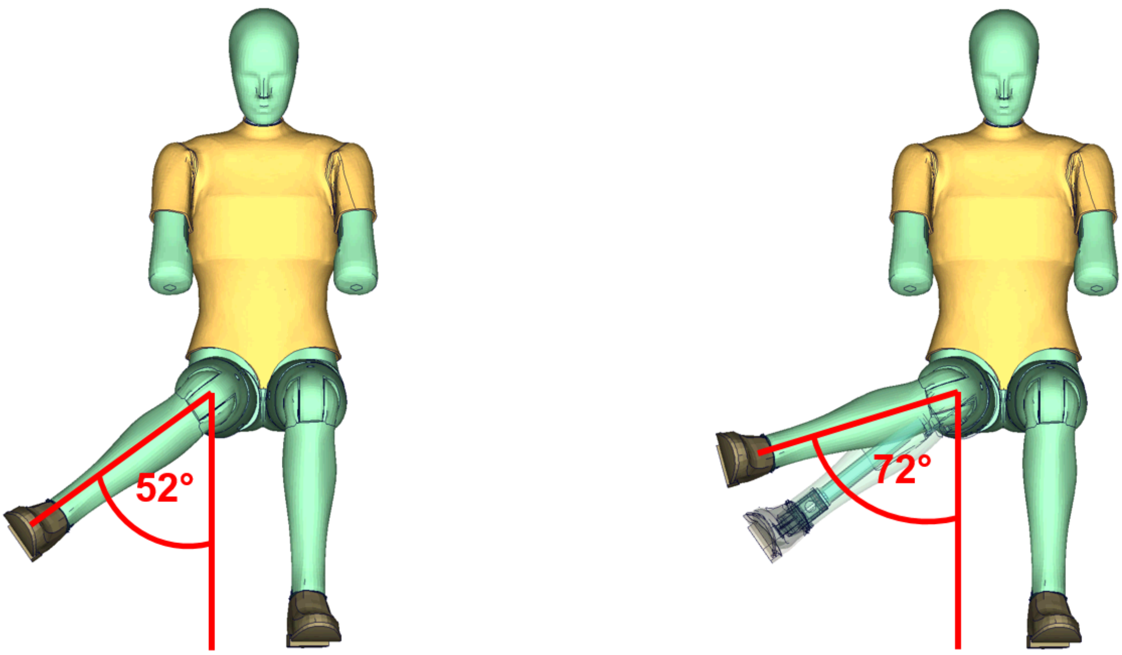


Figure 28: Limit of upper bone z-angle of ES-2 v7.0 (left) and v8.0 (right)

- Abdomen-, neck-, pelvis- and iliac-materials adjusted
- Neck-contact adjusted
- Joint-Stiffness adjusted

8.5 Additional remarks

- Validation and calibration test models were improved
- New sled-test for validation was added (ARP-sled-test)

9. Limitations and further work

Chapter 9 of the FE-manual describes the conducted component tests and the corresponding model performance. There is not much space left for improving the model on component level.
For the following releases DYNAmore plans to include all gathered user feedback of ES-2 v8.0 and older. In addition to that ongoing enhancements of the barrier test performance will be done.

10. Performance on component level

10.1 Component Tests

10.1.1 Arm Test

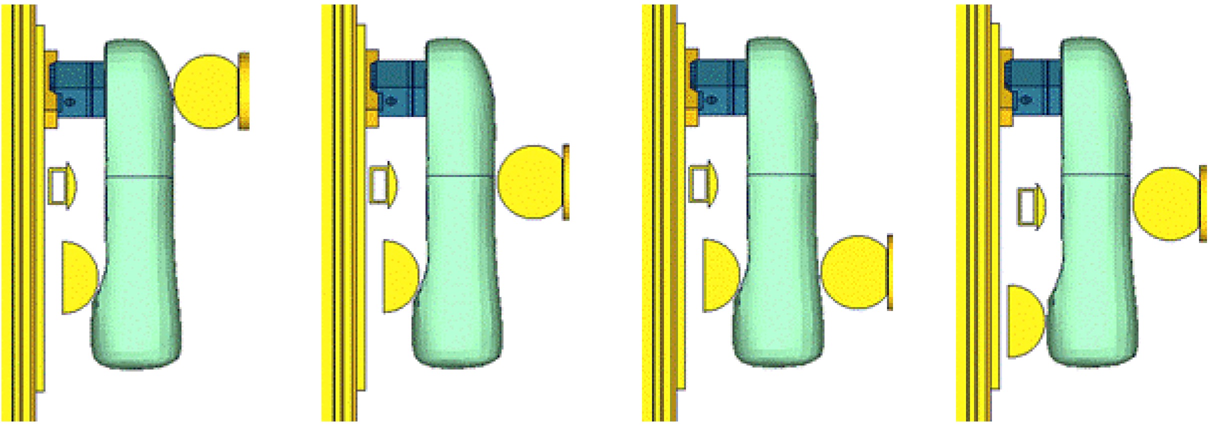
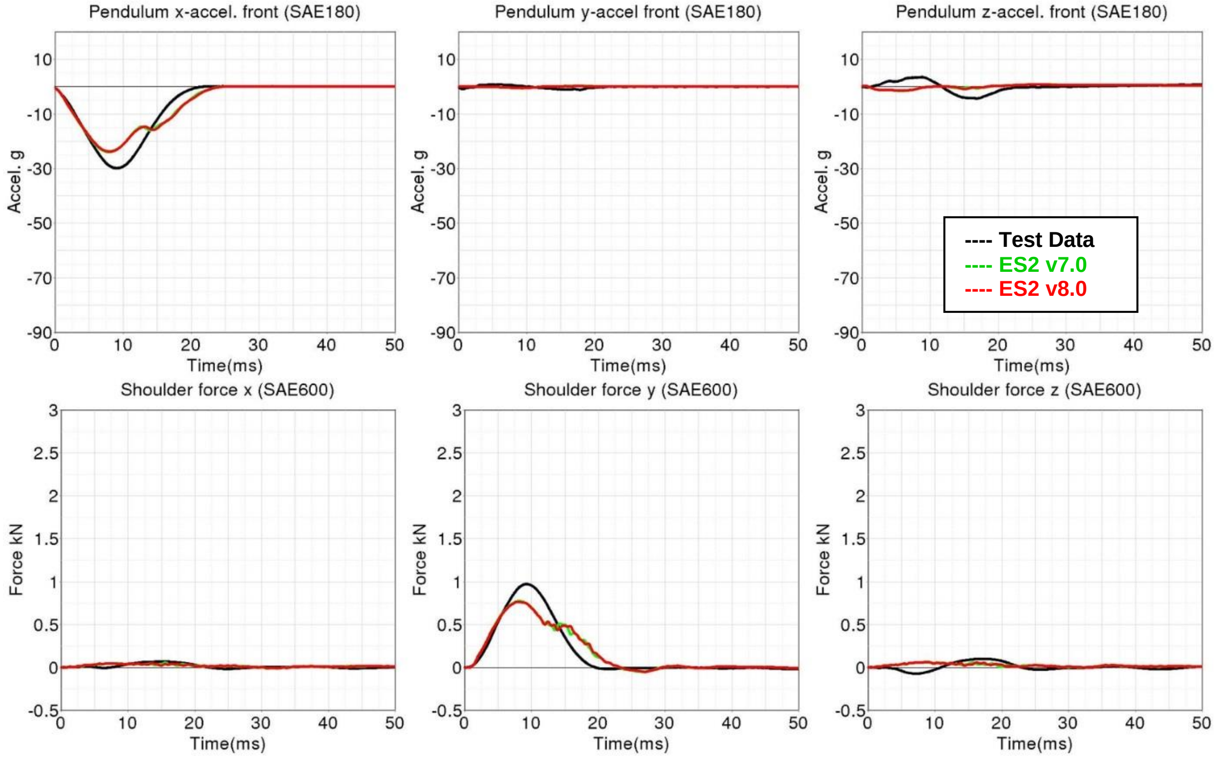


Figure 29: Test setups for Arm test

The arm of the ES2_v5.0 and higher now has an arm bone modeled with solids and a new mesh for the arm flesh. The bone and arm foam are separated in the arm. We also have a completely new modeled arm joint and a new mesh for the load cell. The test setup for the arm test is shown in the figure above. The arm is impacted with a pendulum at three different positions with two different velocities each. An additional modified configuration is used wherein the arm is impacted at the mid-position with two velocities.

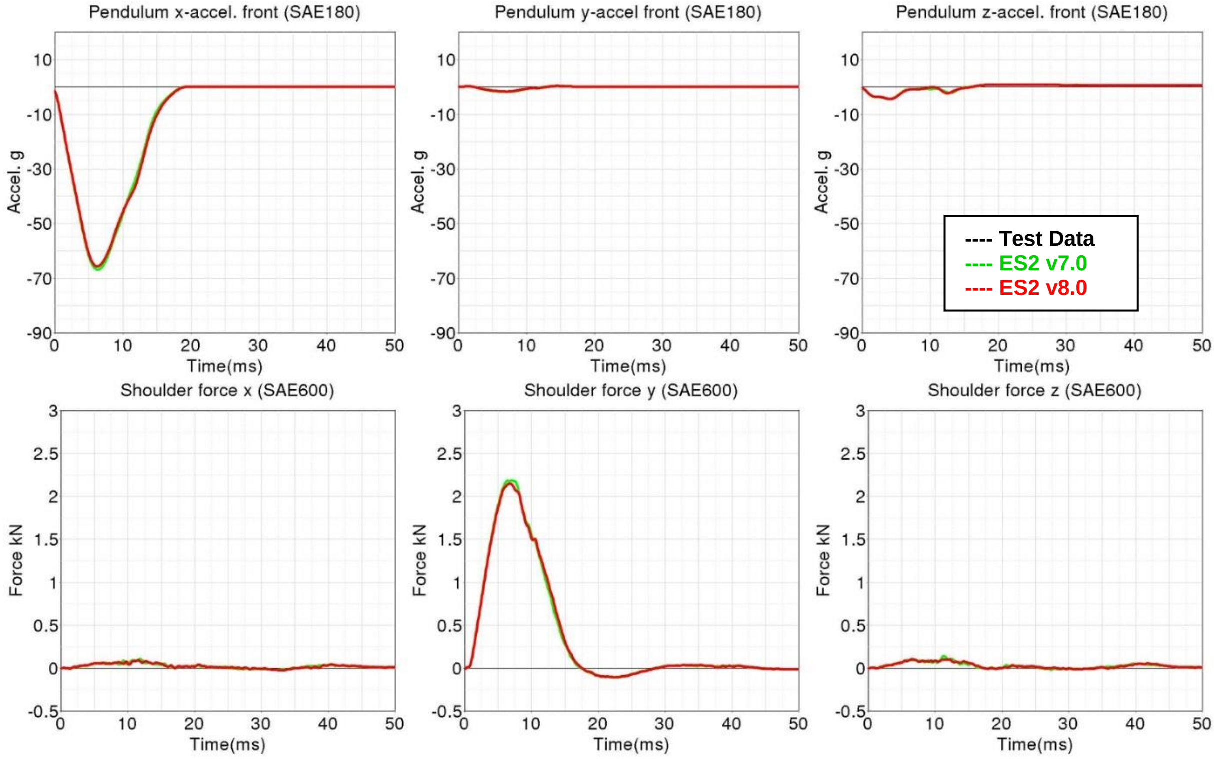
Results for top impact, low velocity

Z1V1



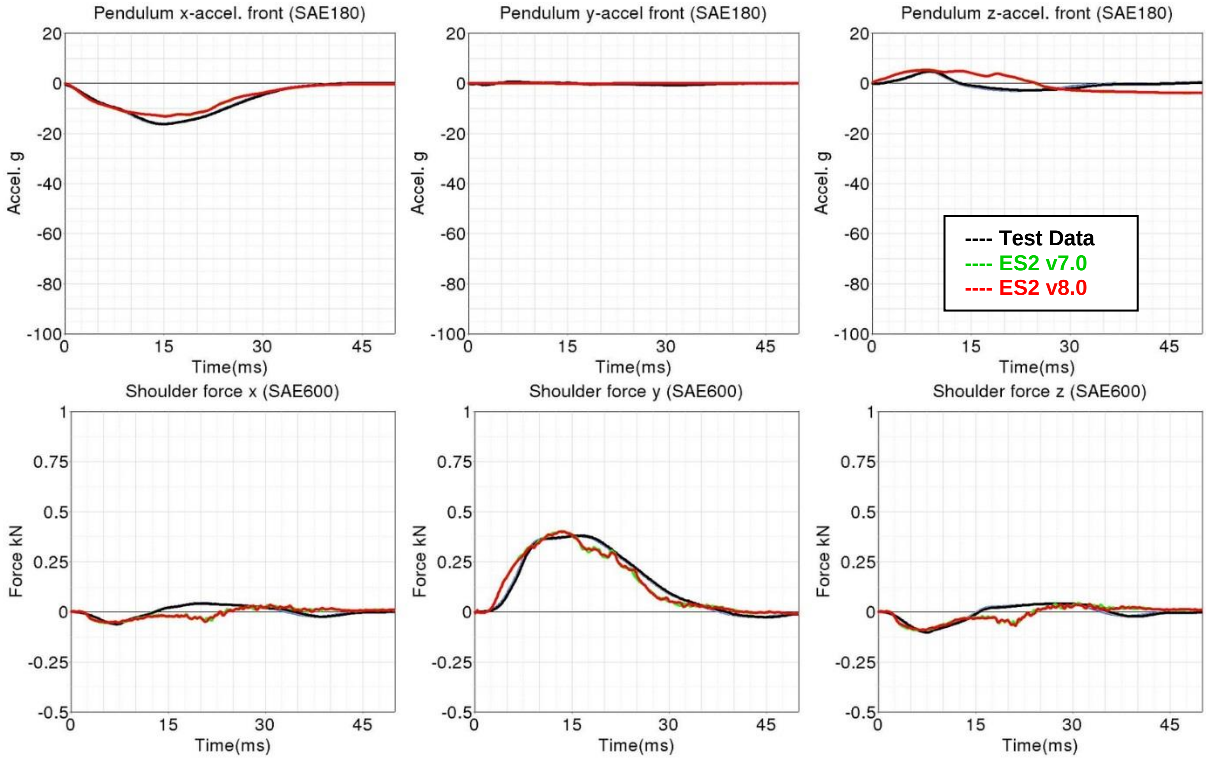
Results for top impact, high velocity

Z1V2



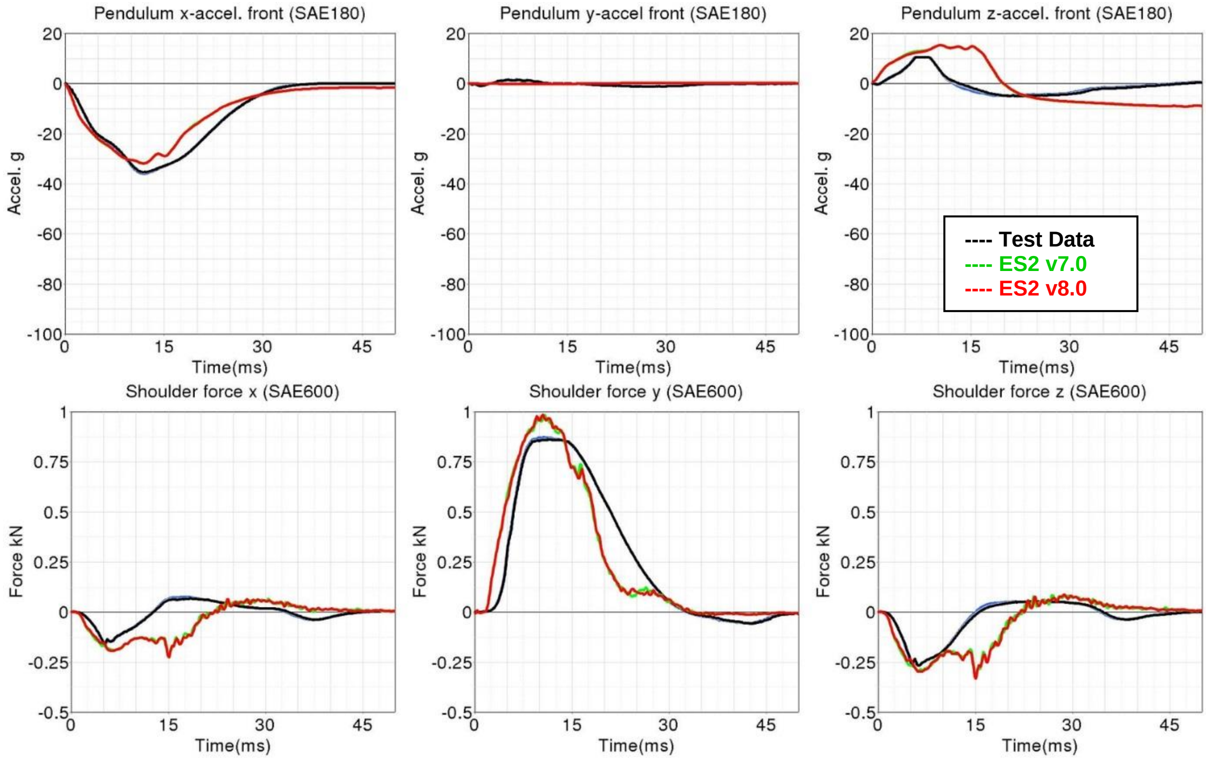
Results for mid-position impact, low velocity

Z2V1

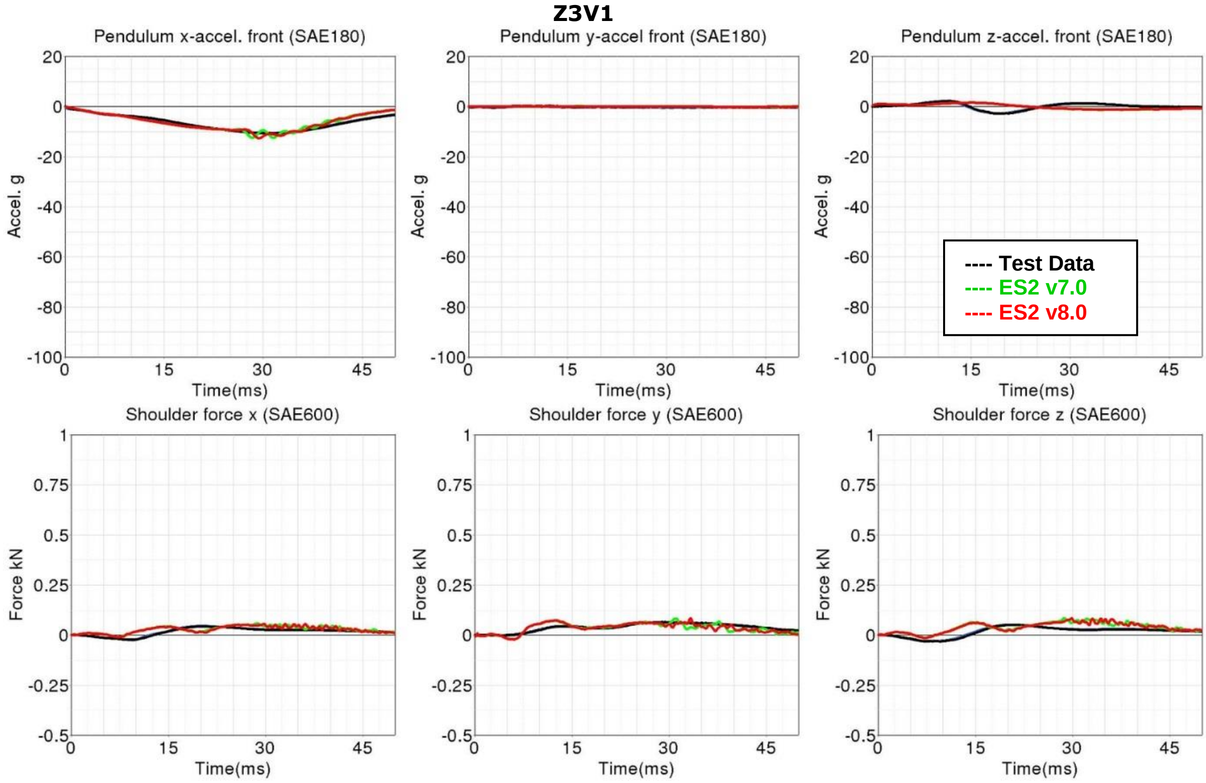


Results for mid-position impact, high velocity

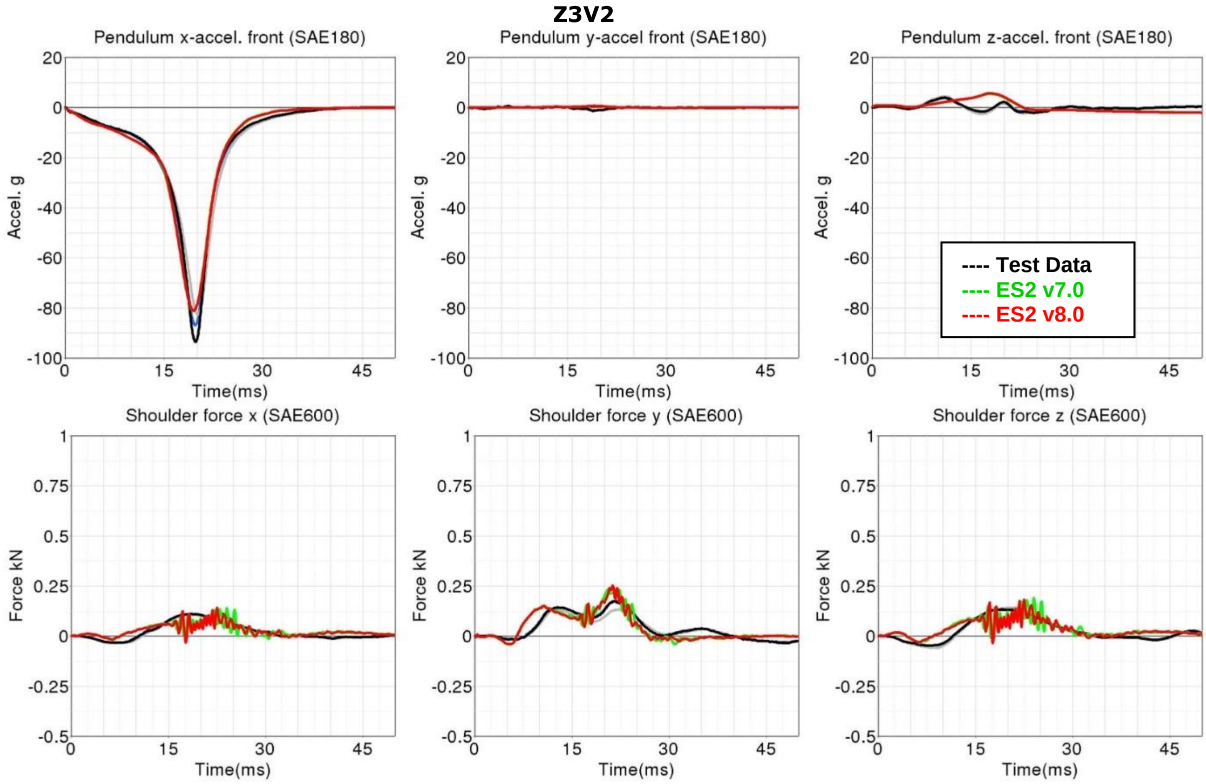
Z2V2



Results for bottom impact, low velocity

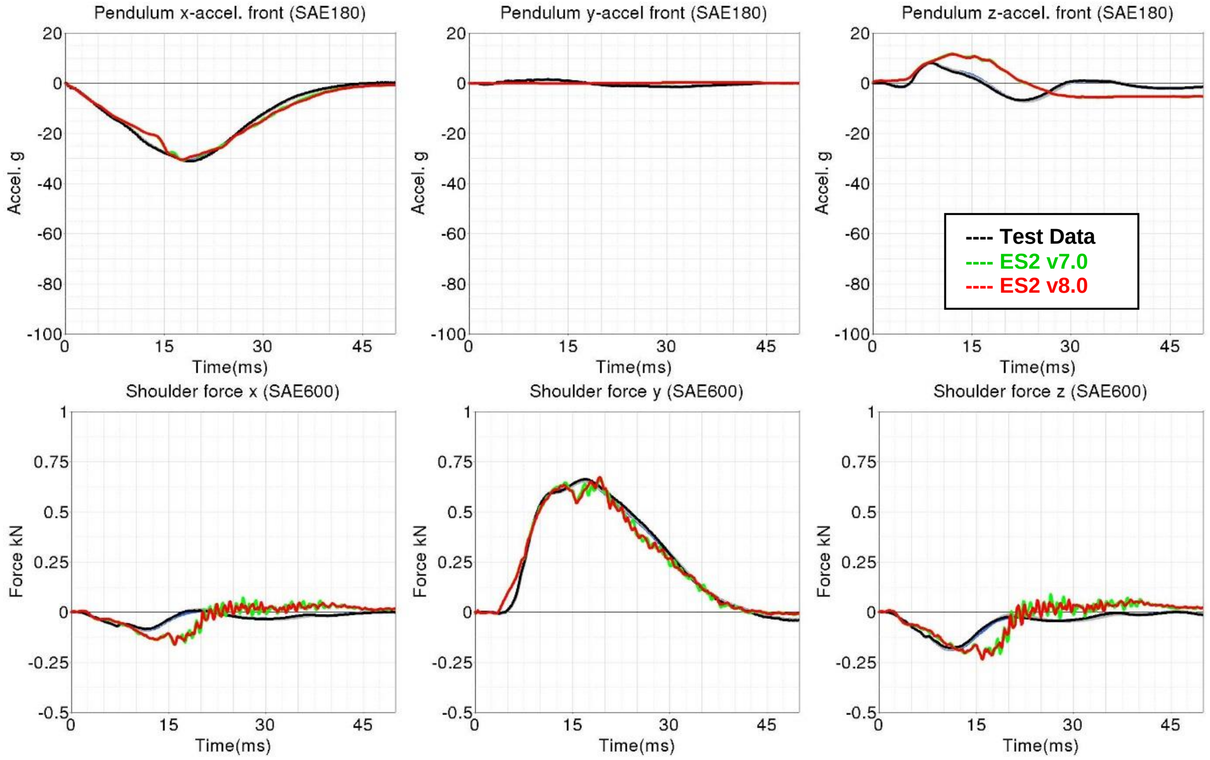


Results for bottom impact, high velocity



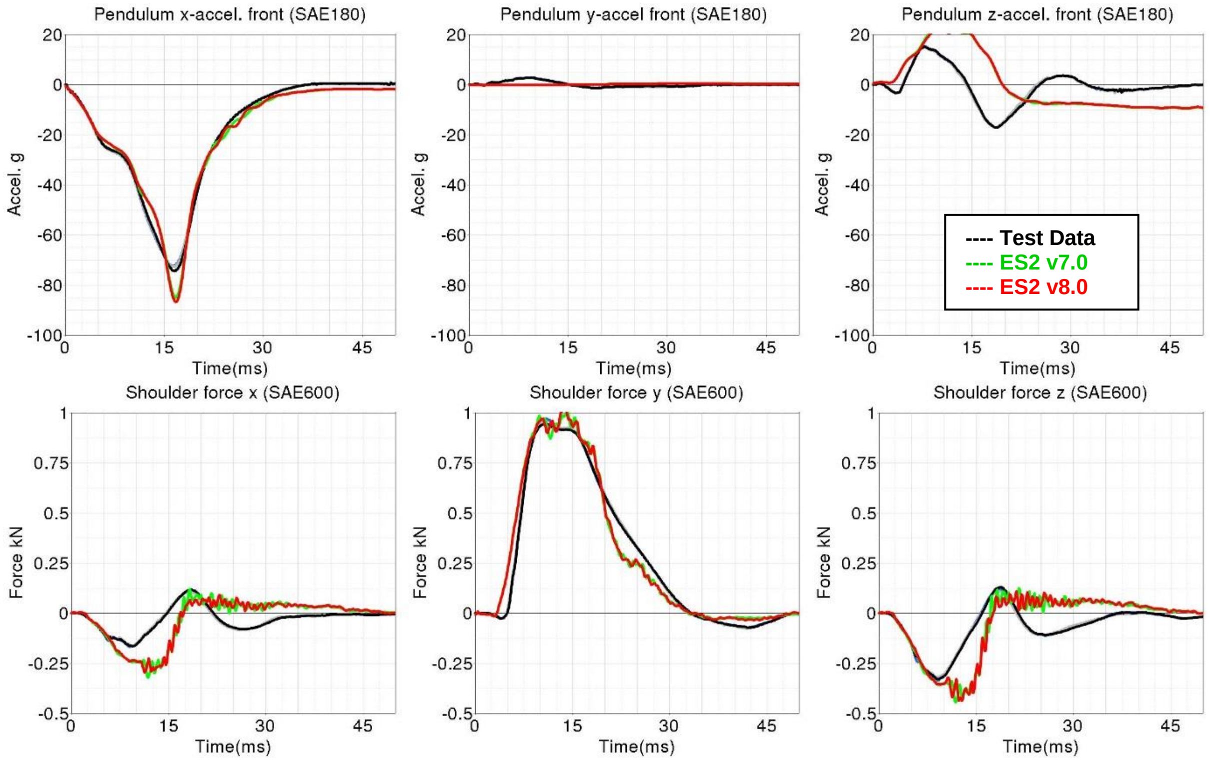
Results for mid-position impact, low velocity (Add. configuration)

Z2V2E



Results for mid-position impact, high velocity (Add. configuration)

Z2V3E



10.1.2 Clavicle test

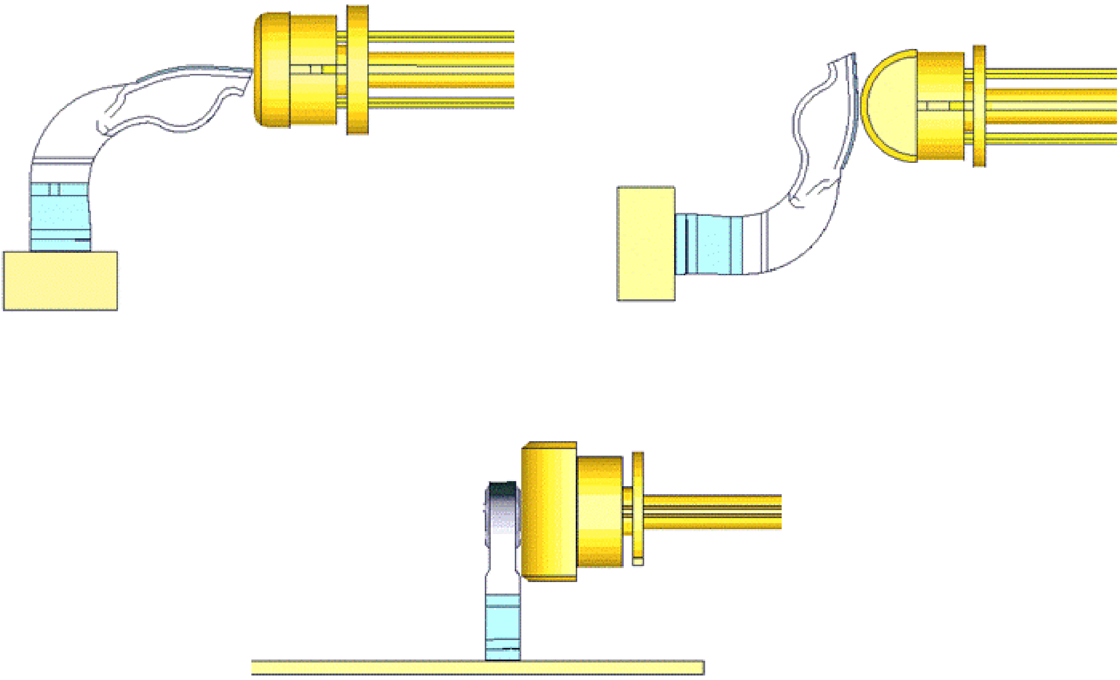
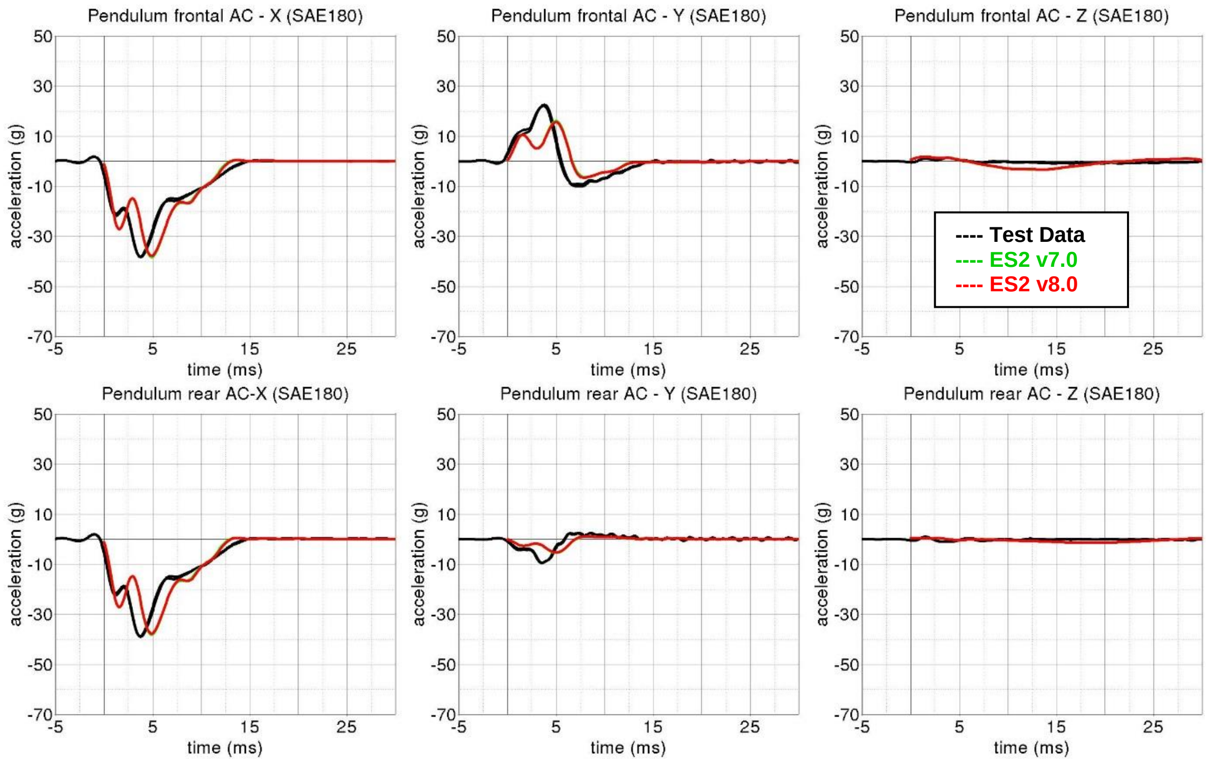
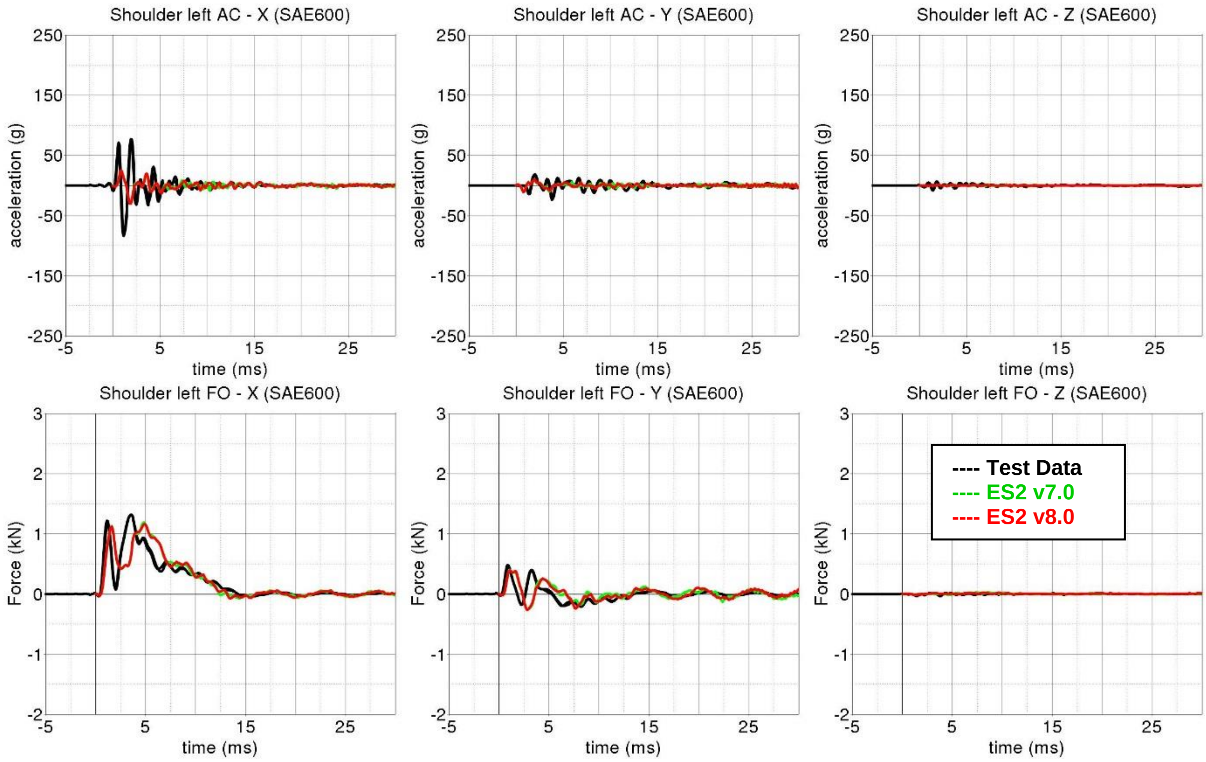


Figure 30: Clavicle test: Pendulum impact on Clavicle in x- , y- and z-direction respectively

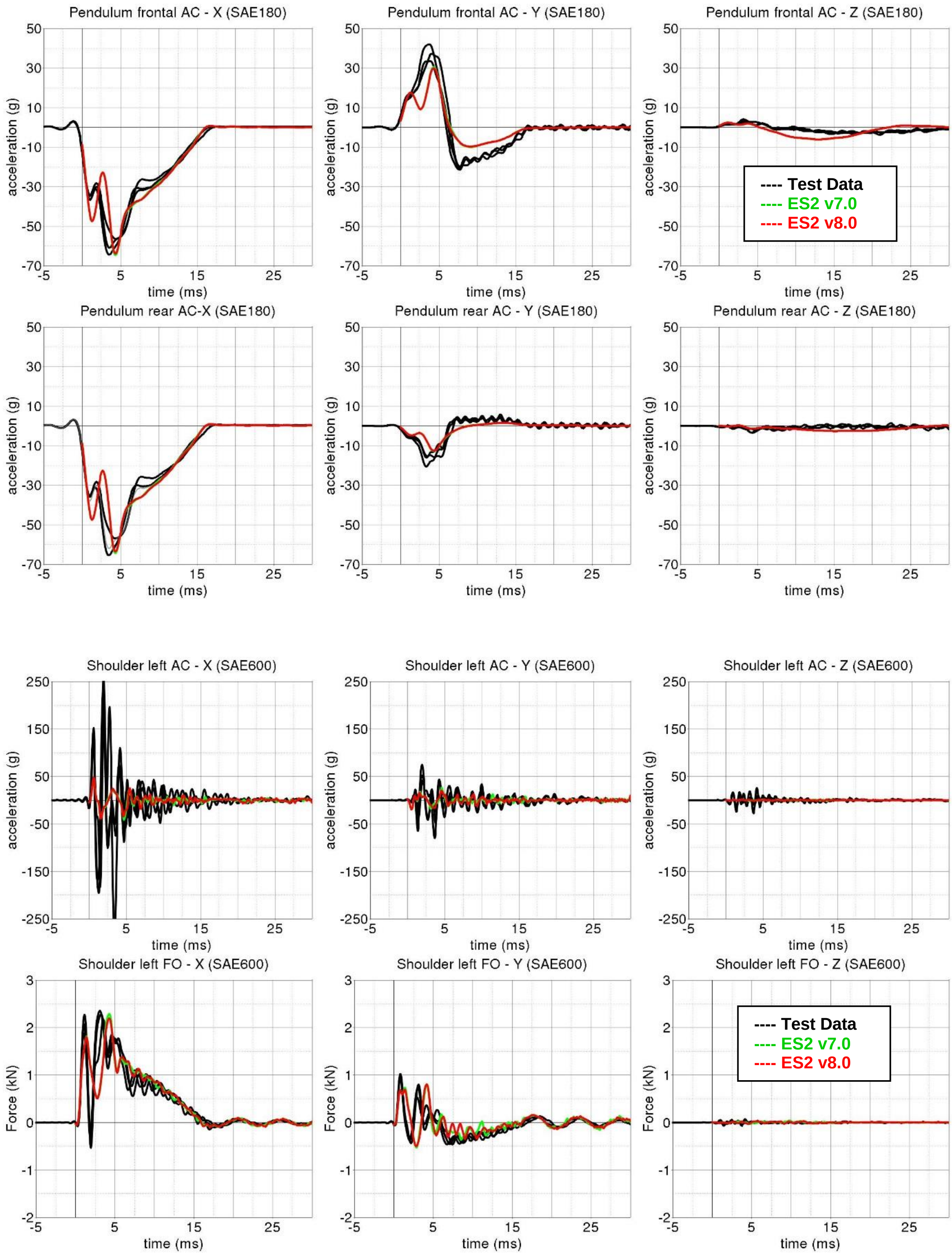
In the clavicle test, the clavicle is impacted by a pendulum in three different directions with two velocities each. The test setup for the three different directions of impact are shown in the figure above.

Results for X-direction impact, low velocity

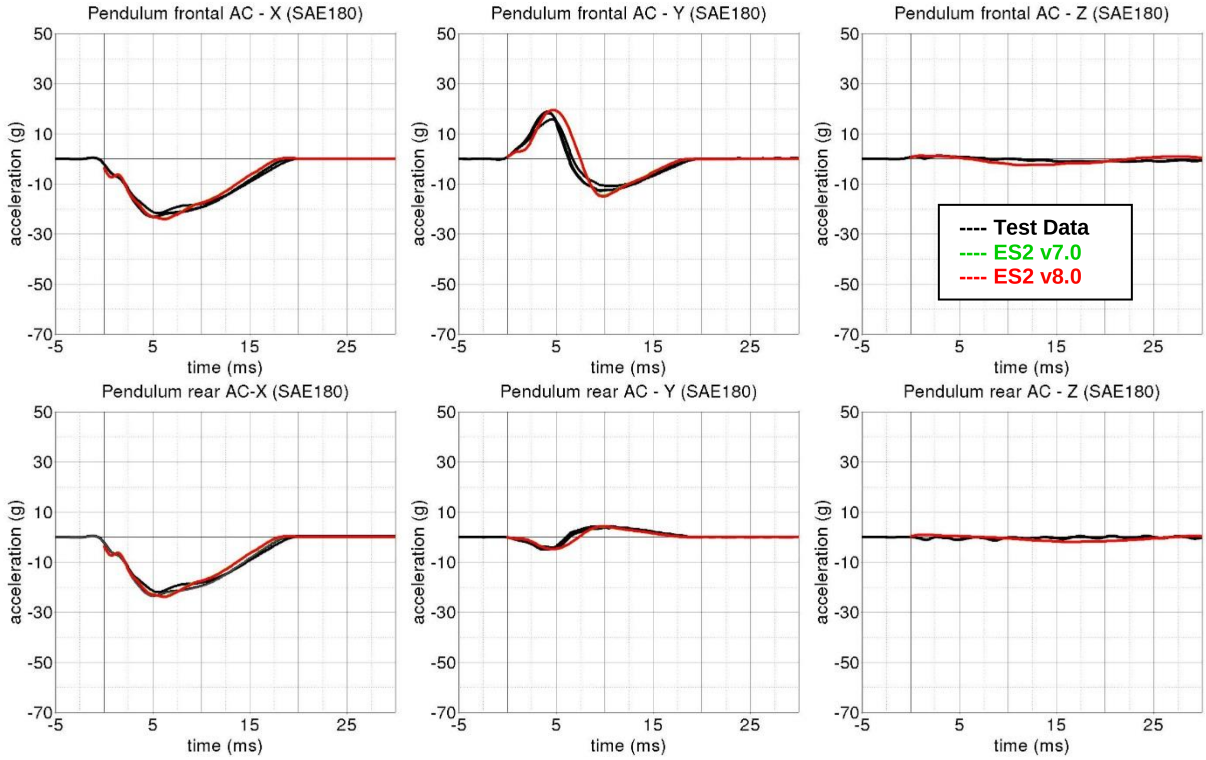


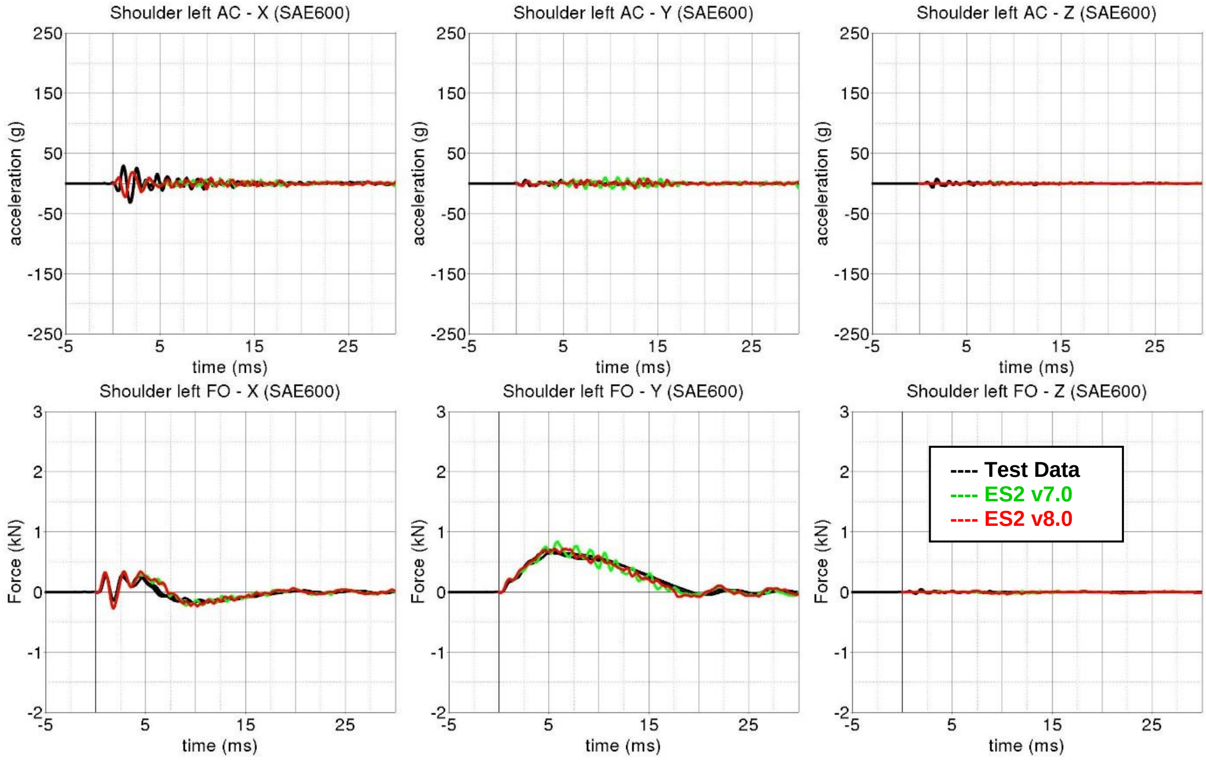


Results for X-direction impact, high velocity

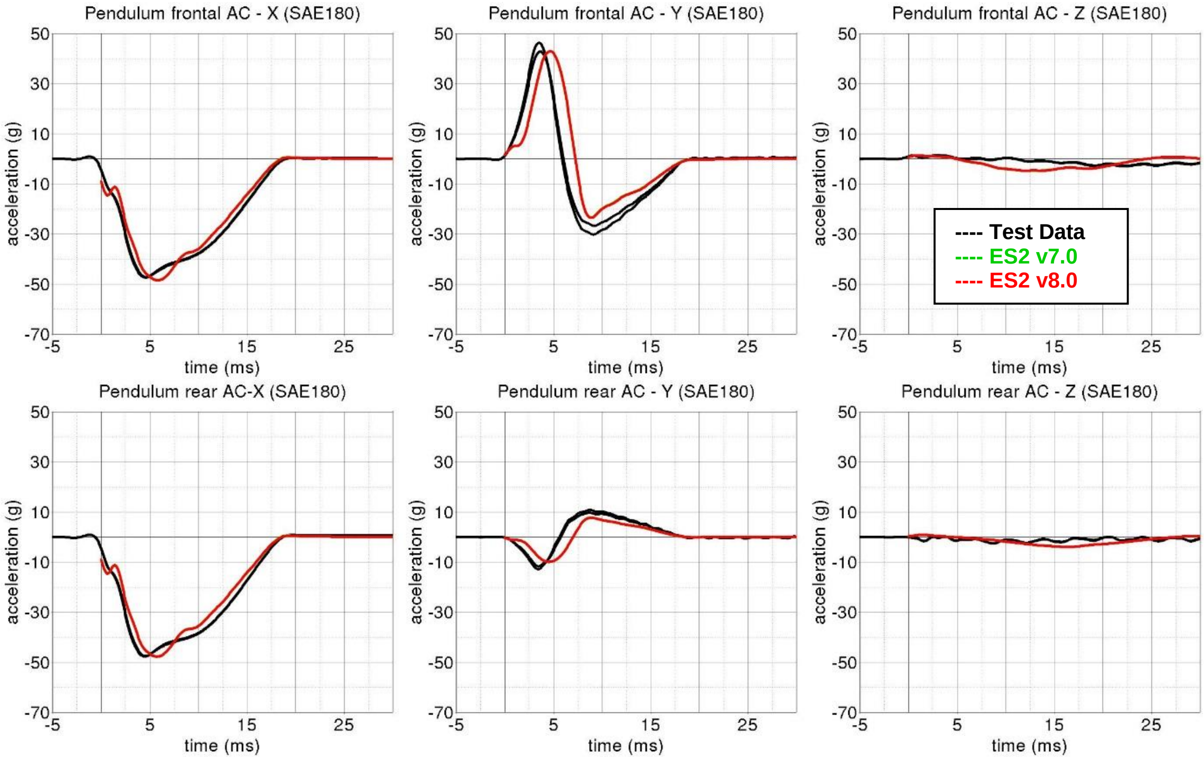


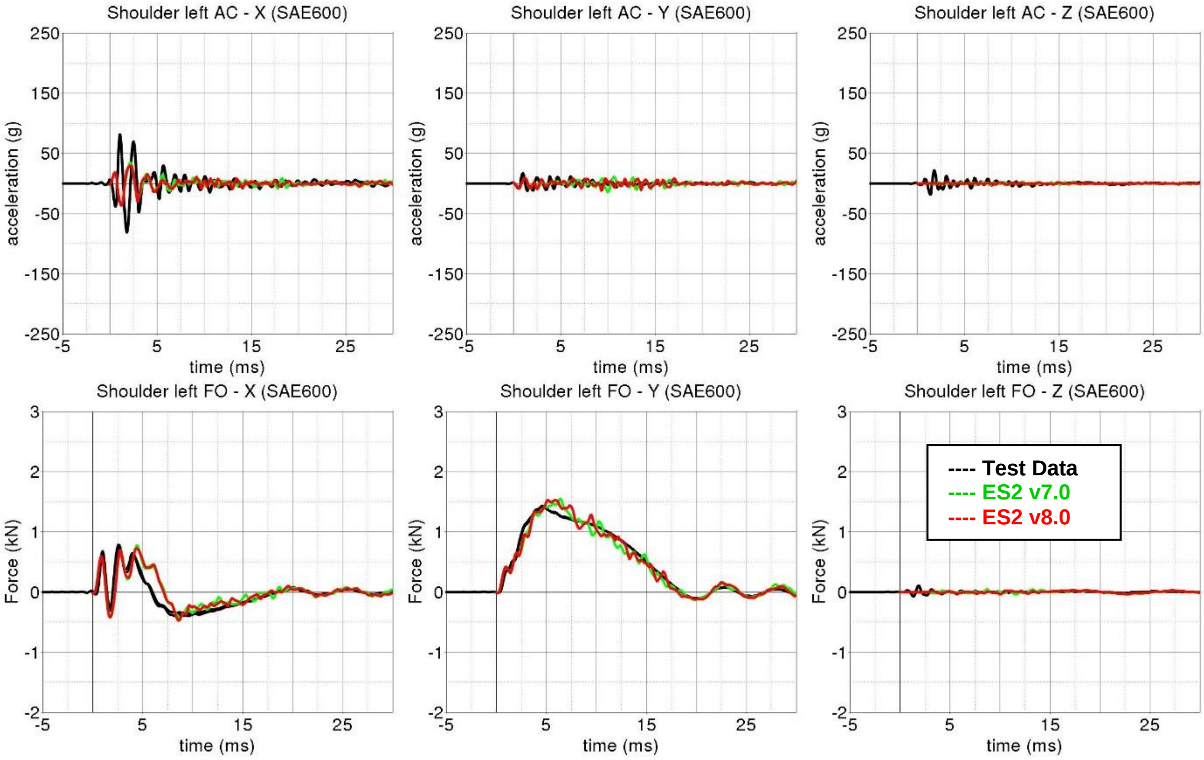
Results for Y-direction impact, low velocity



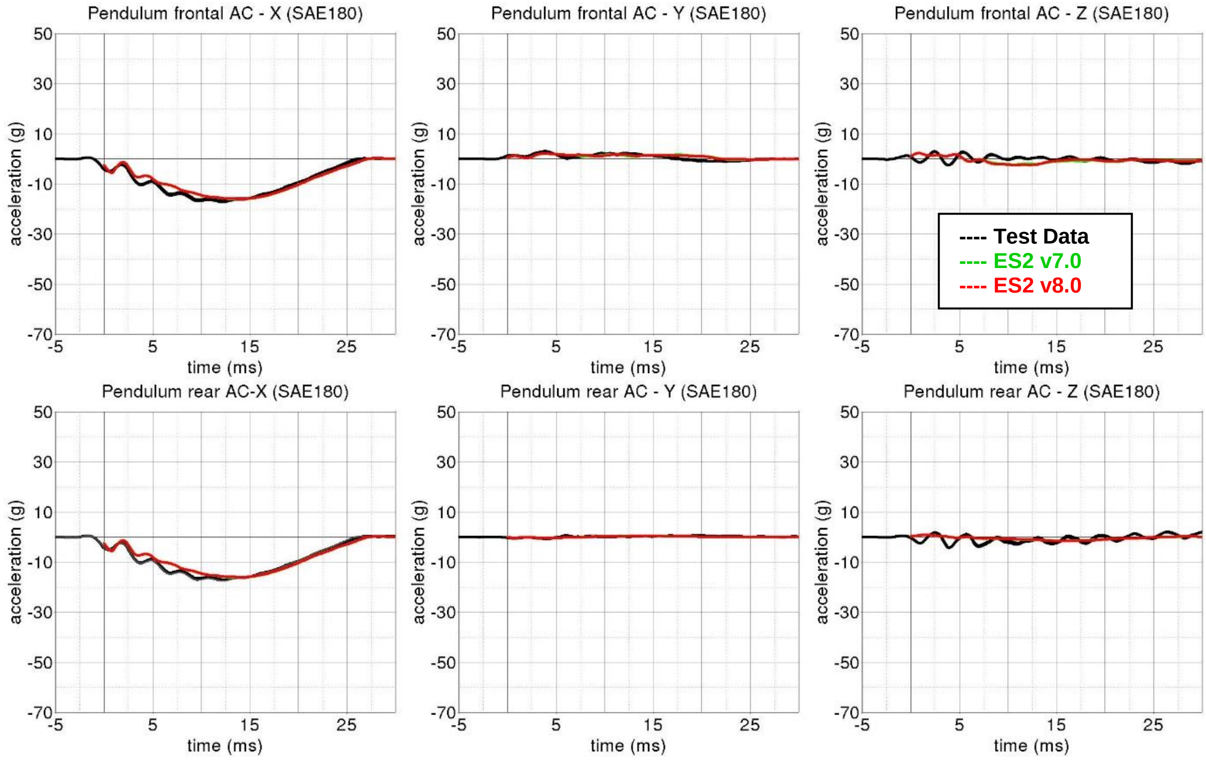


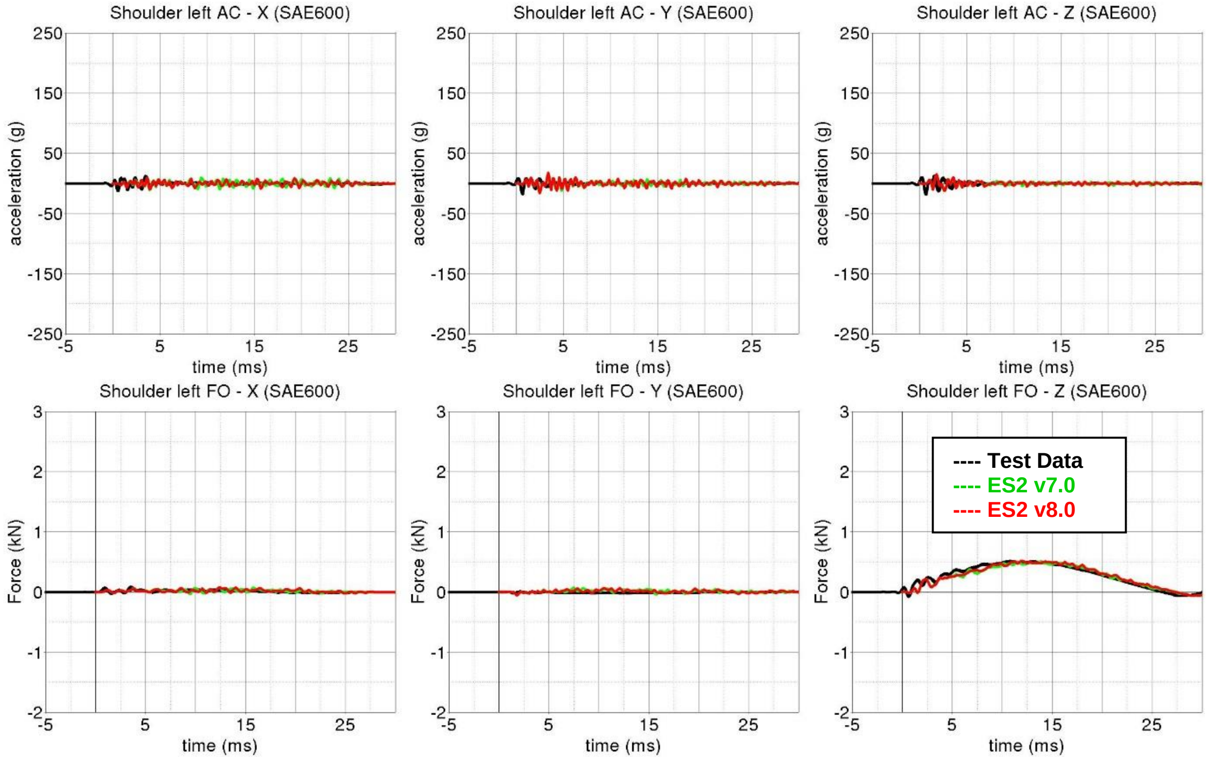
Results for Y-direction impact, high velocity



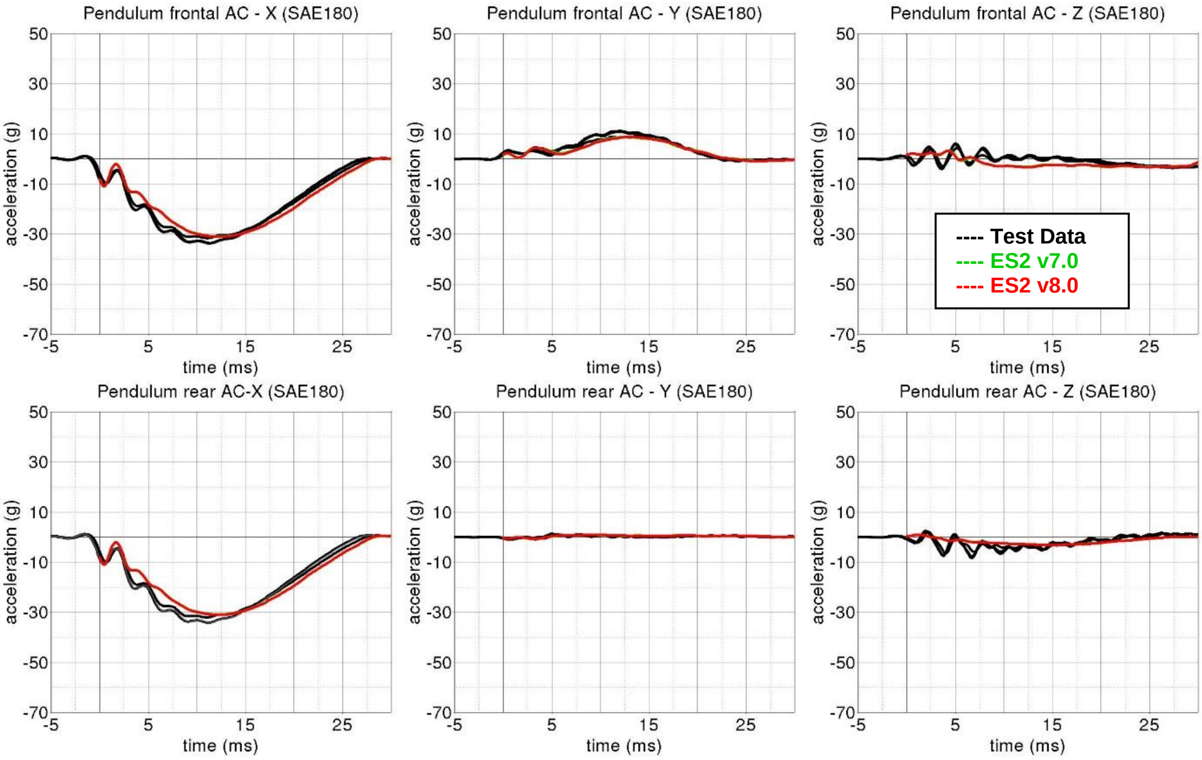


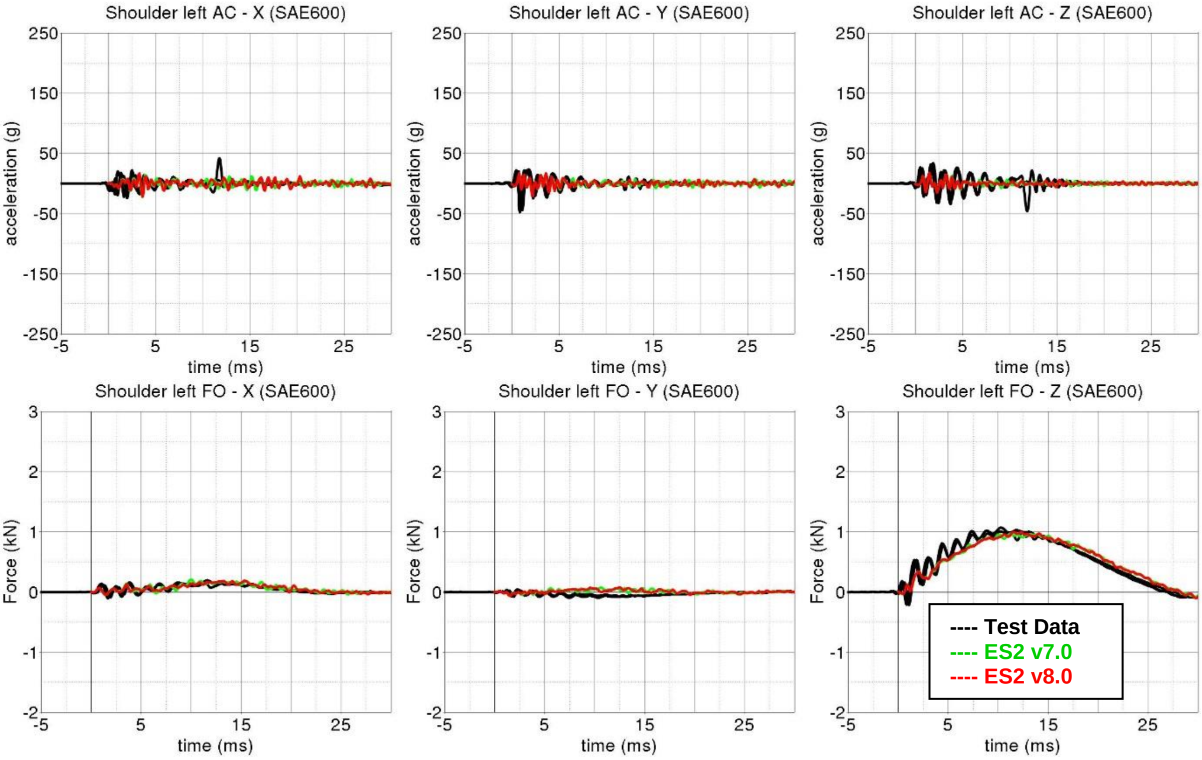
Results for Z-direction impact, low velocity





Results for Z-direction impact, high velocity





10.1.3 Clavicle Box test

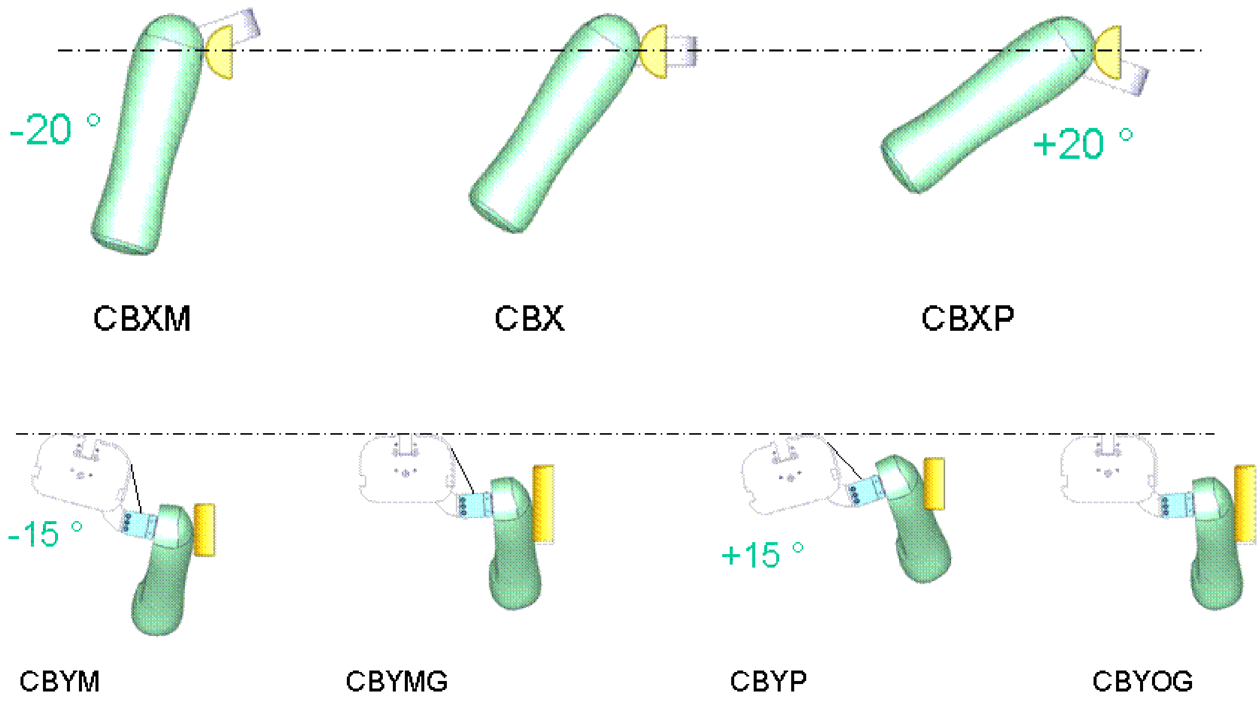
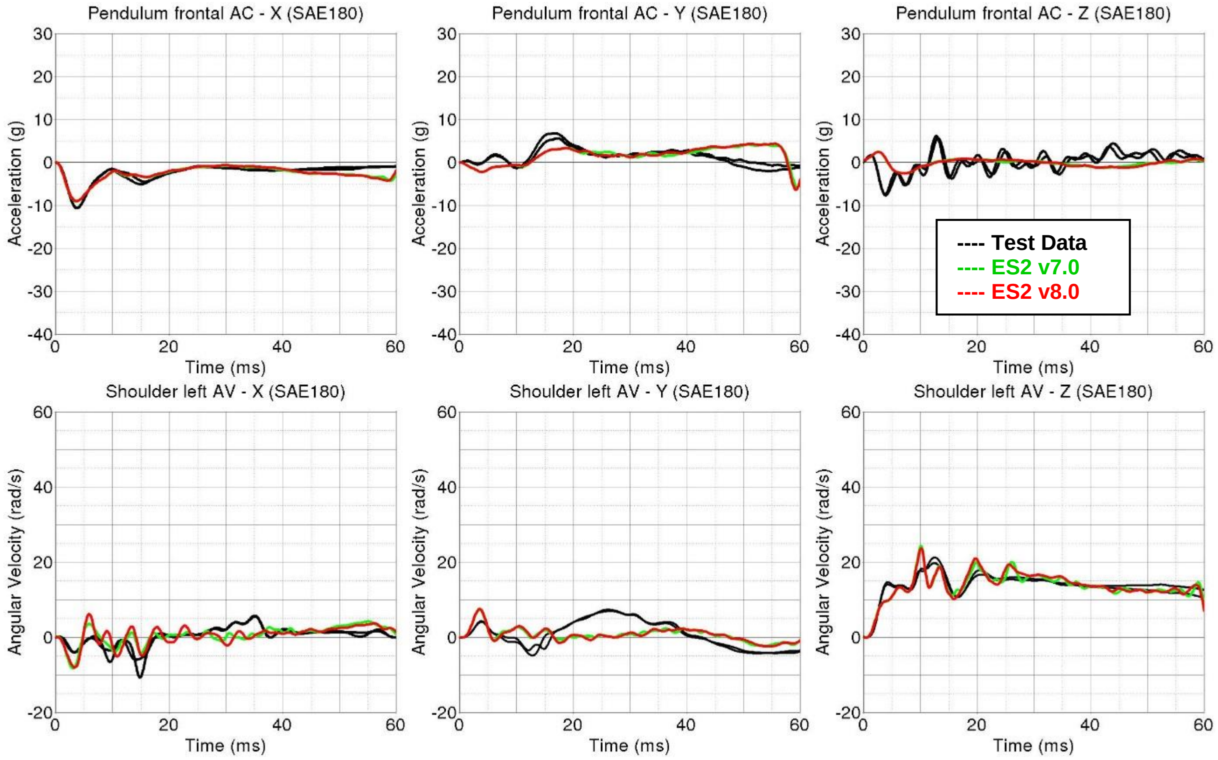
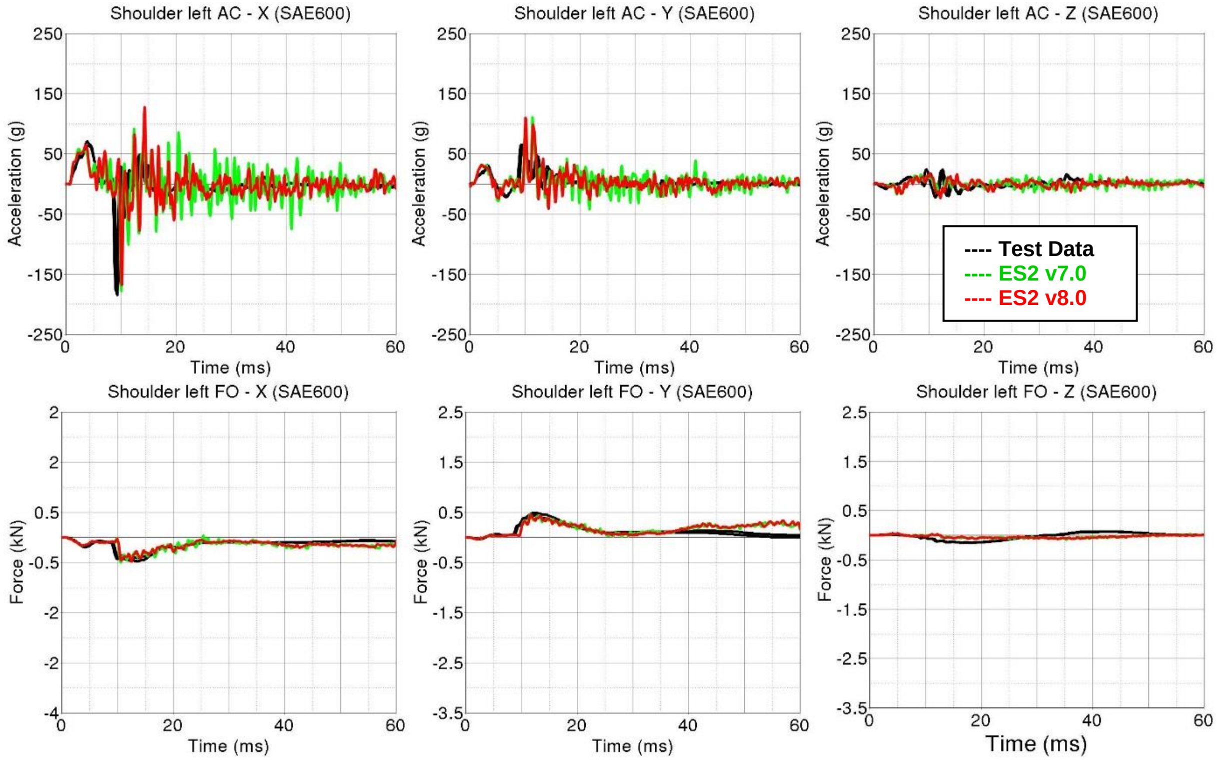


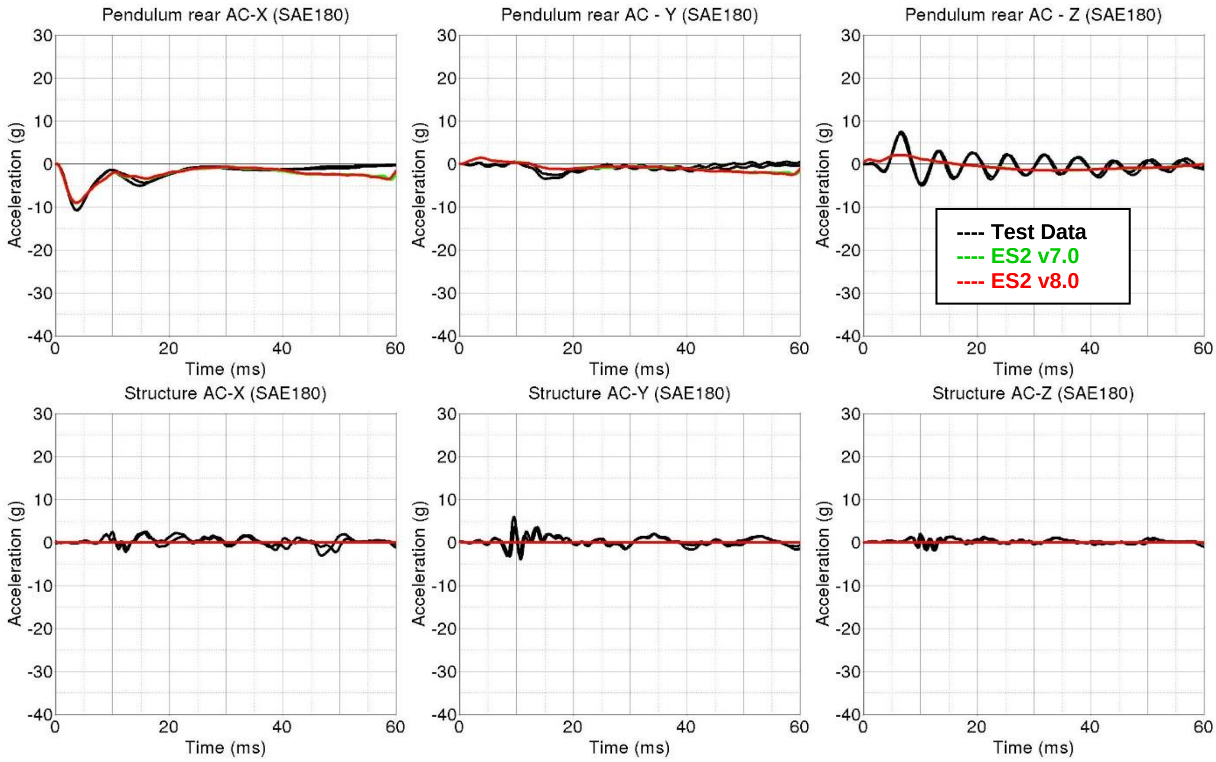
Figure 31: Test configurations for Clavicle Box test

The various test configurations for the clavicle box test are shown in the figure above. The pendulum impacts the arm and clavicle box assembly in x- and y-directions. For the impact in y-direction, tests are carried out with low and high velocities of the pendulum. An additional set of tests is carried out without the pre-stressed clavicle strap.

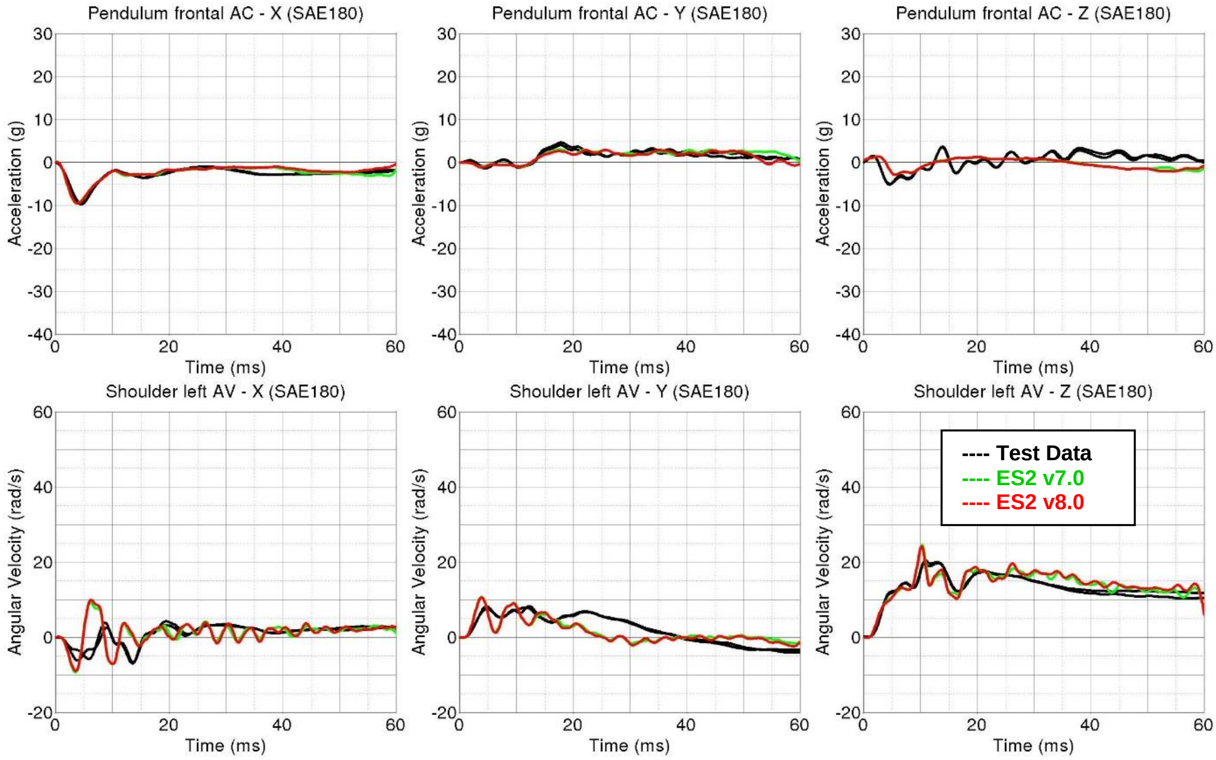
Results for X-direction impact, low velocity (CBX)

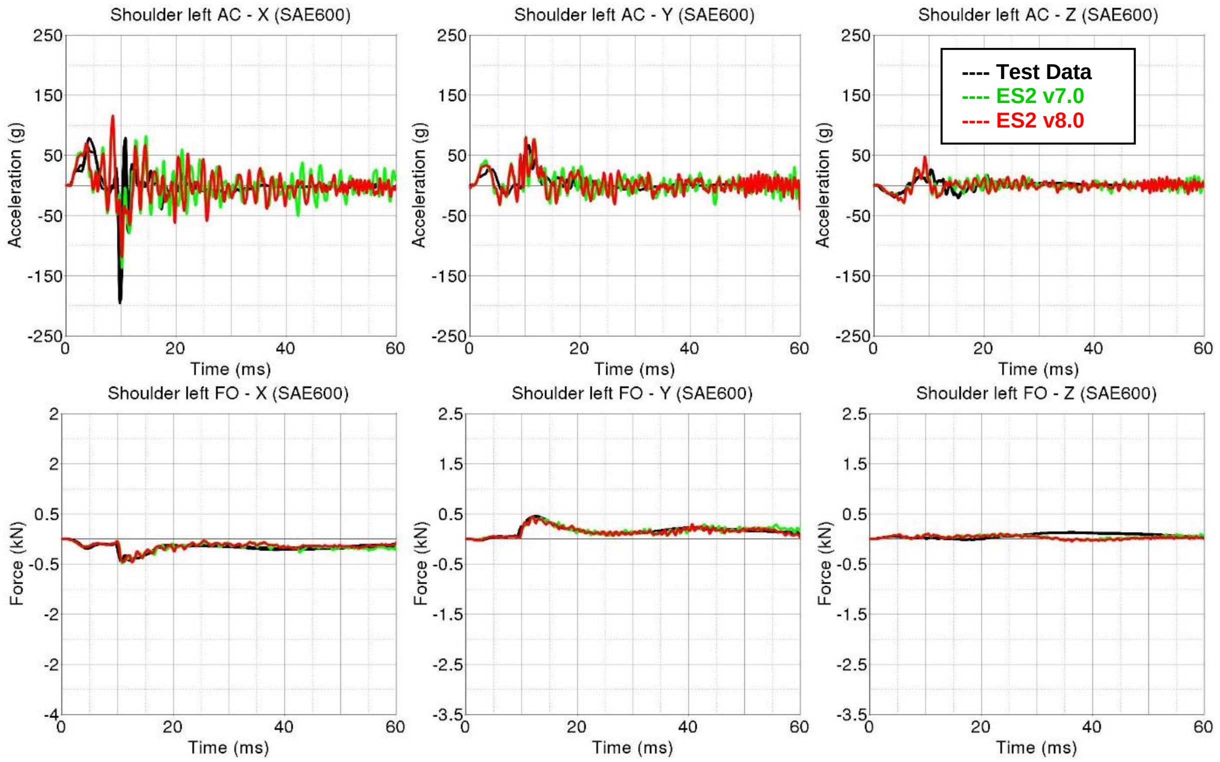


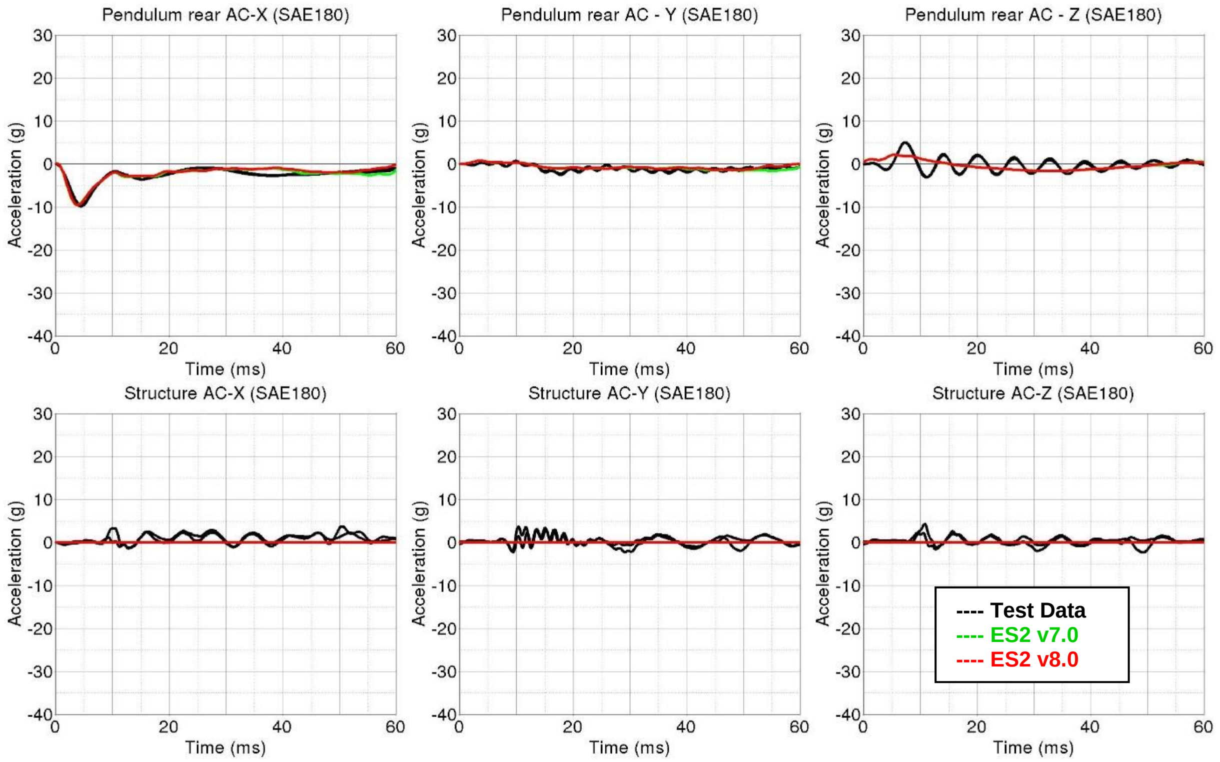




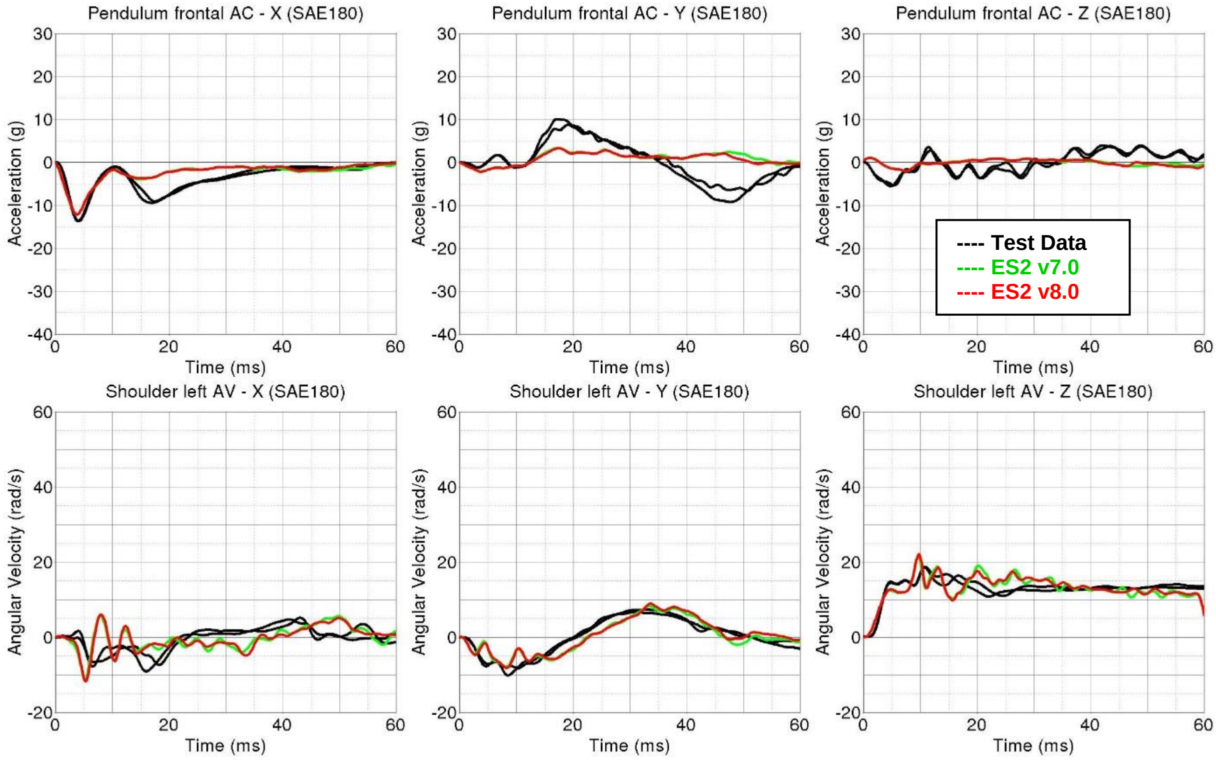
Results for X-direction impact, low velocity (CBXM)

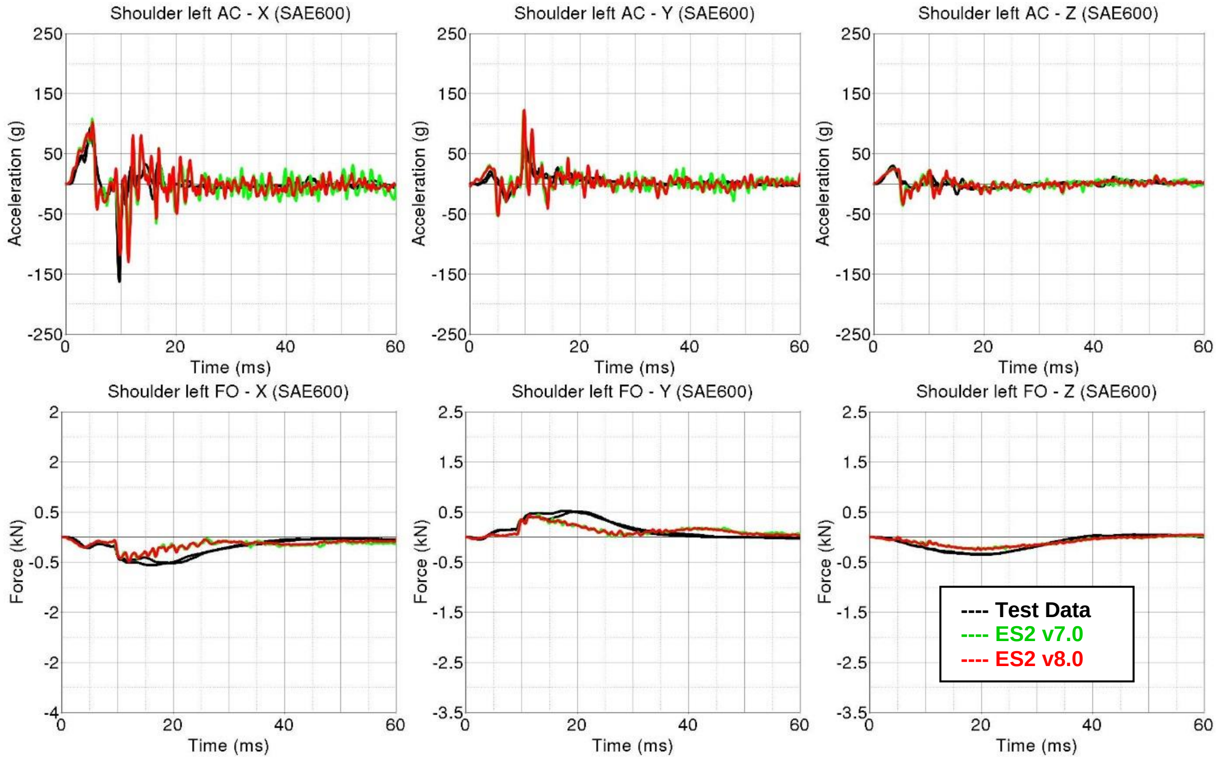


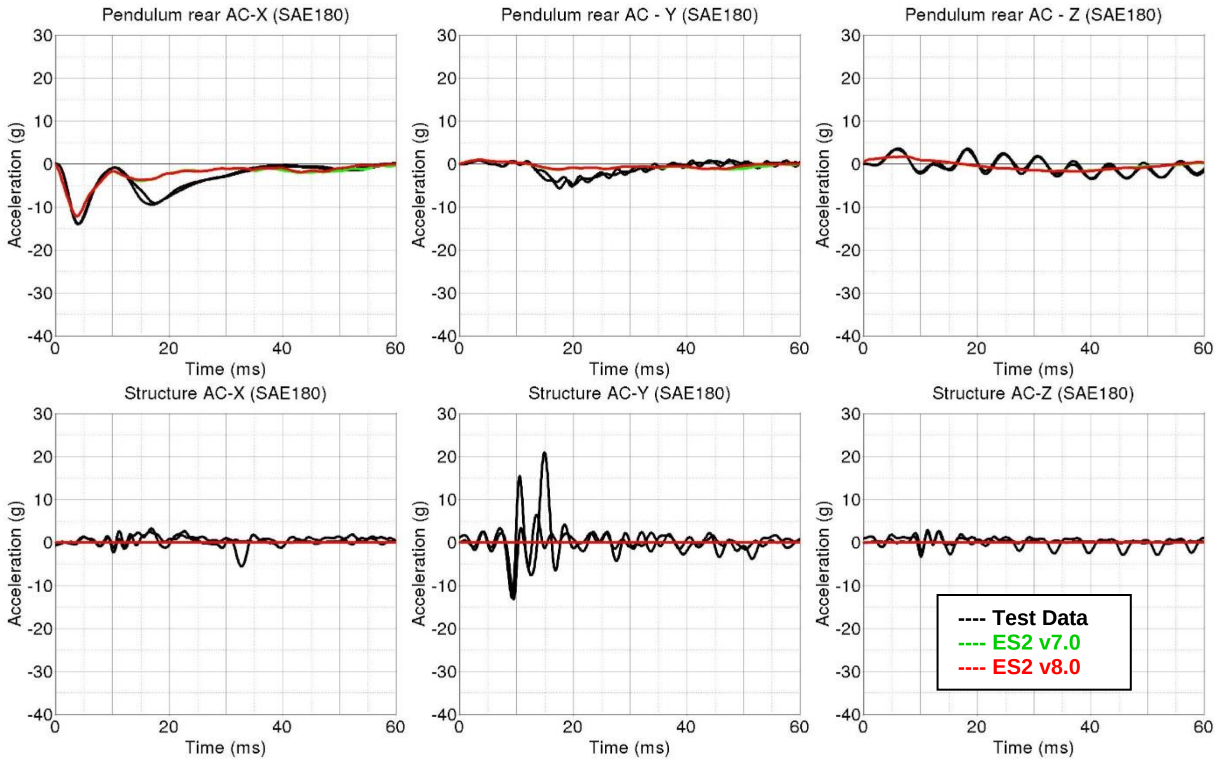

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Acceleration (g)
Force (kN)
Time (ms)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)
Acceleration (g)
Time (ms)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0

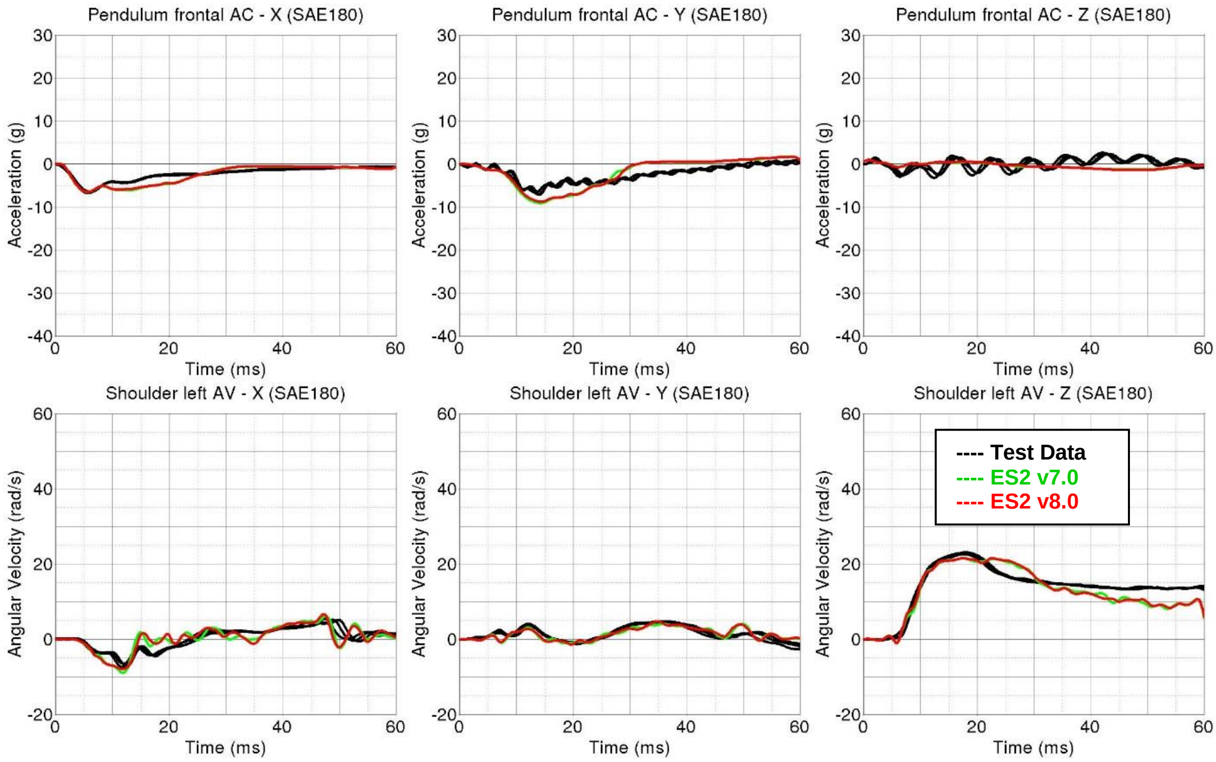
Results for X-direction impact, low velocity (CBXP)

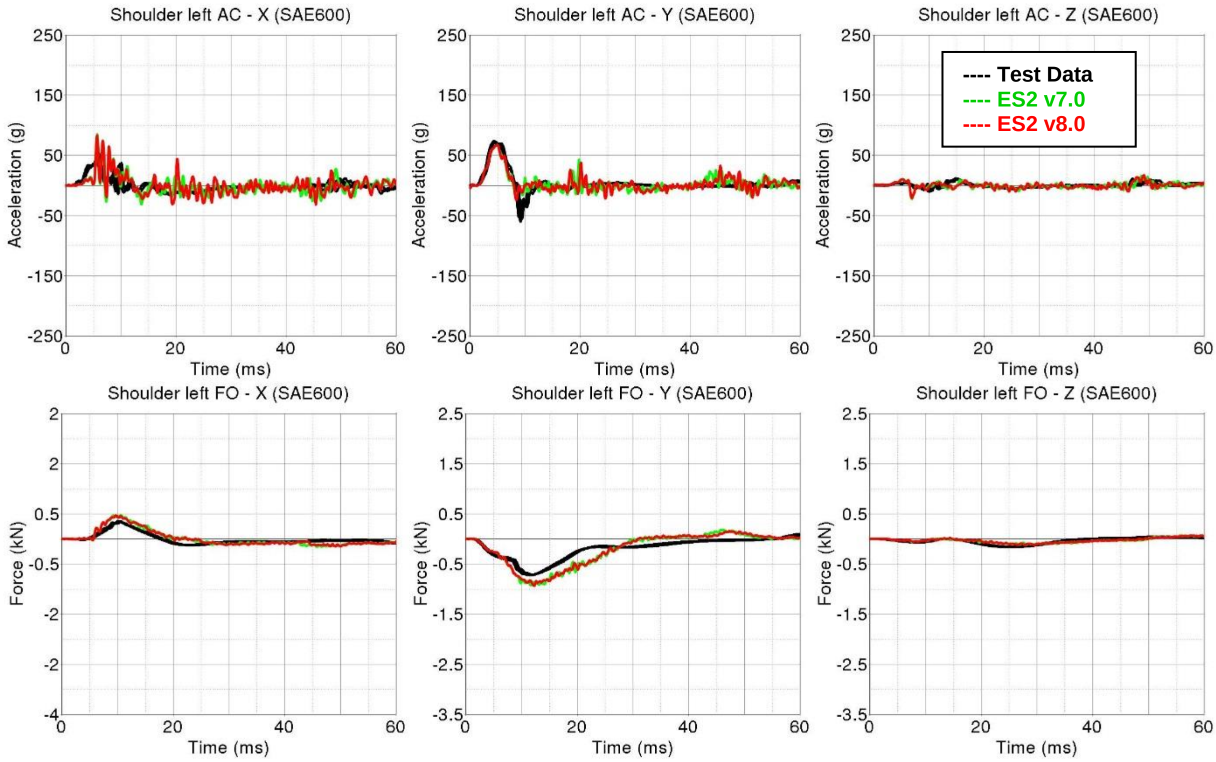


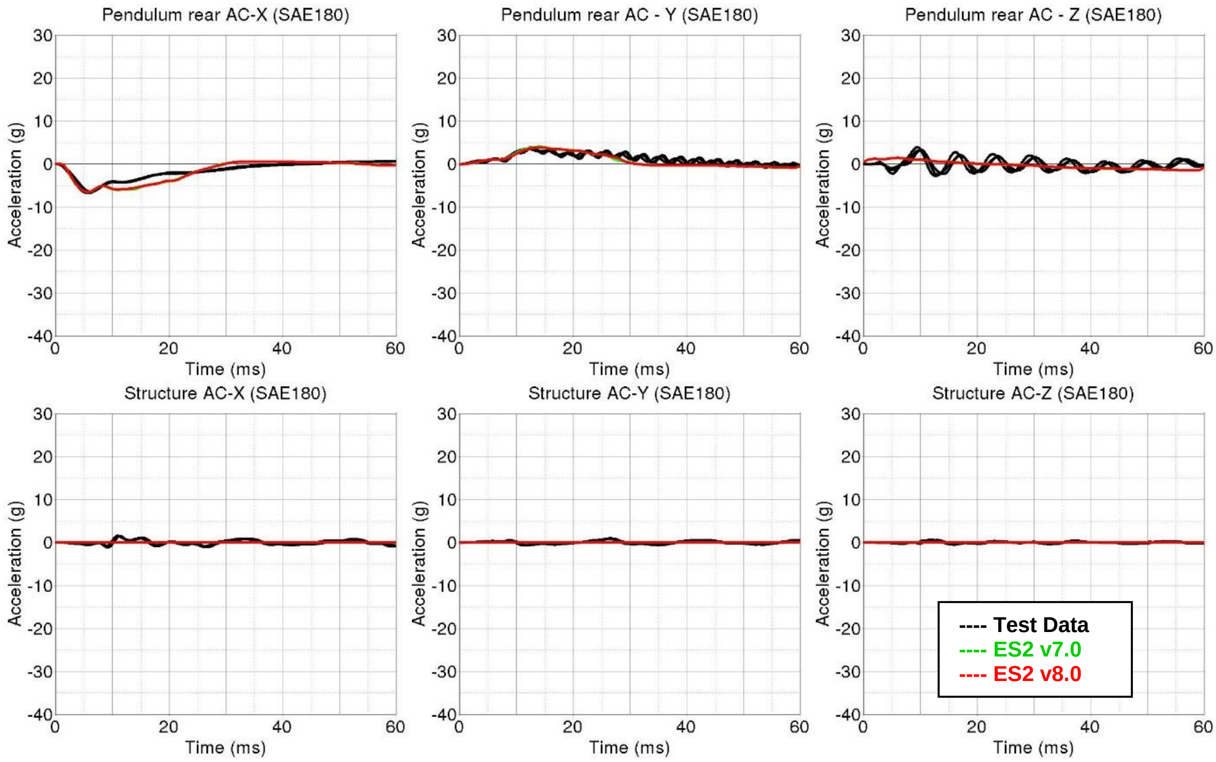




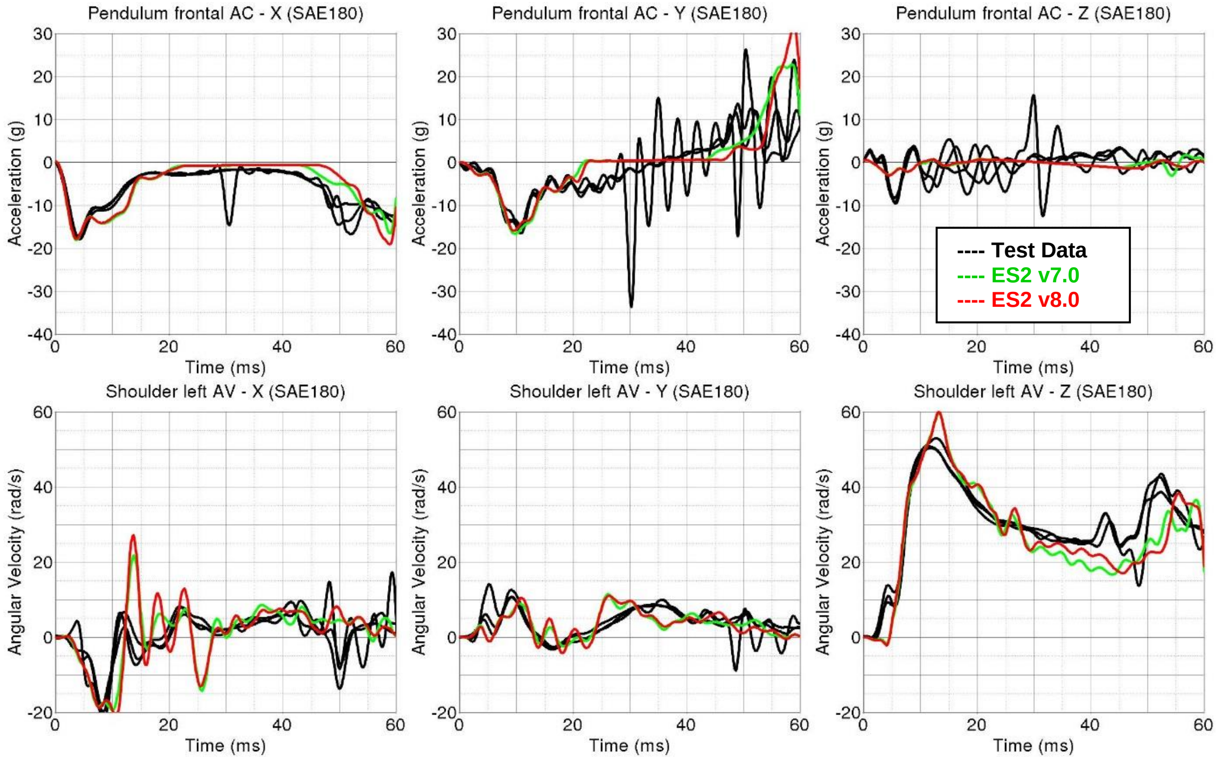
Results for Y-direction impact, low velocity (CBYM3)

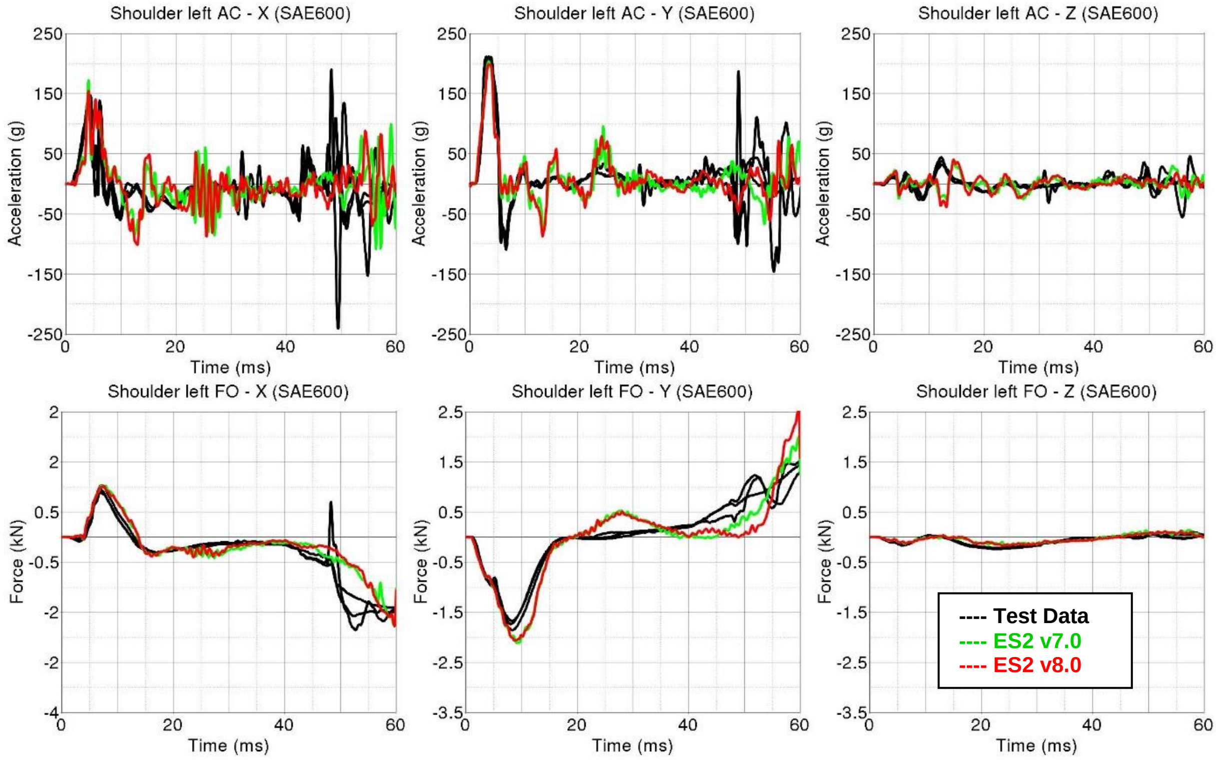


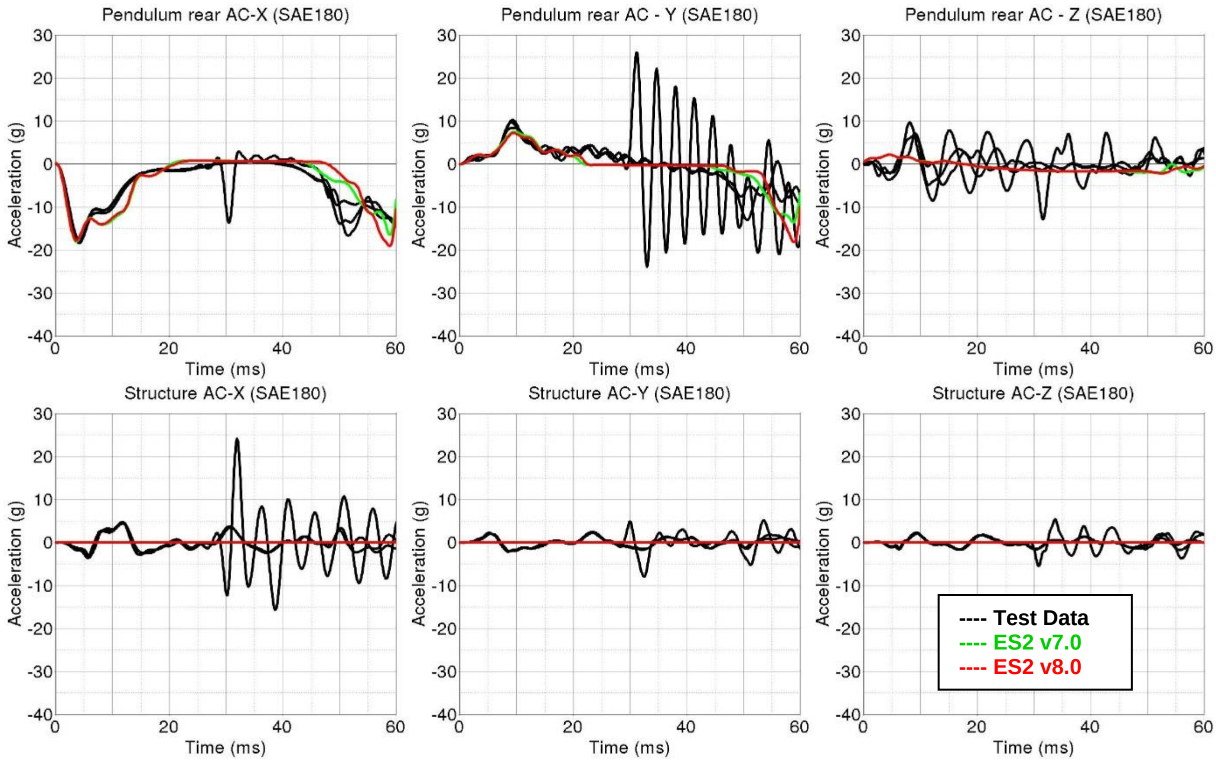

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Acceleration (g)
Force (kN)
Time (ms)


Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Acceleration (g)
Time (ms)

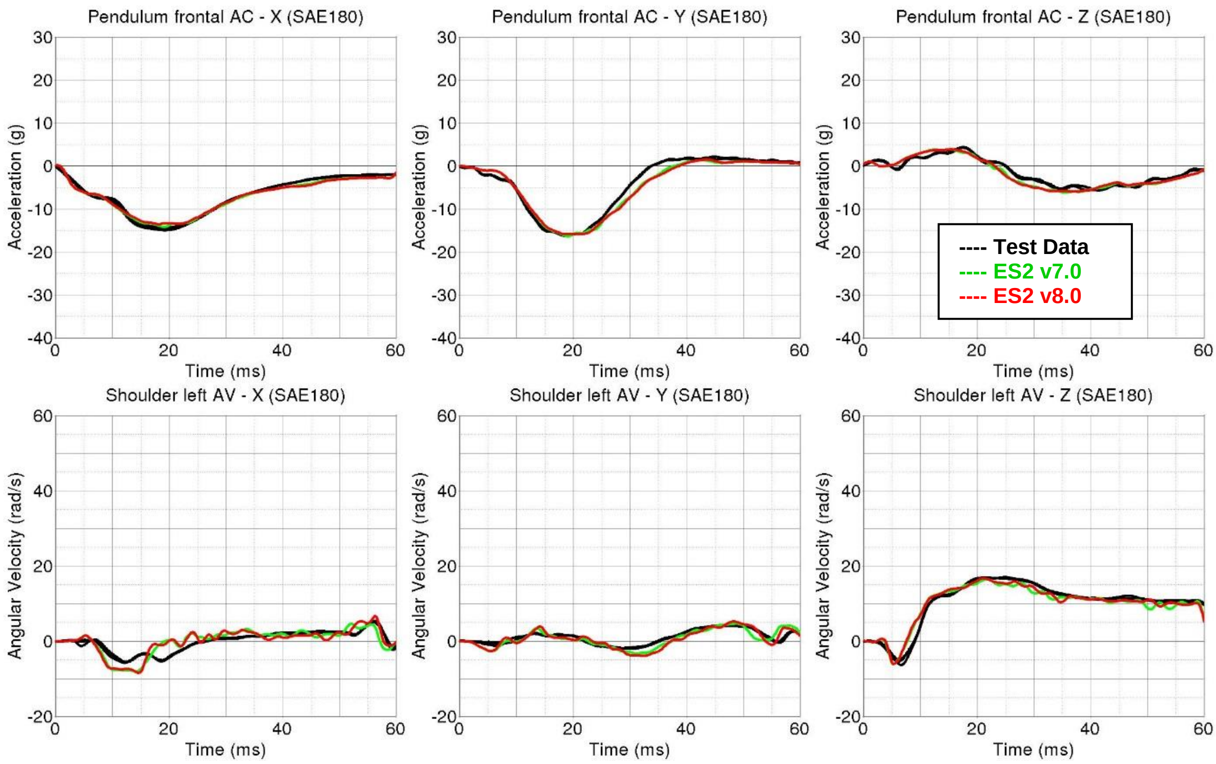
Results for Y-direction impact, high velocity (CBYM6)

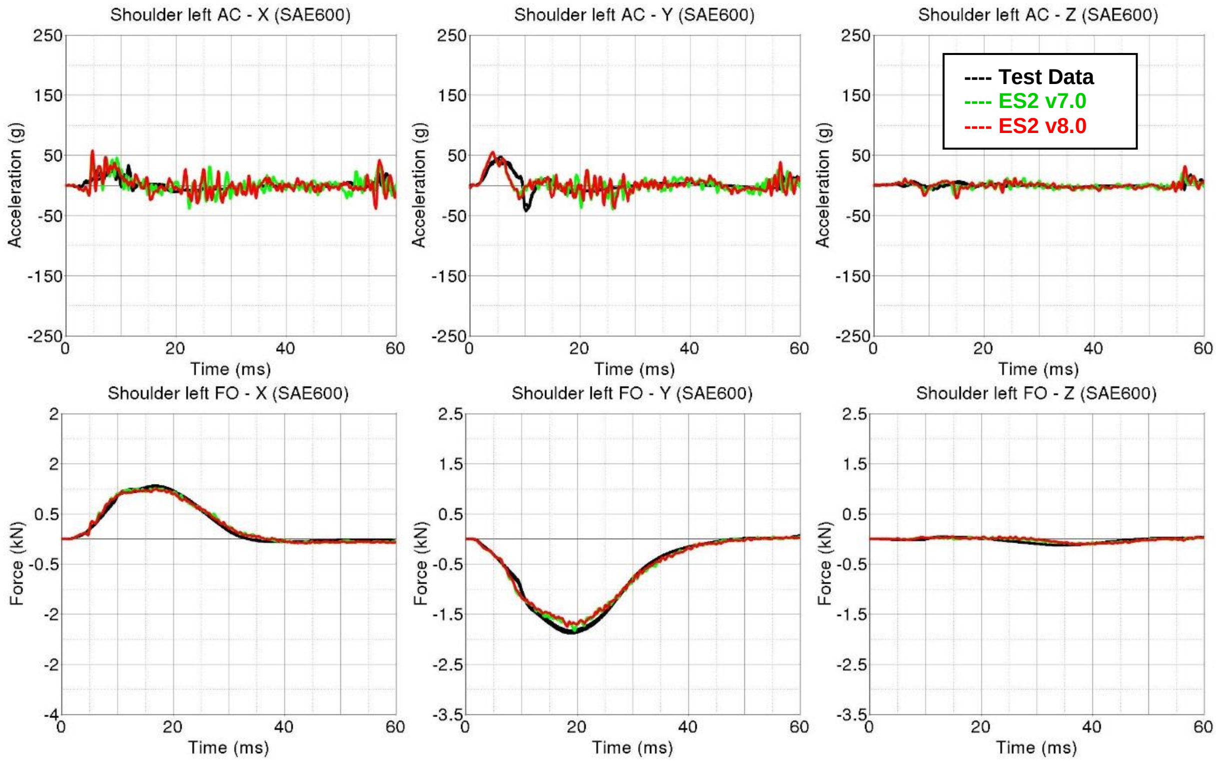


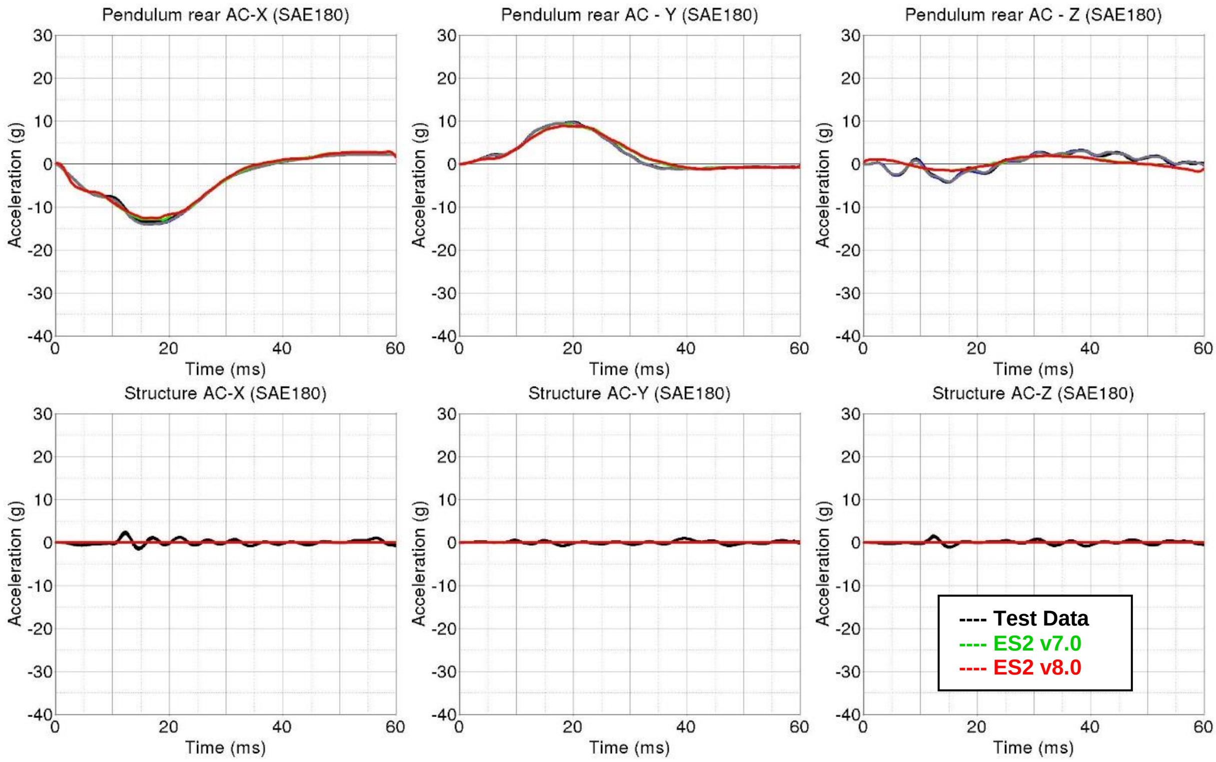




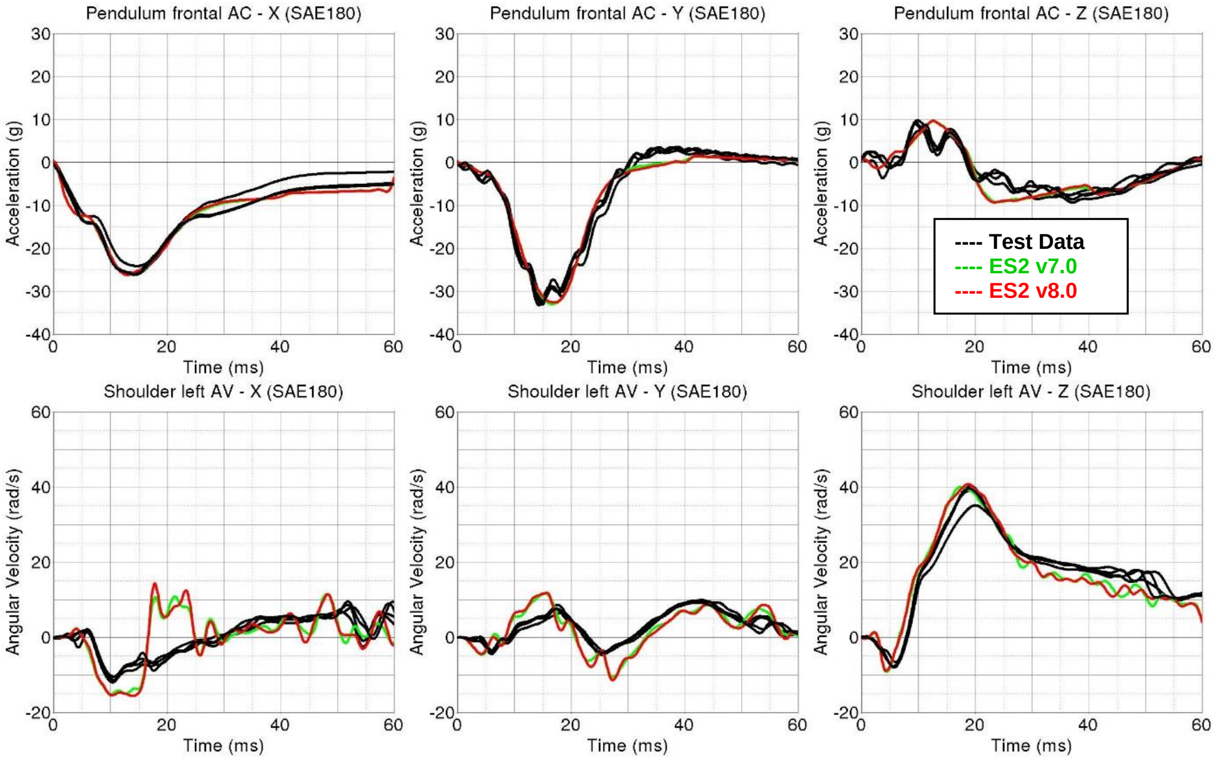
Results for Y-direction impact, low velocity (CBYP3)

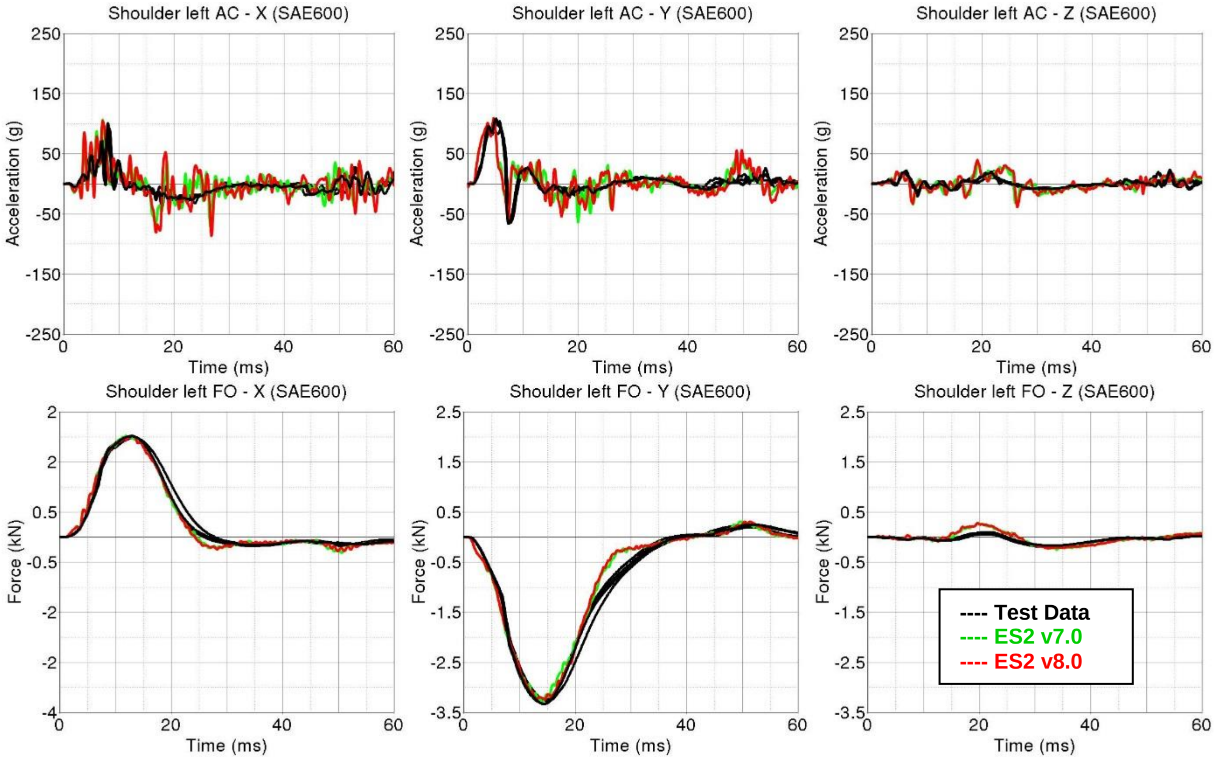


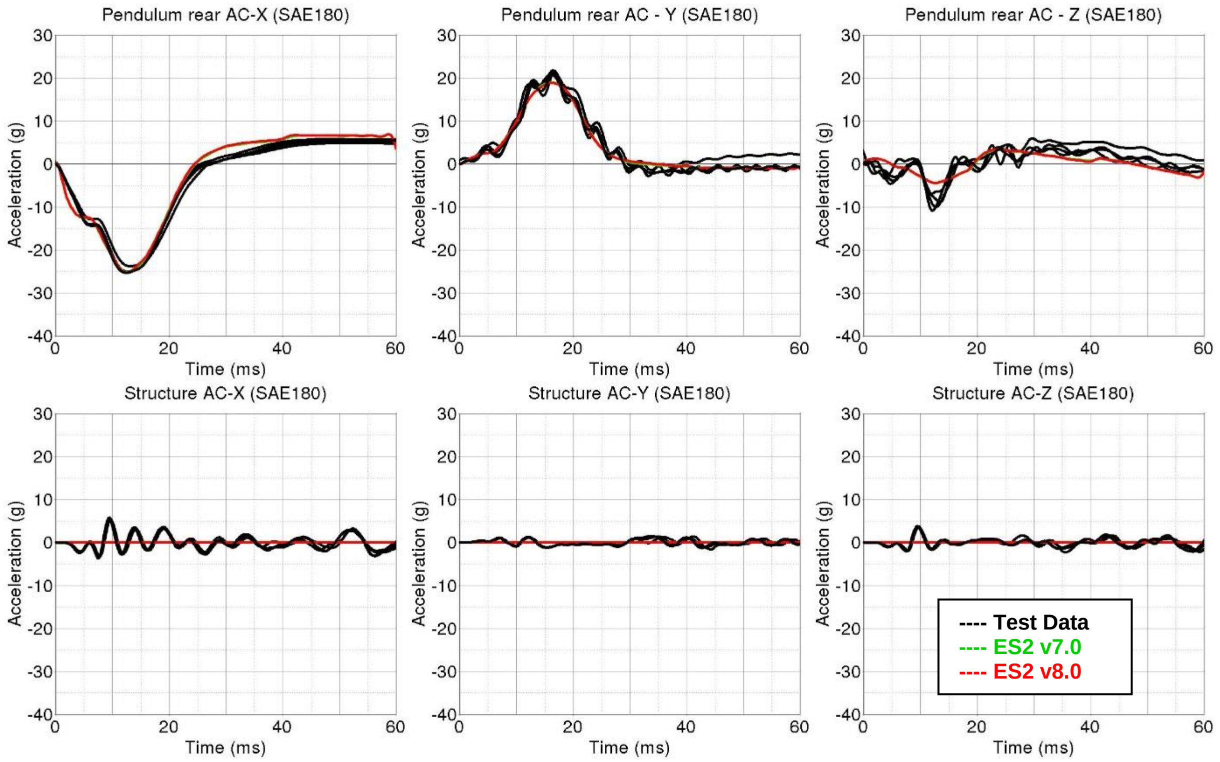

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Acceleration (g)
Force (kN)
Time (ms)


Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Acceleration (g)
Time (ms)

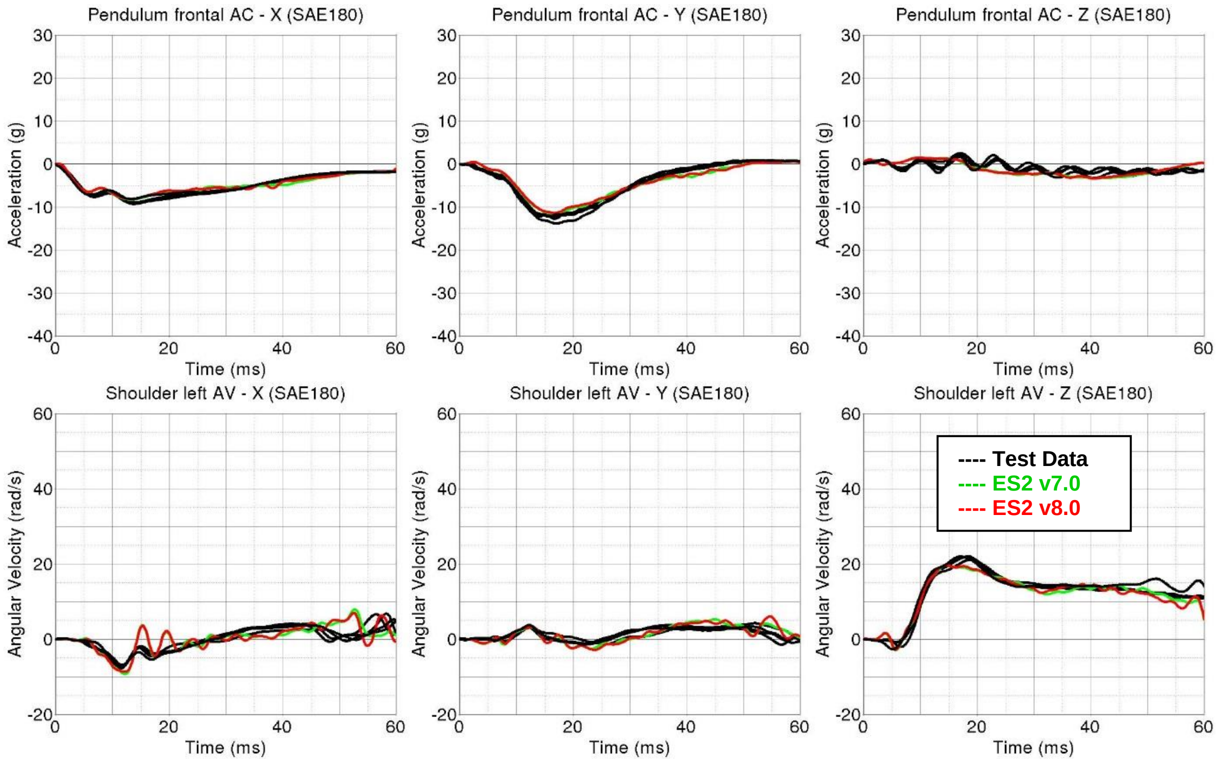
Results for Y-direction impact, high velocity (CBYP5)

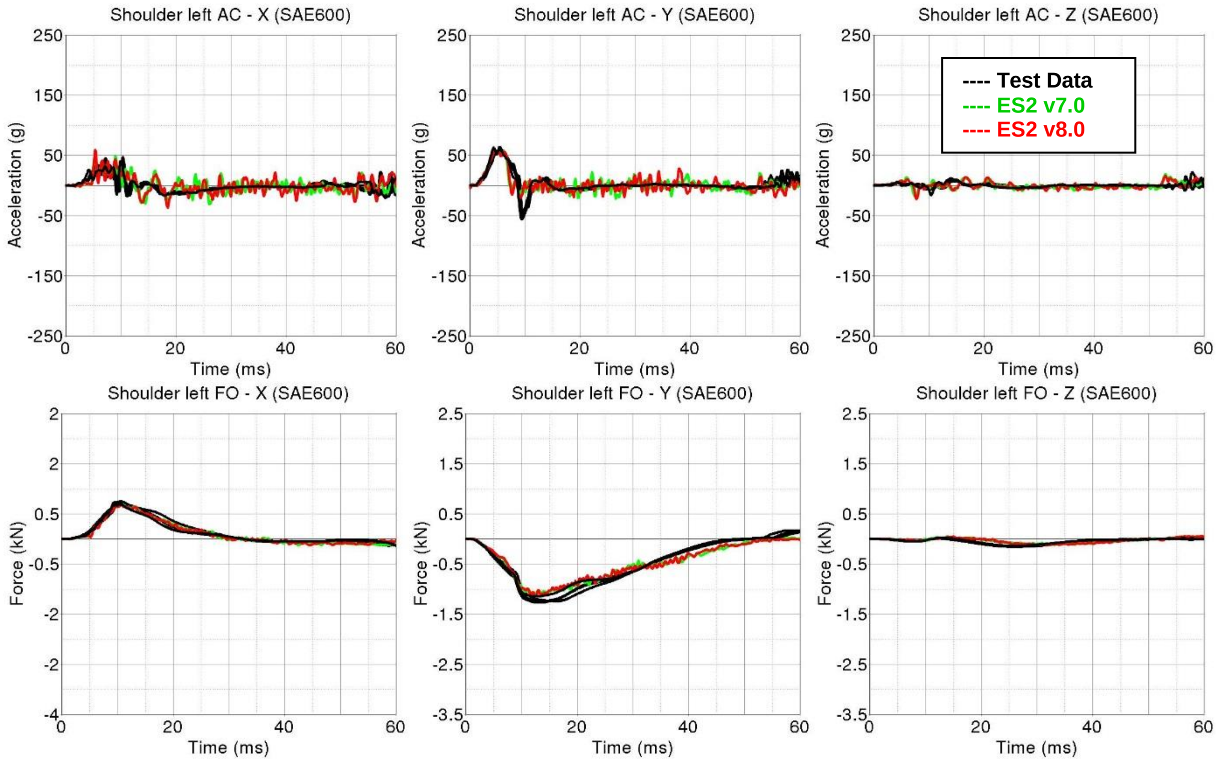


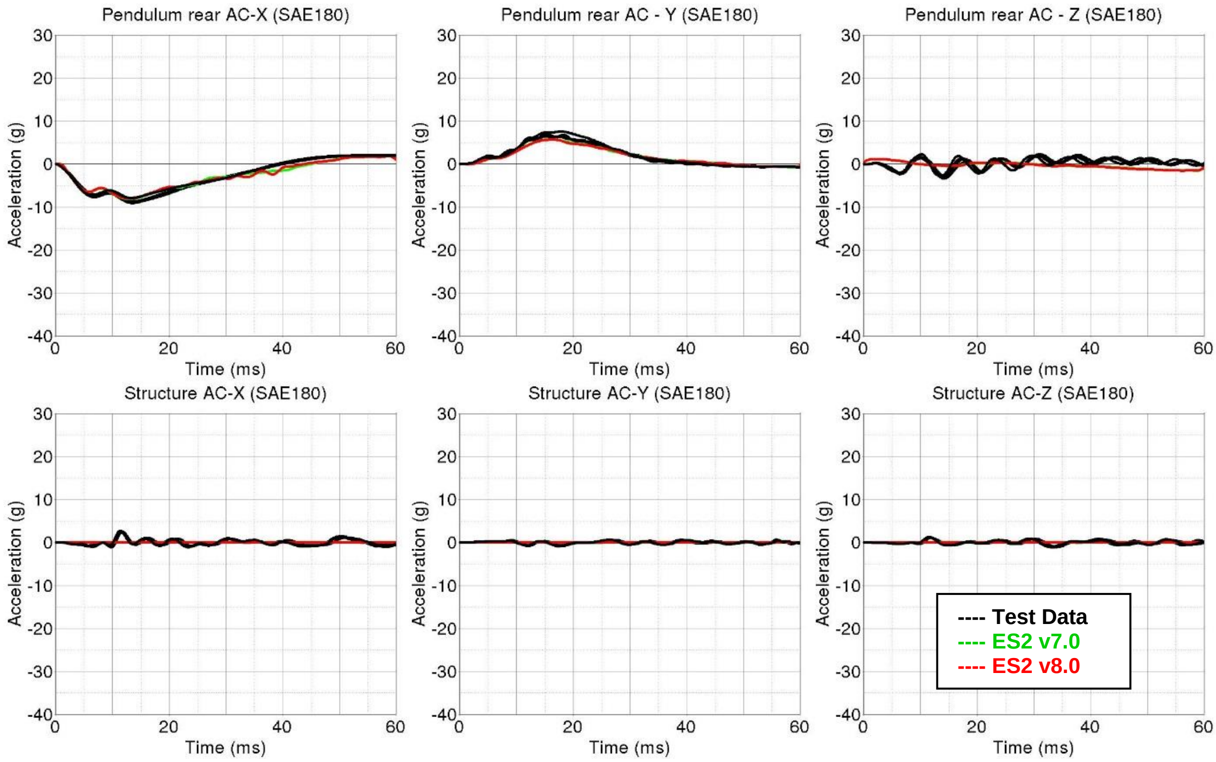




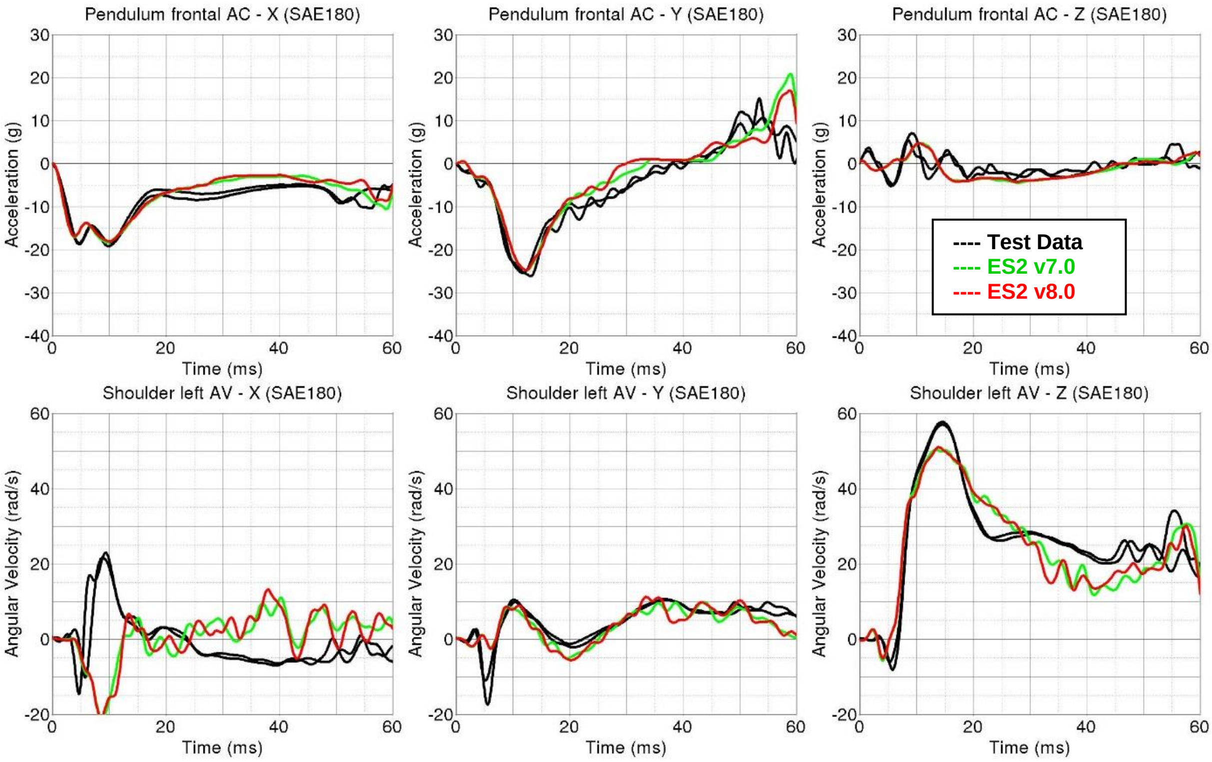
Results for Y-direction impact, low velocity, with clavicle strap (CBYMG3)

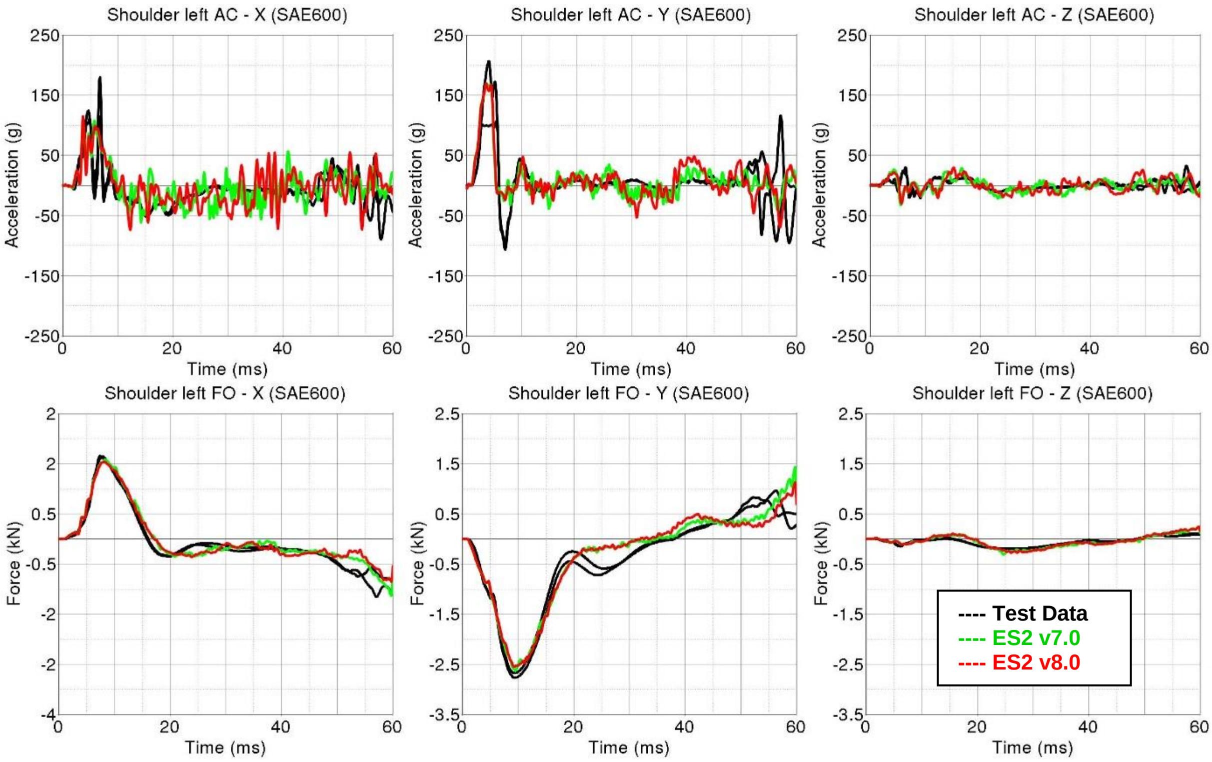


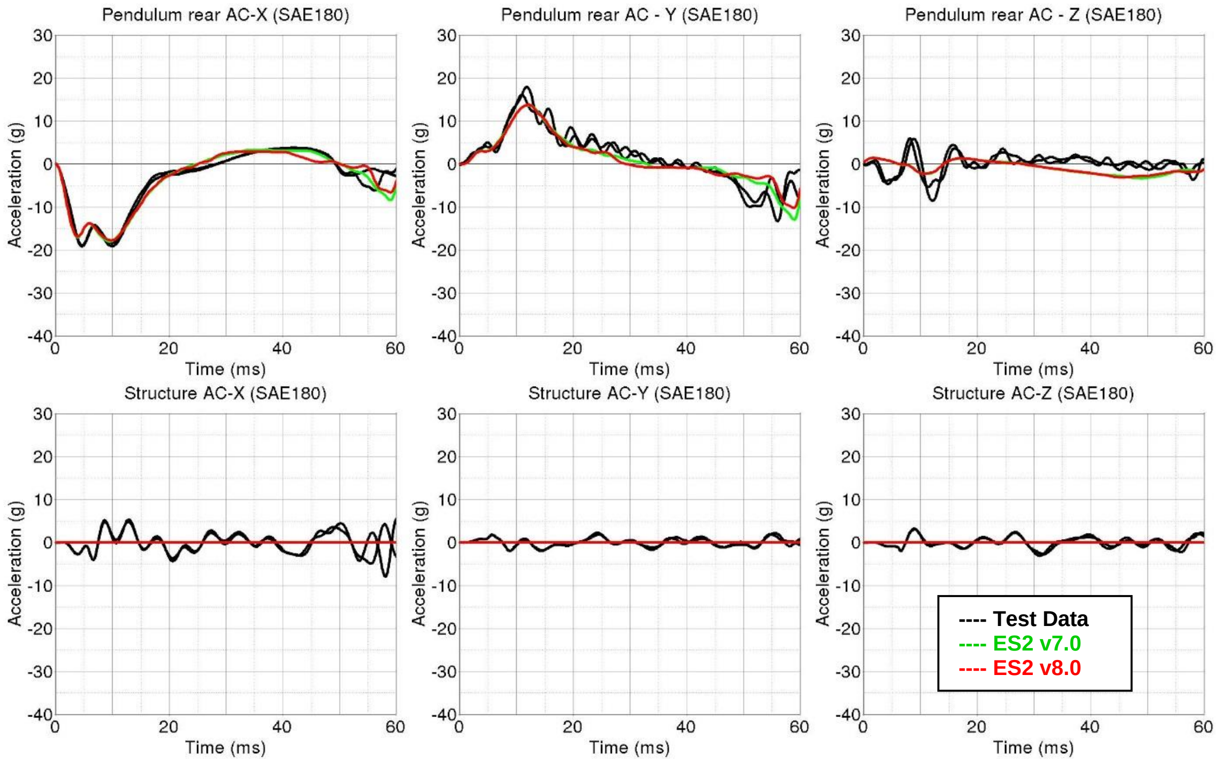

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Acceleration (g)
Force (kN)
Time (ms)


Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Acceleration (g)
Time (ms)

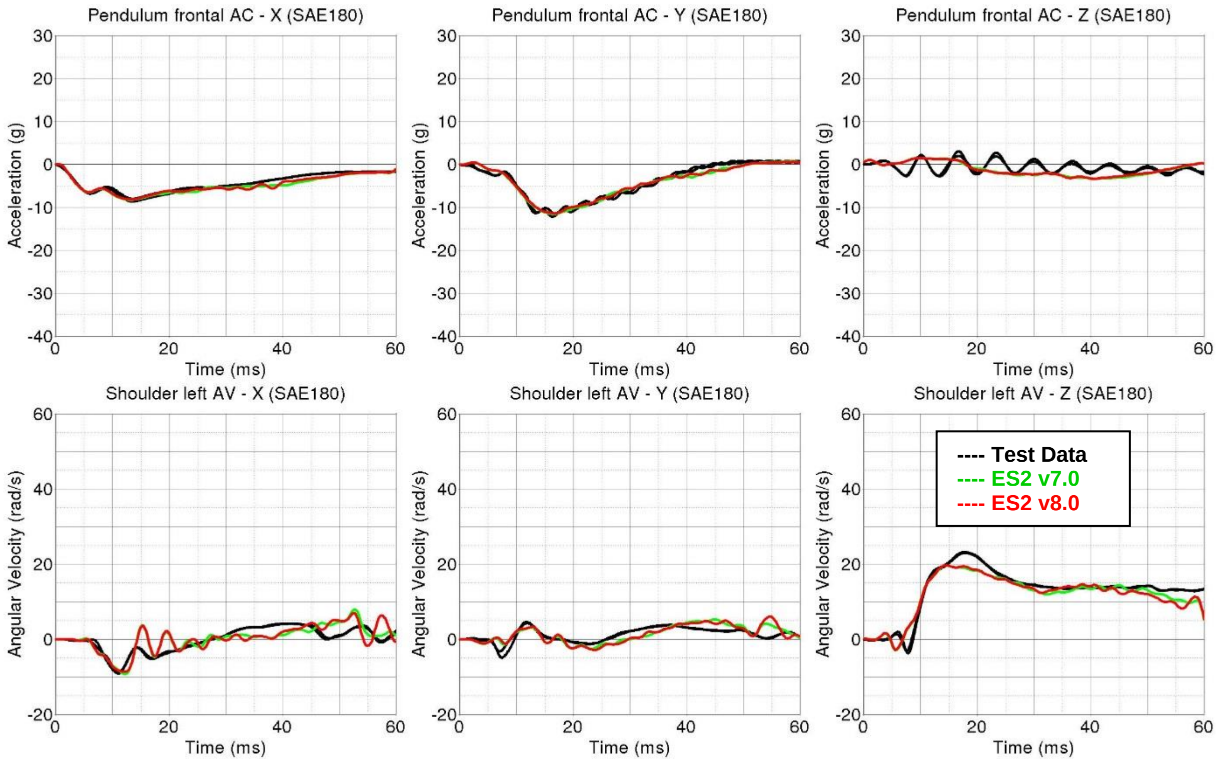
Results for Y-direction impact, high velocity, with clavicle strap (CBYMG6)

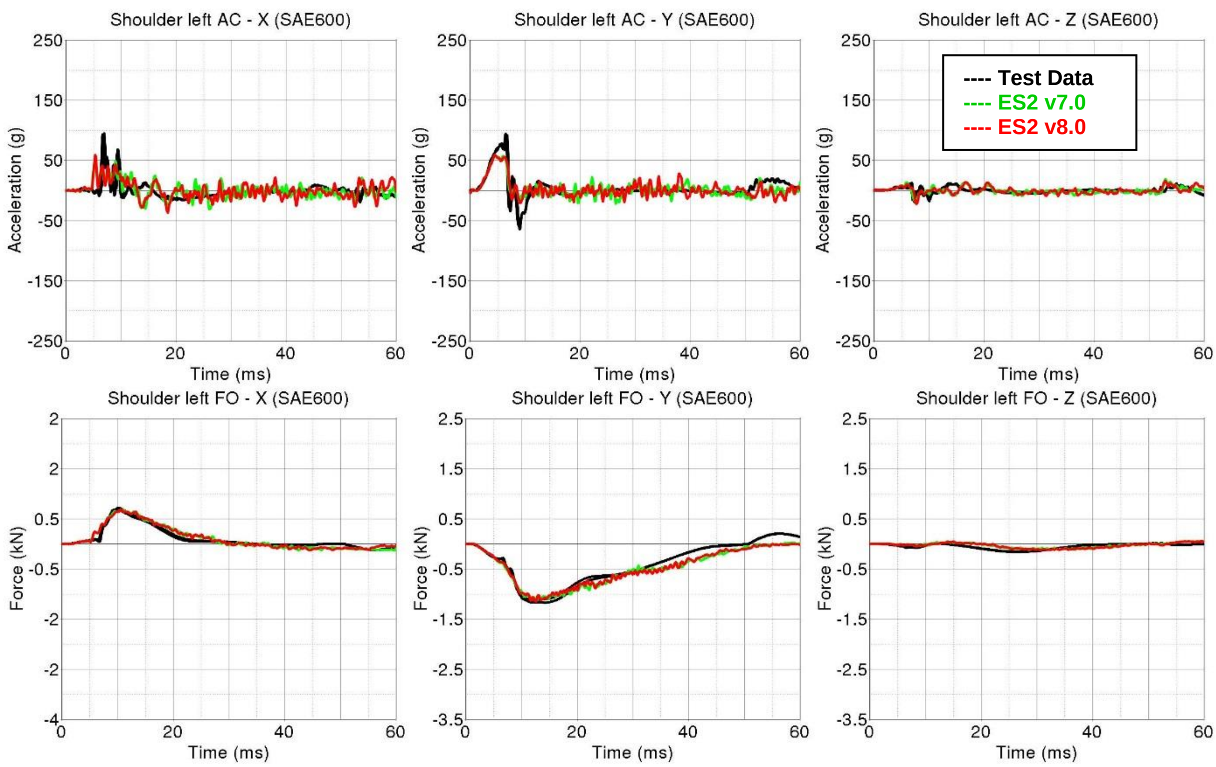


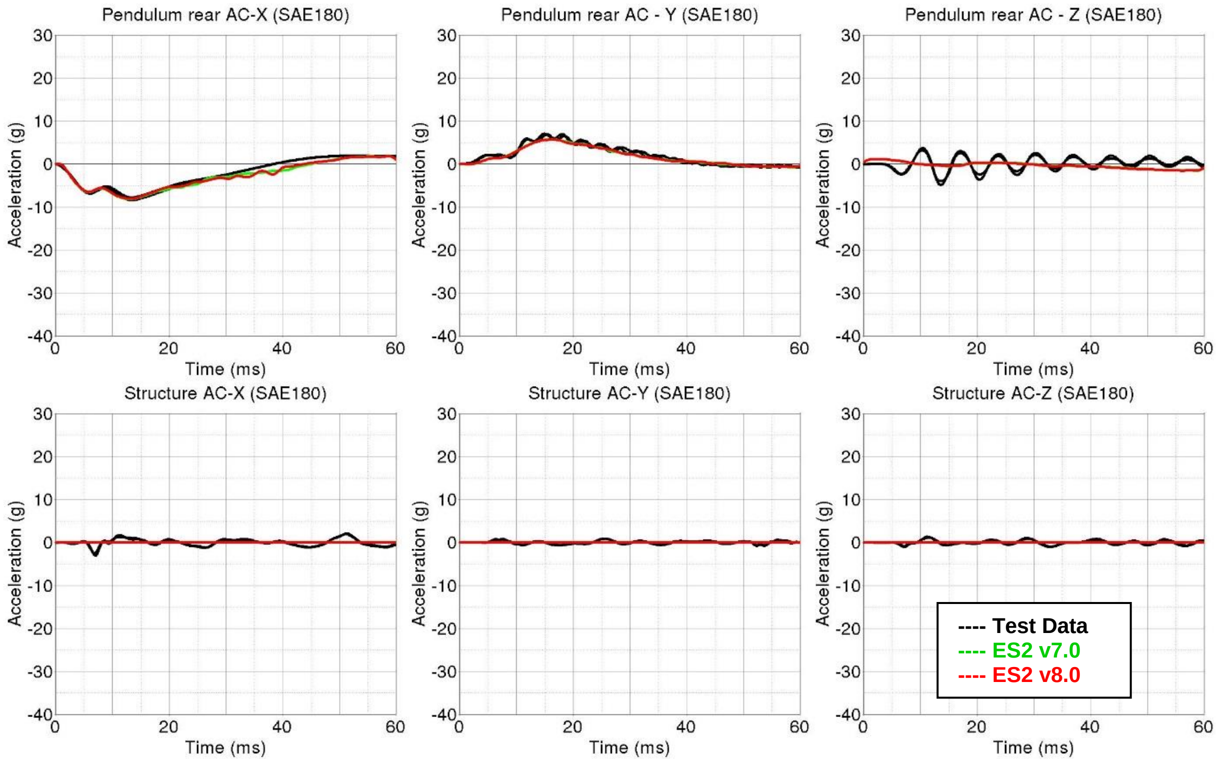




Results for Y-direction impact, low velocity, w/o clavicle strap (CBYOG)




Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Acceleration (g)
Force (kN)
Time (ms)


Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Acceleration (g)
Time (ms)

10.1.4 Abdomen slab test

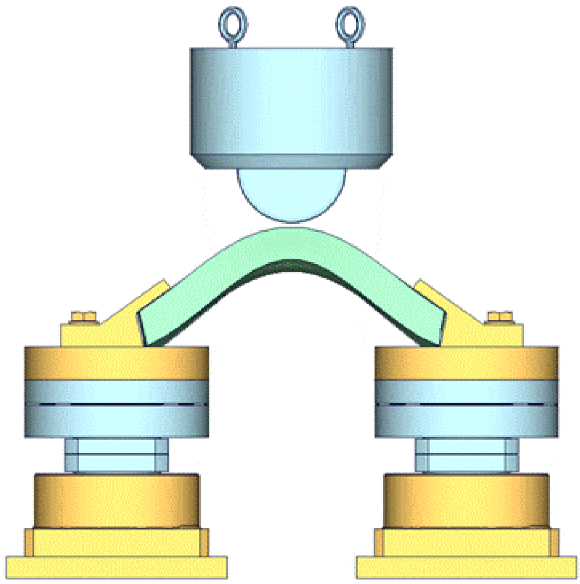
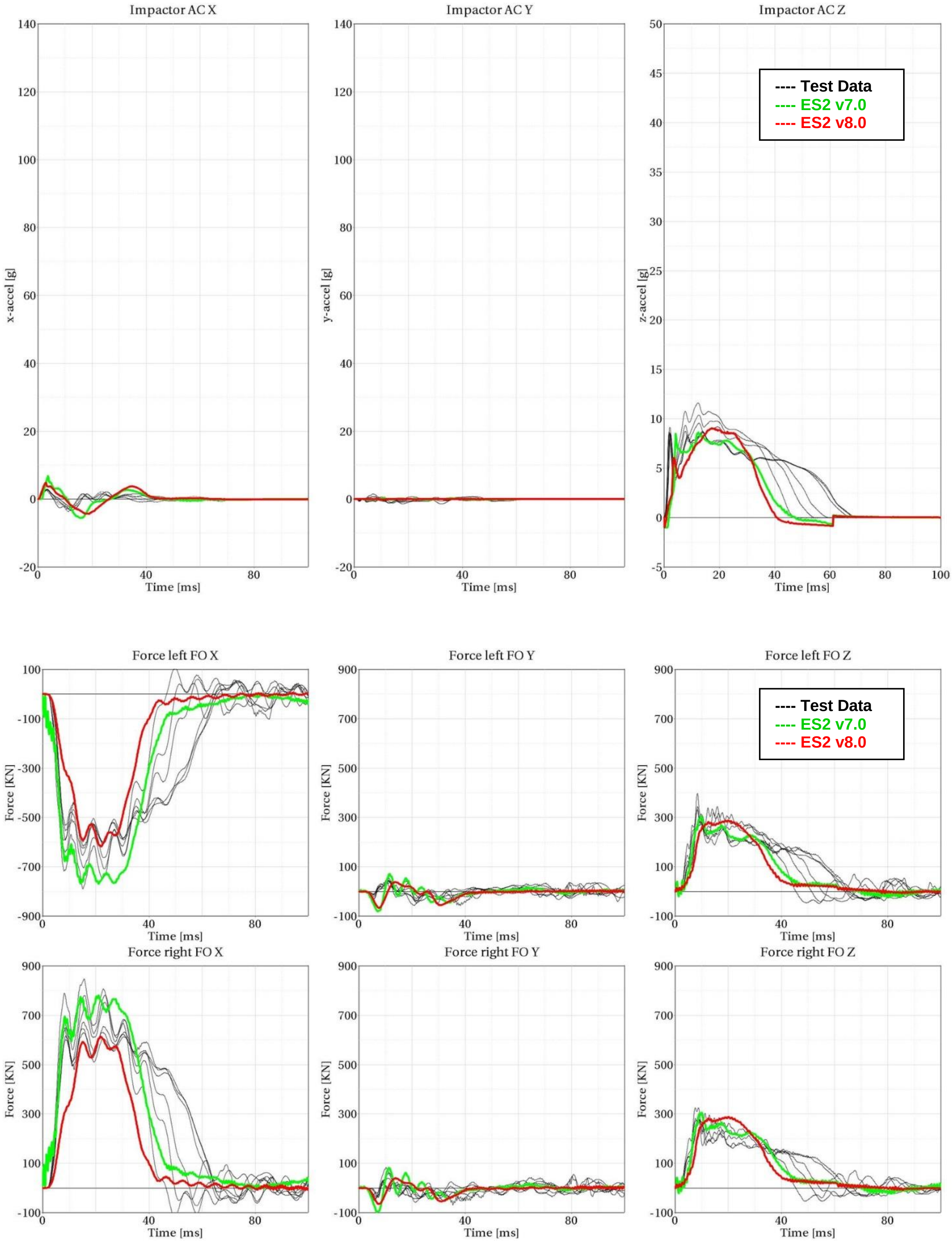


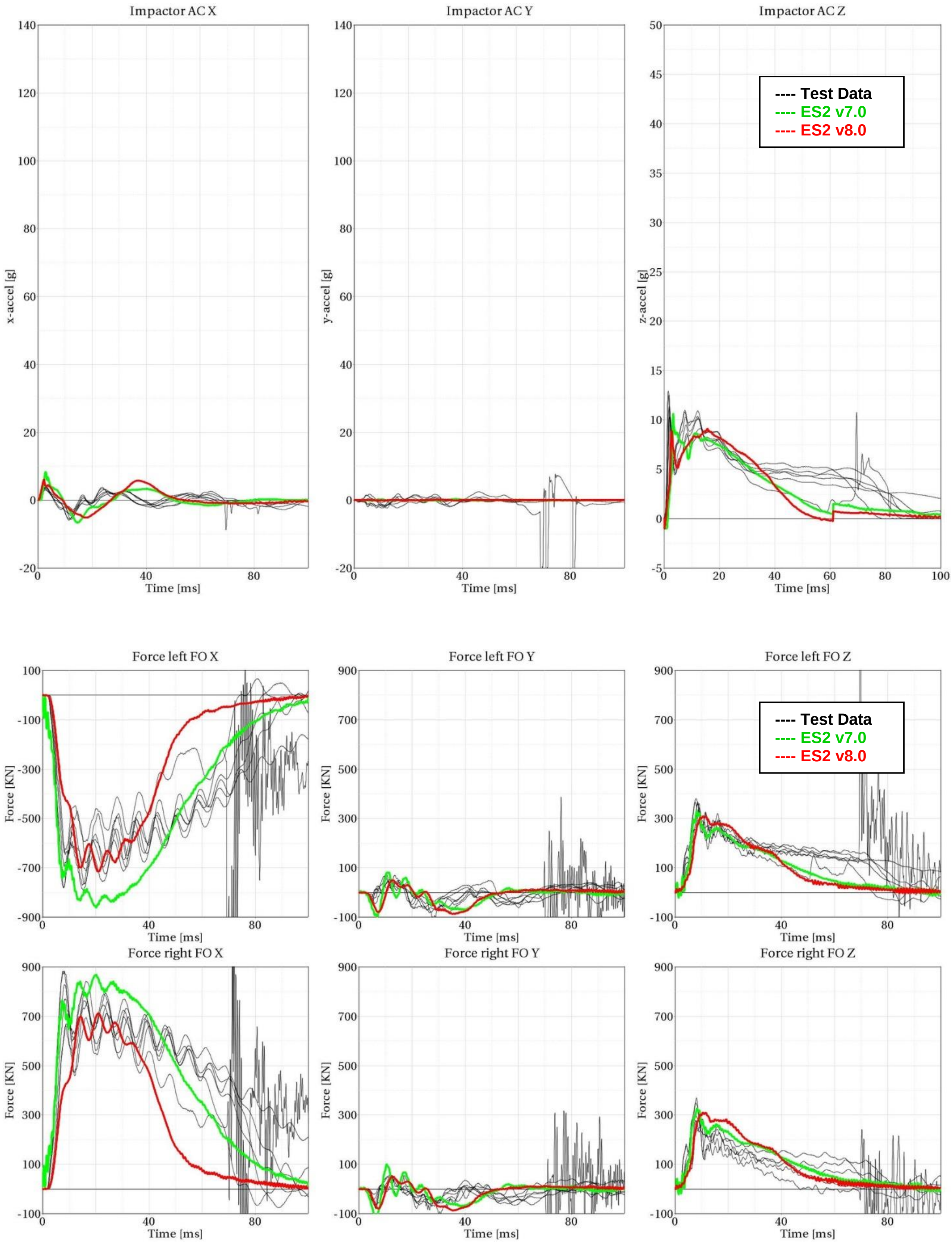
Figure 32: Test setup for Abdomen slab test

For the abdomen slab component test, the abdomen slab is held in a fixed position by two fixtures as shown in the figure above. The abdomen slab is impacted by a pendulum at two different velocities.

Results for low velocity impact



Results for high velocity impact



10.1.5 Abdomen test

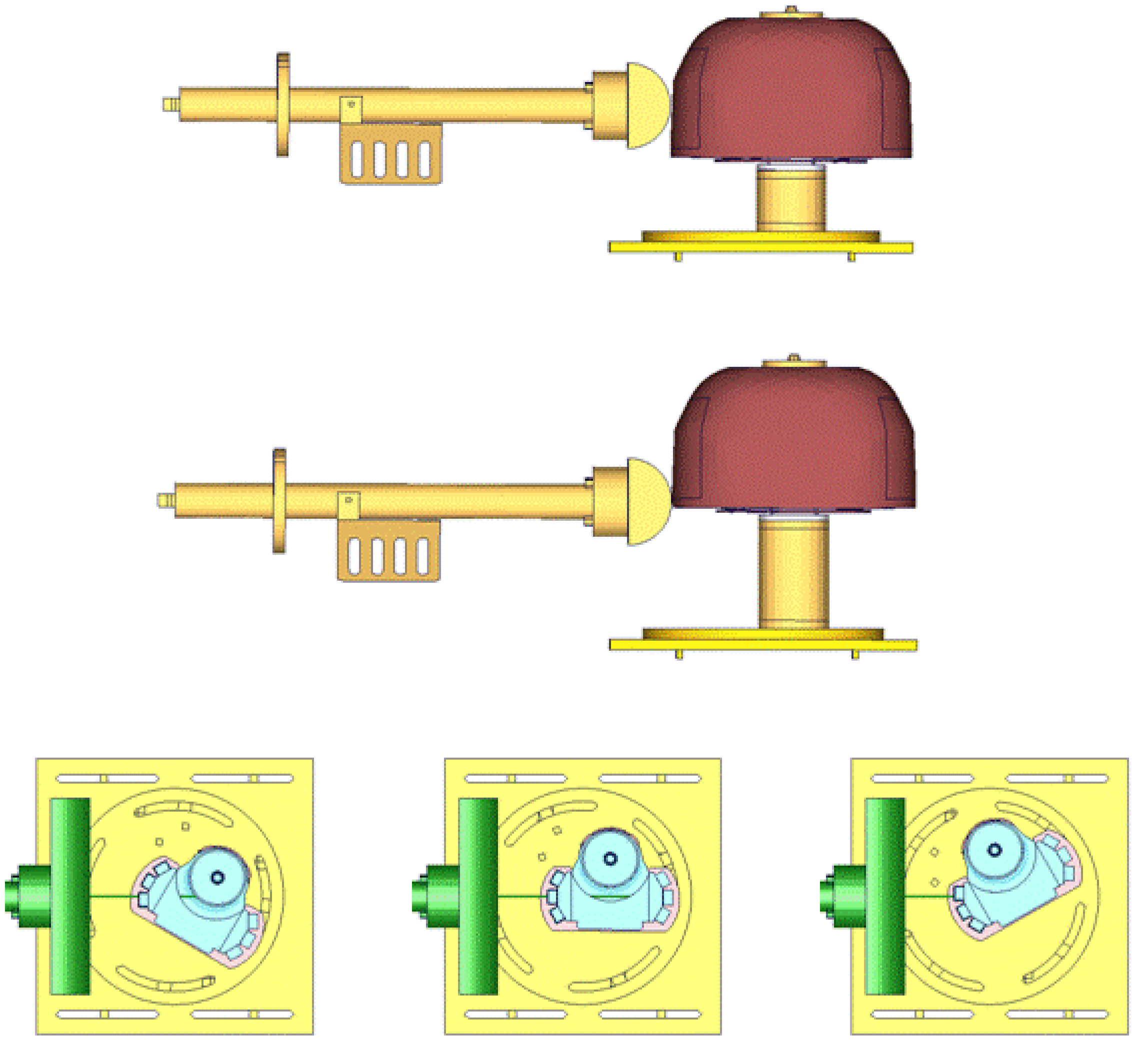
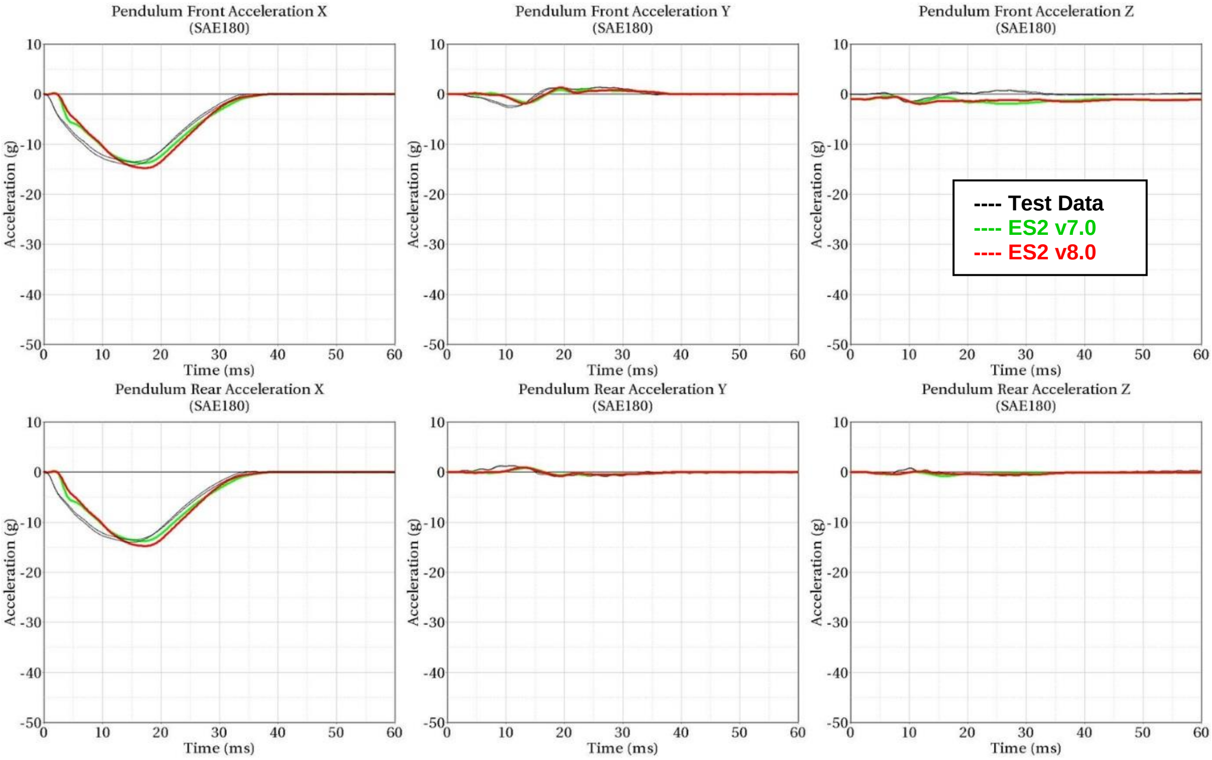
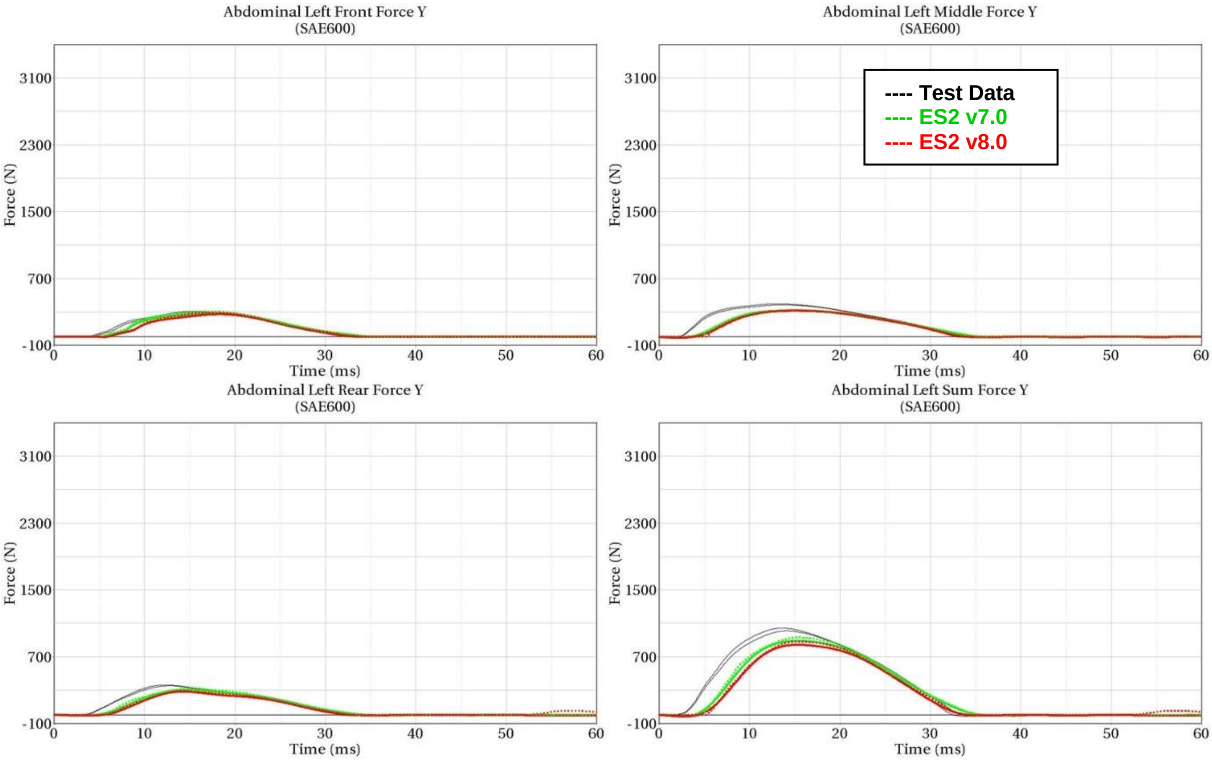


Figure 33: Test setup for Abdomen test

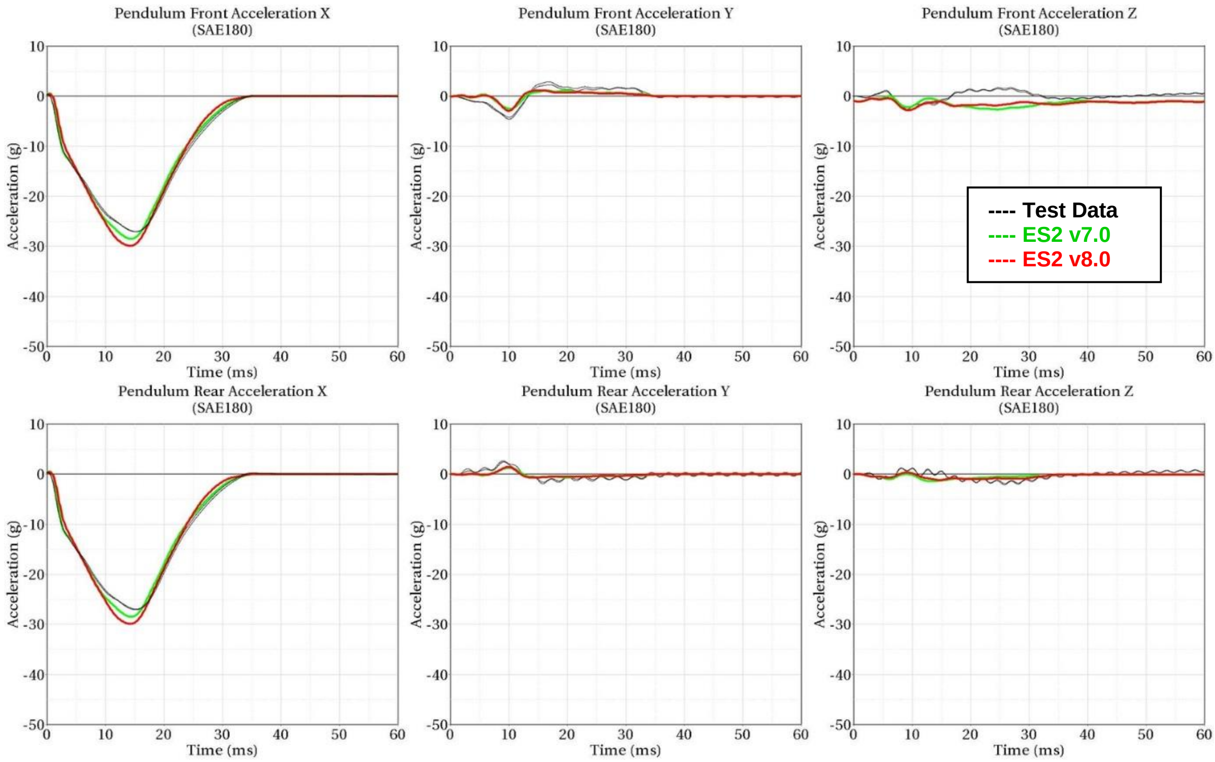
The test setup for the abdomen test is shown in the figure above. The Abdomen assembly is impacted by a pendulum at two different heights with three different velocities and three different abdomen assembly orientations each. The different abdomen assembly orientations are achieved by rotating the abdomen assembly by 30 degrees on either side of the adaptor axis.

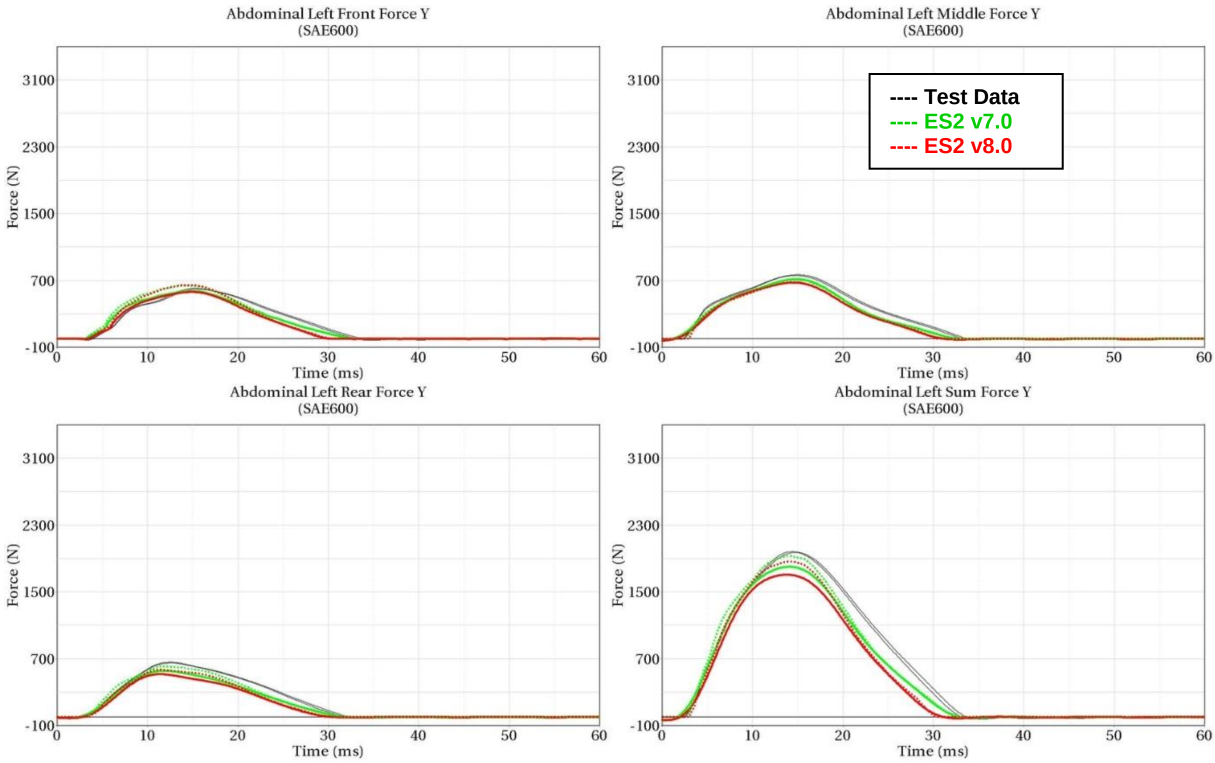
Results for 90° orientation, middle impact, low velocity



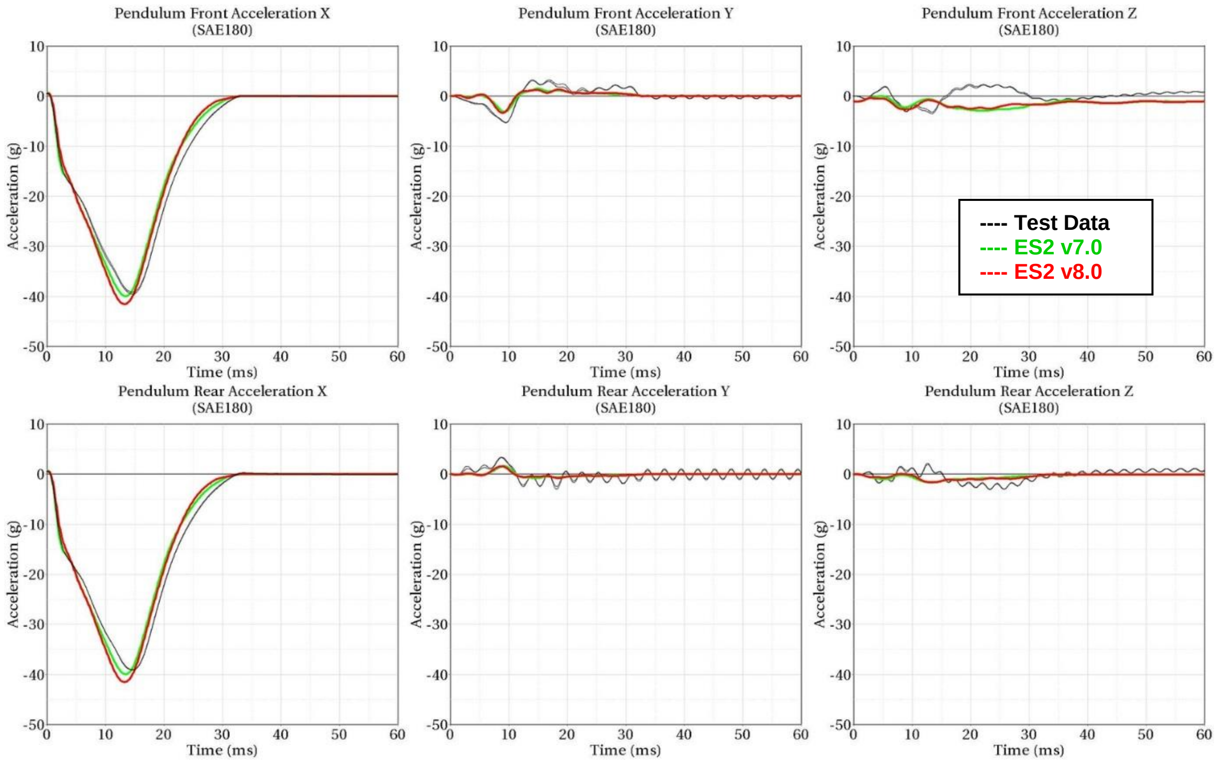


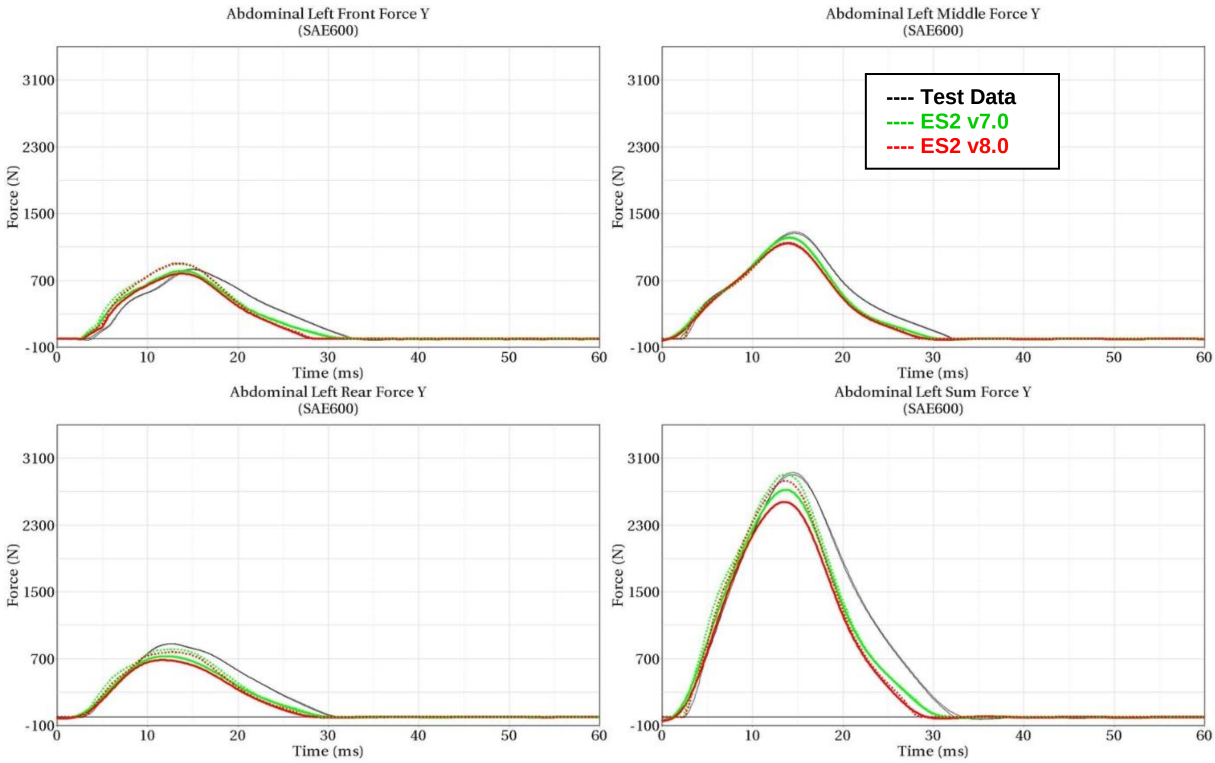
Results for 90° orientation, middle impact, medium velocity



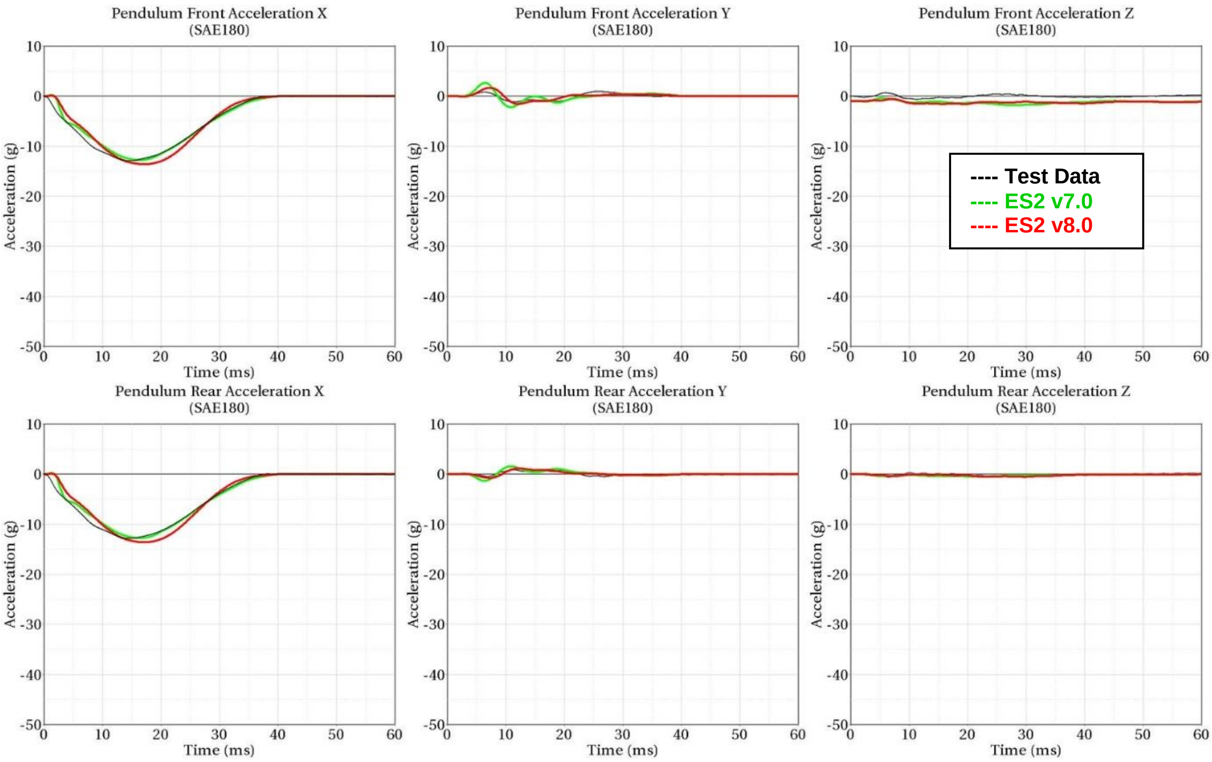


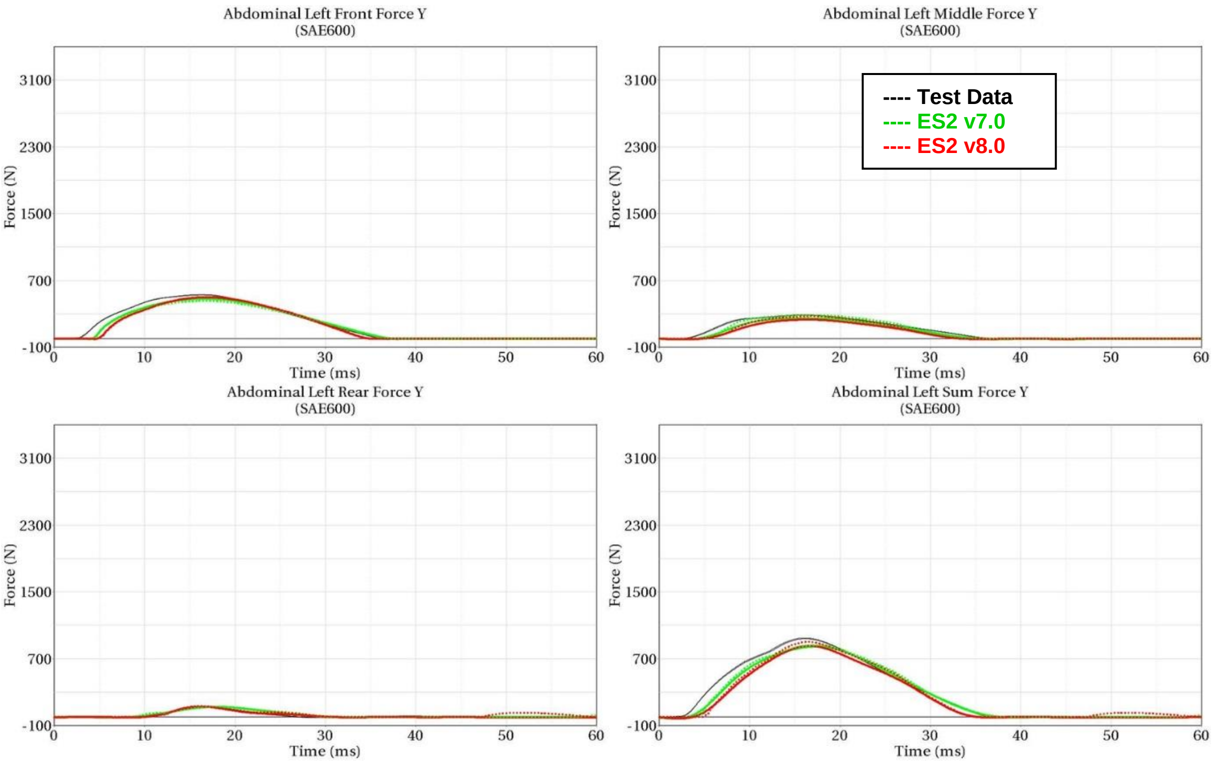
Results for 90° orientation, middle impact, high velocity



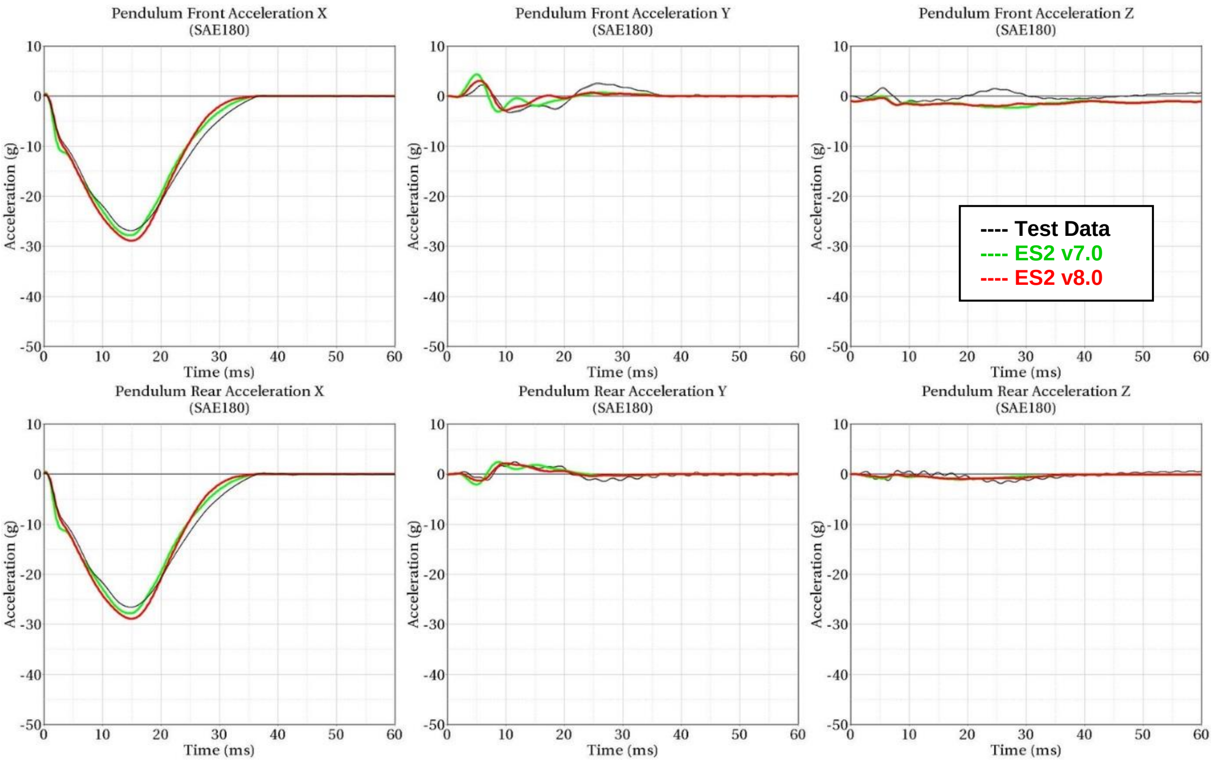


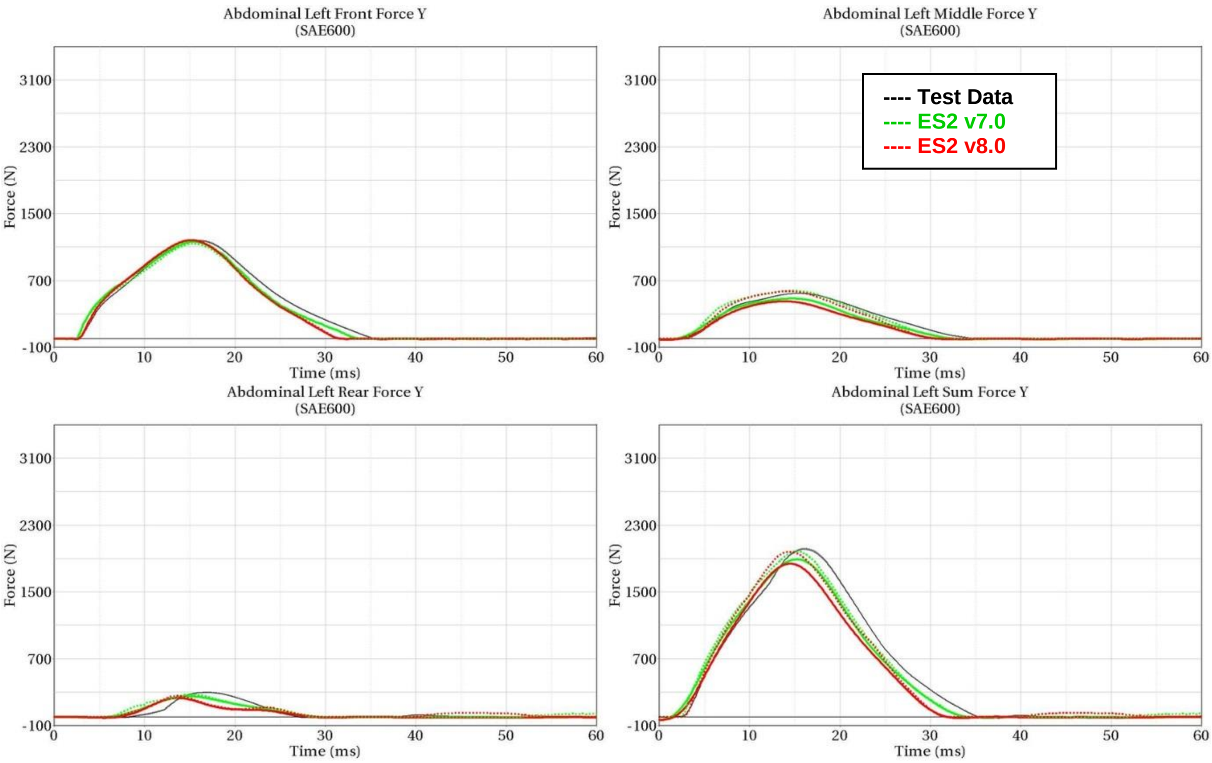
Results for 60° orientation, middle impact, low velocity



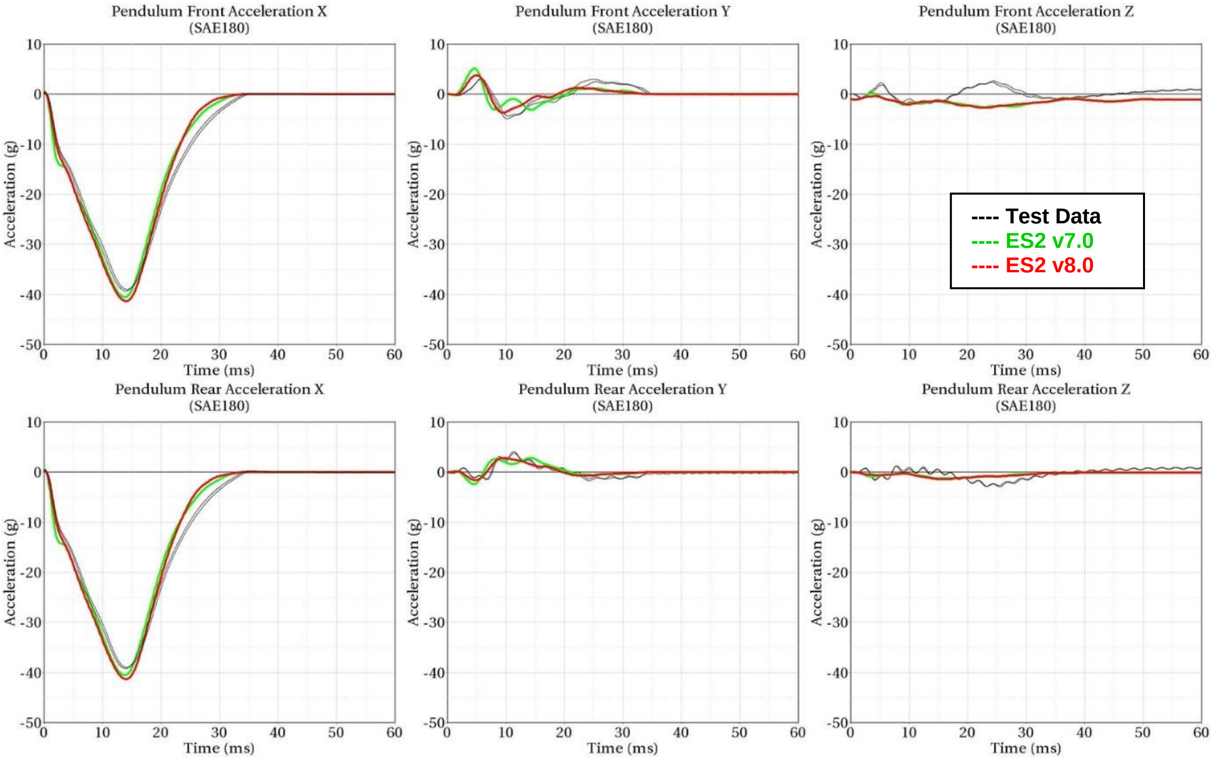


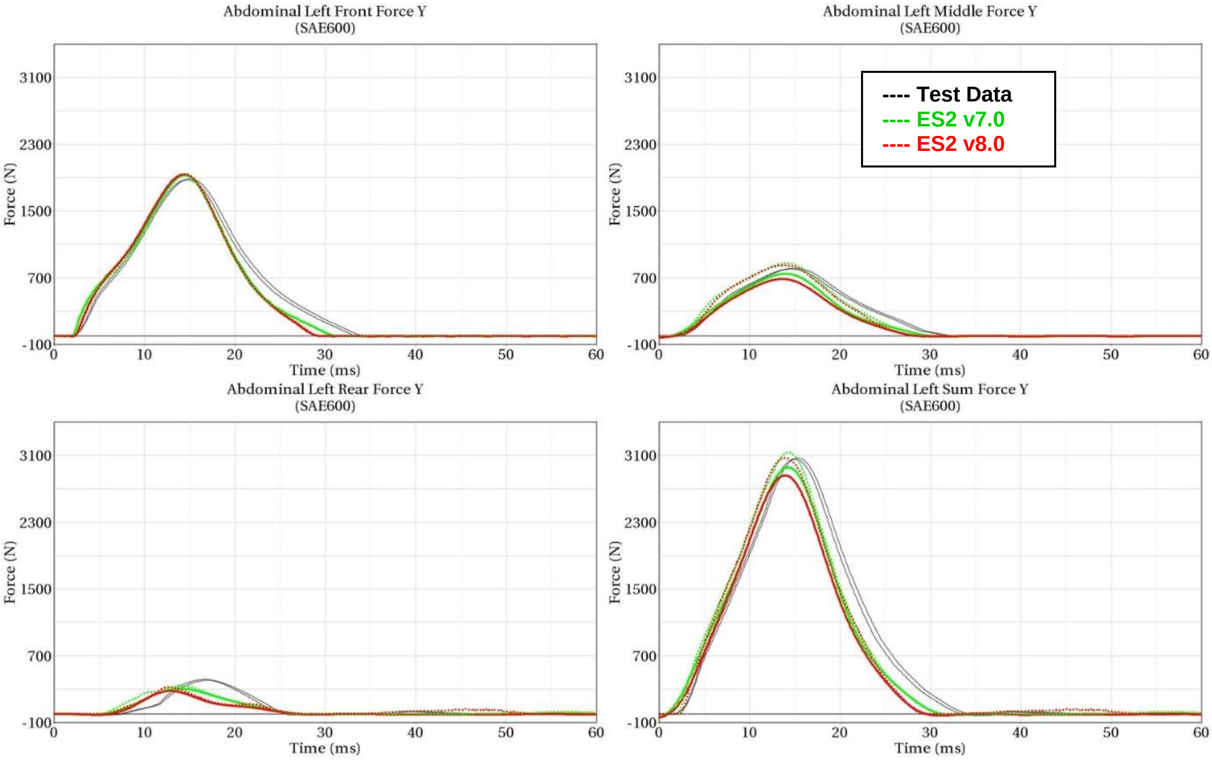
Results for 60° orientation, middle impact, medium velocity



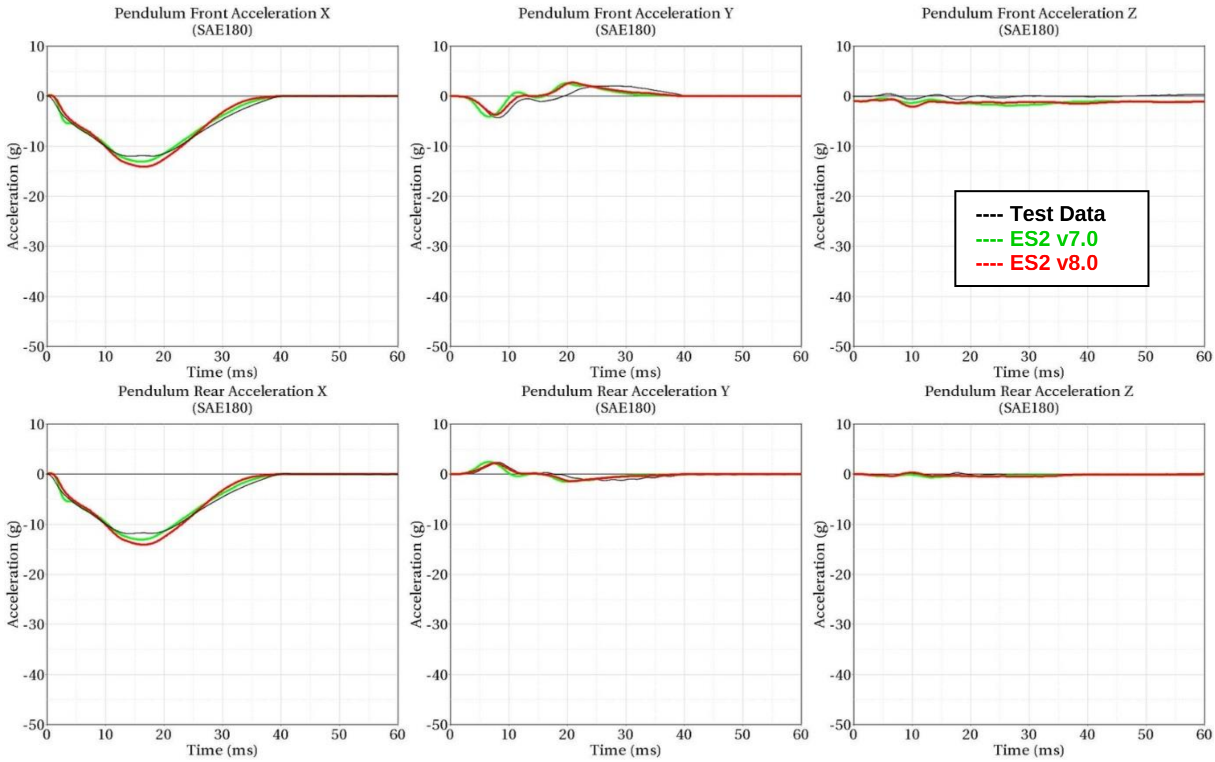


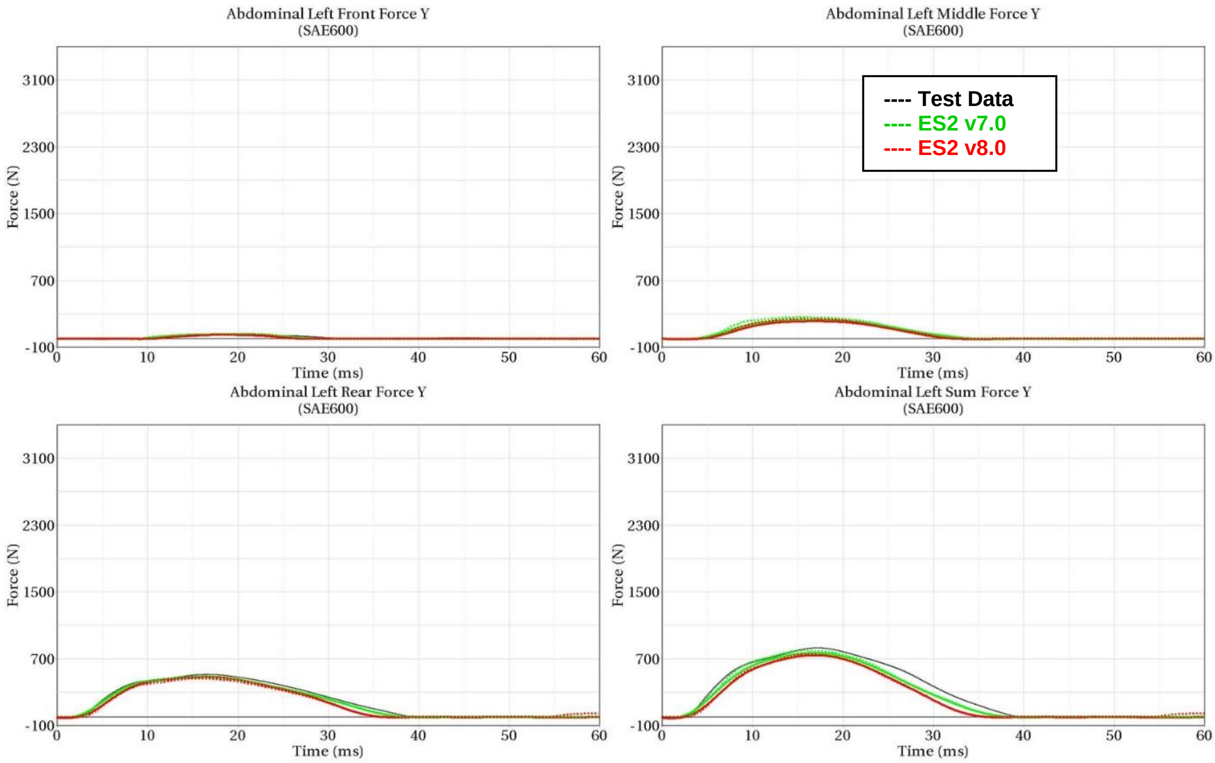
Results for 60° orientation, middle impact, high velocity



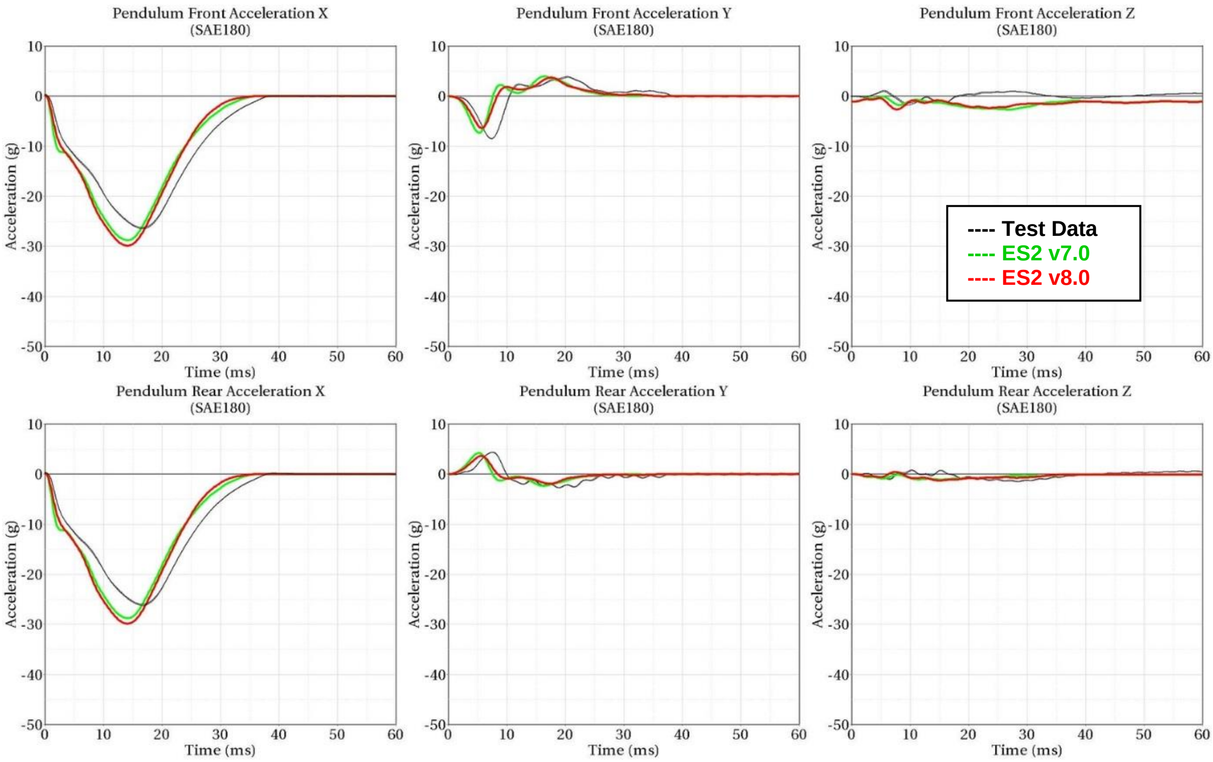


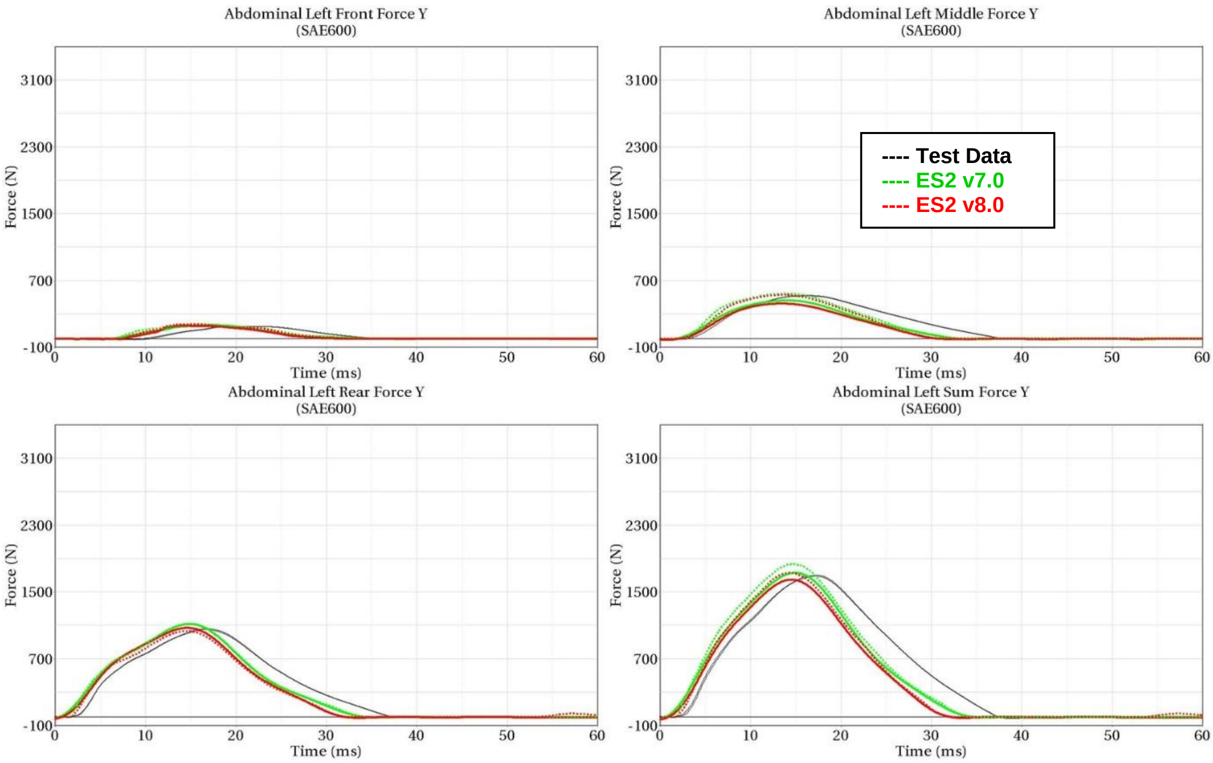
Results for 120° orientation, middle impact, low velocity



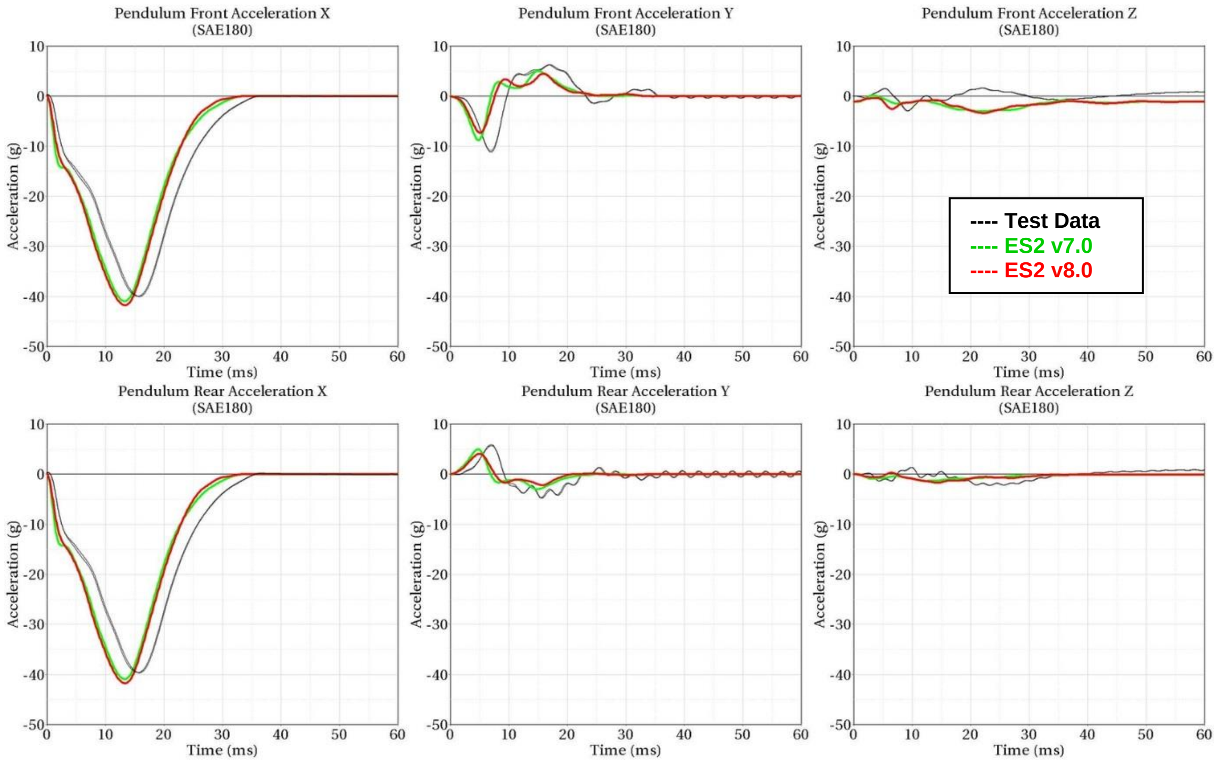


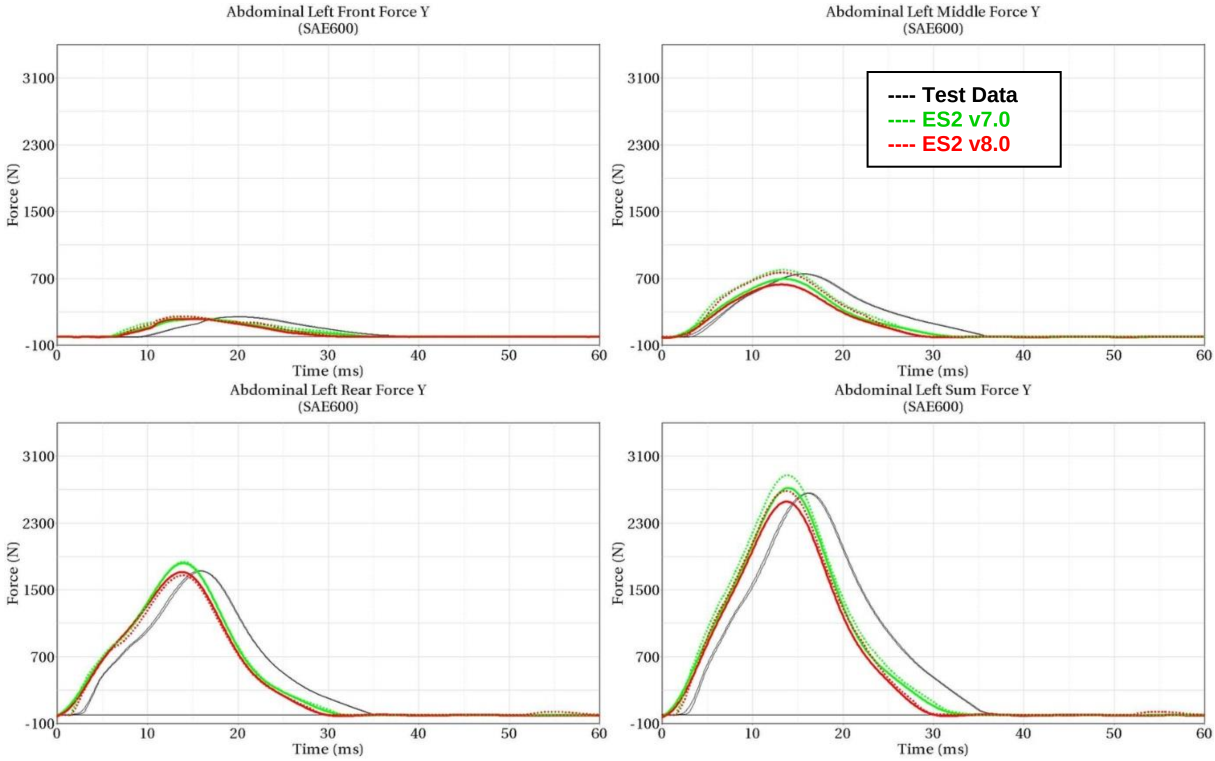
Results for 120° orientation, middle impact, medium velocity



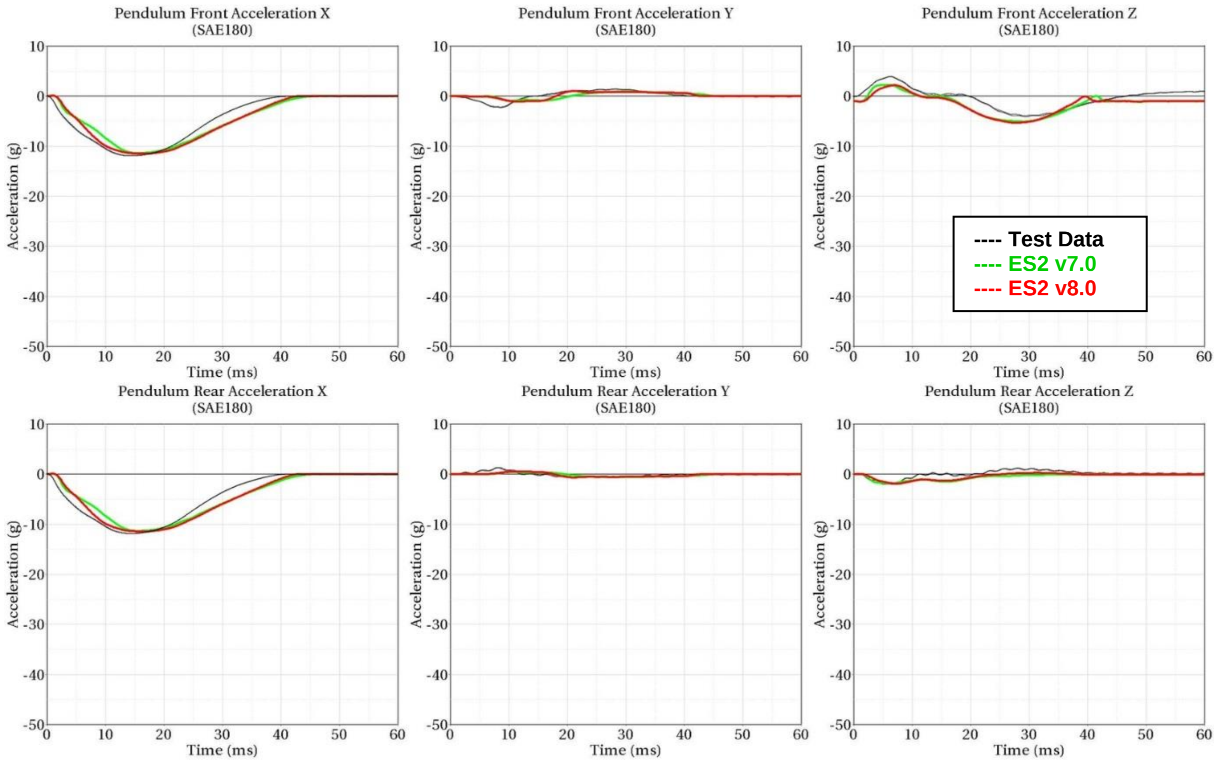


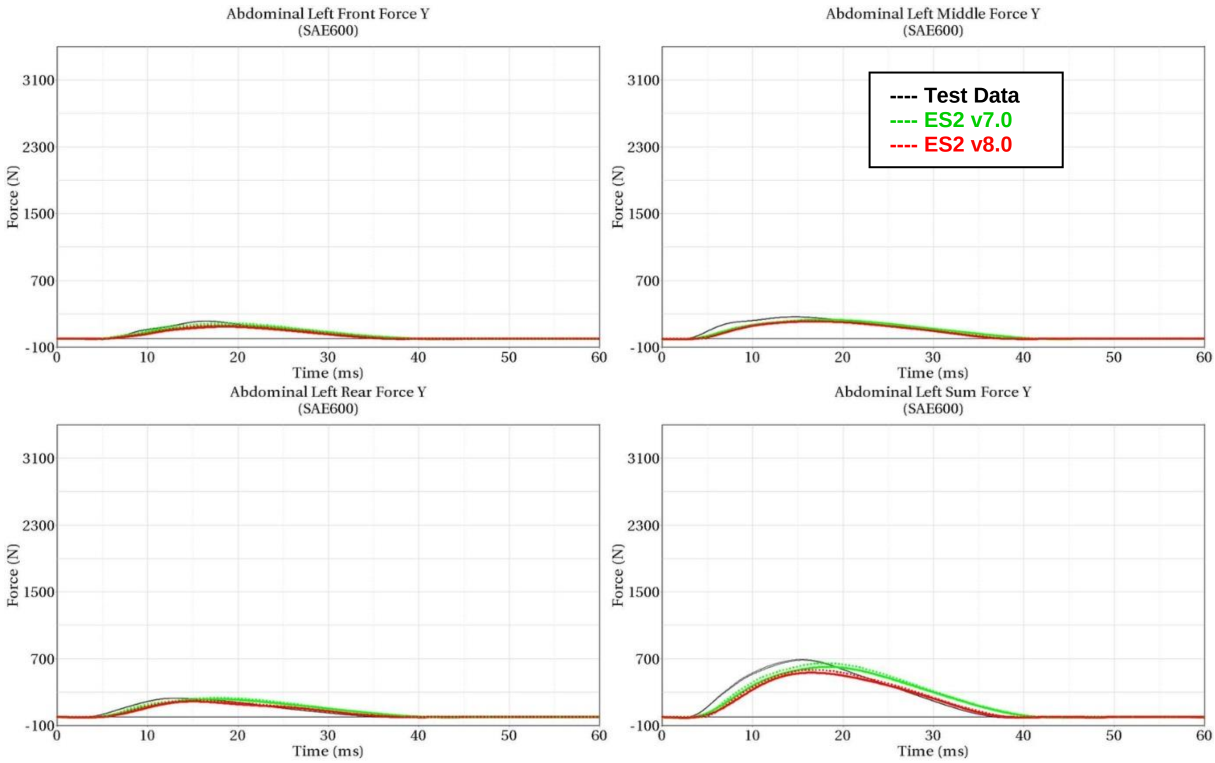
Results for 120° orientation, middle impact, high velocity



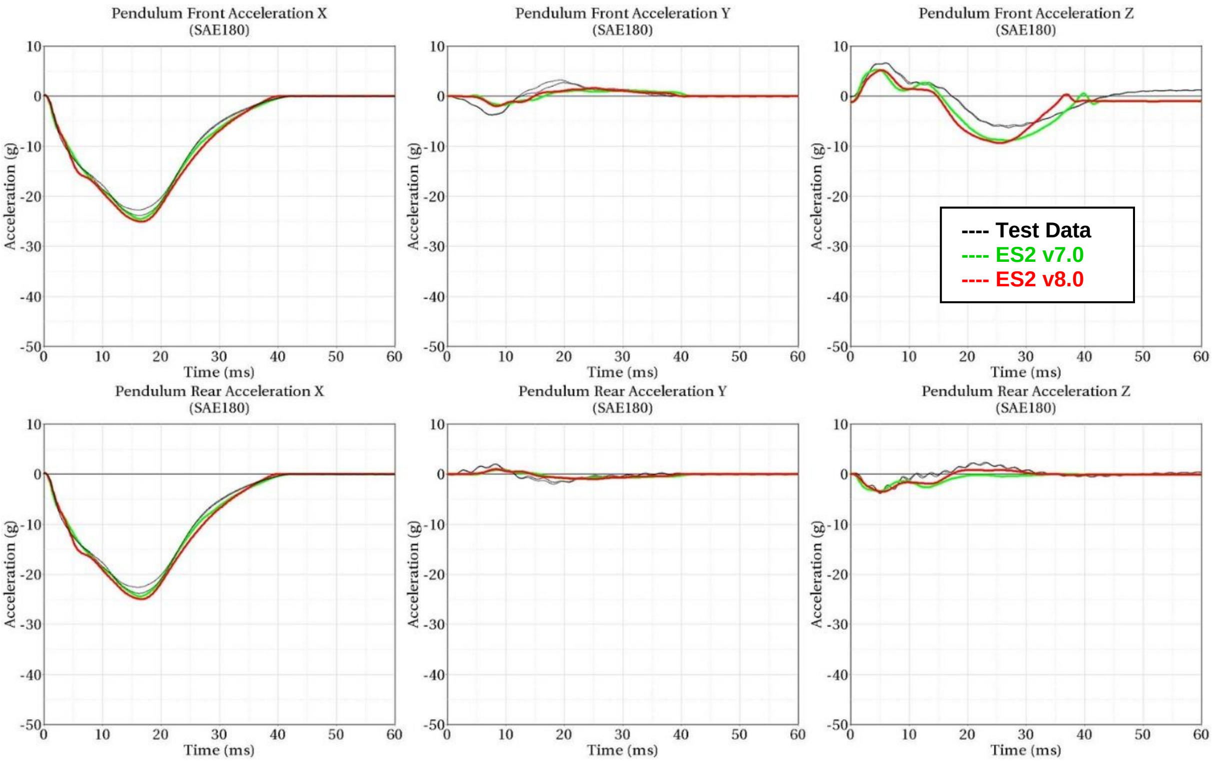


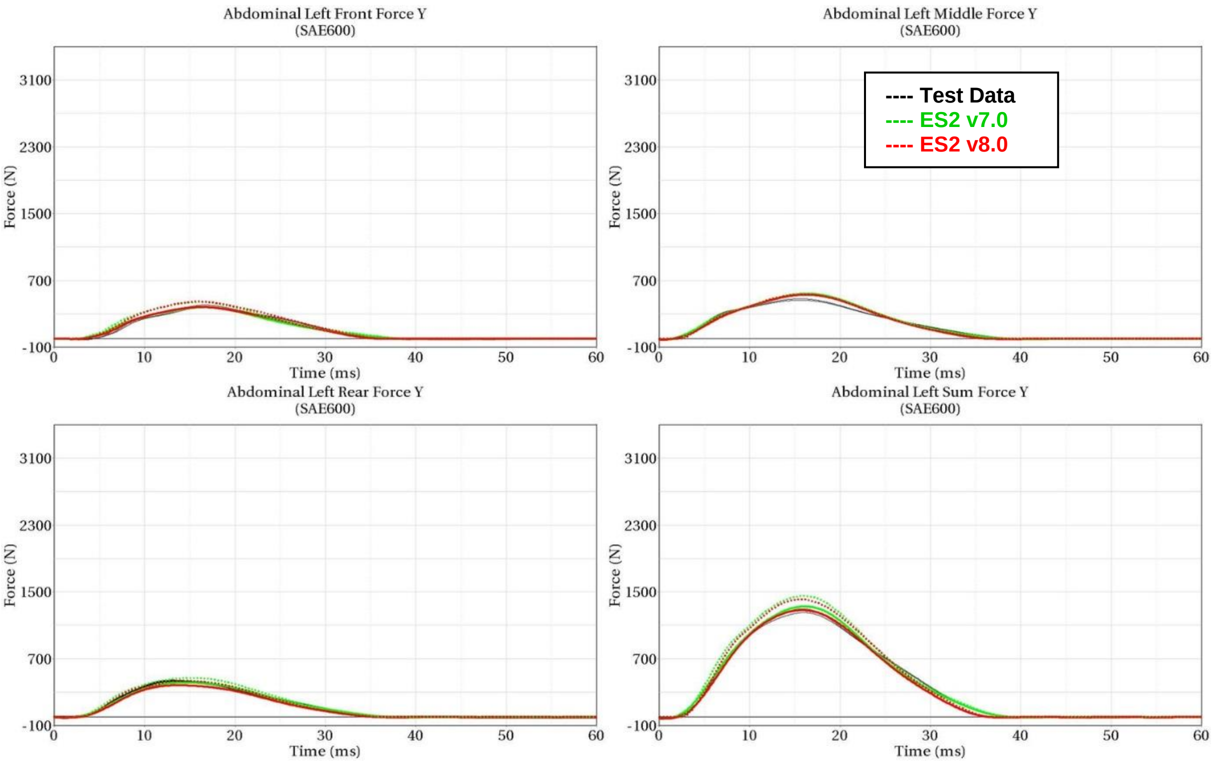
Results for 90° orientation, top impact, low velocity



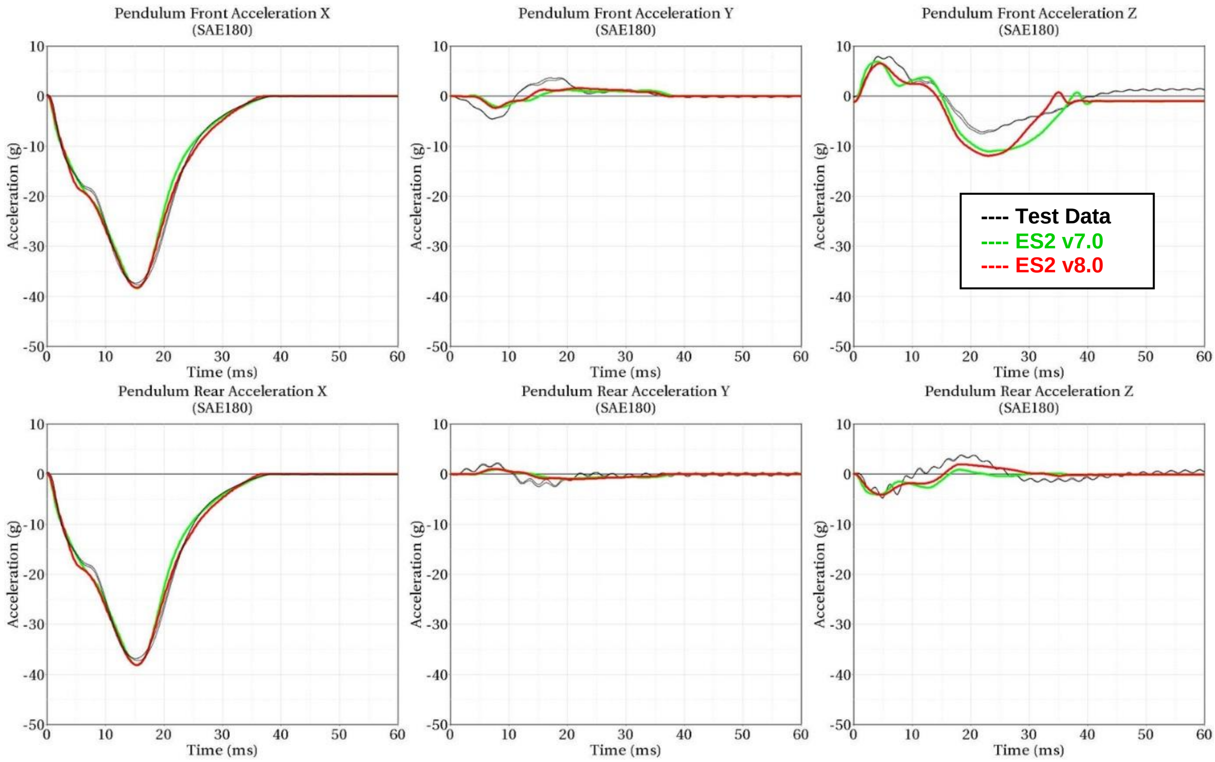


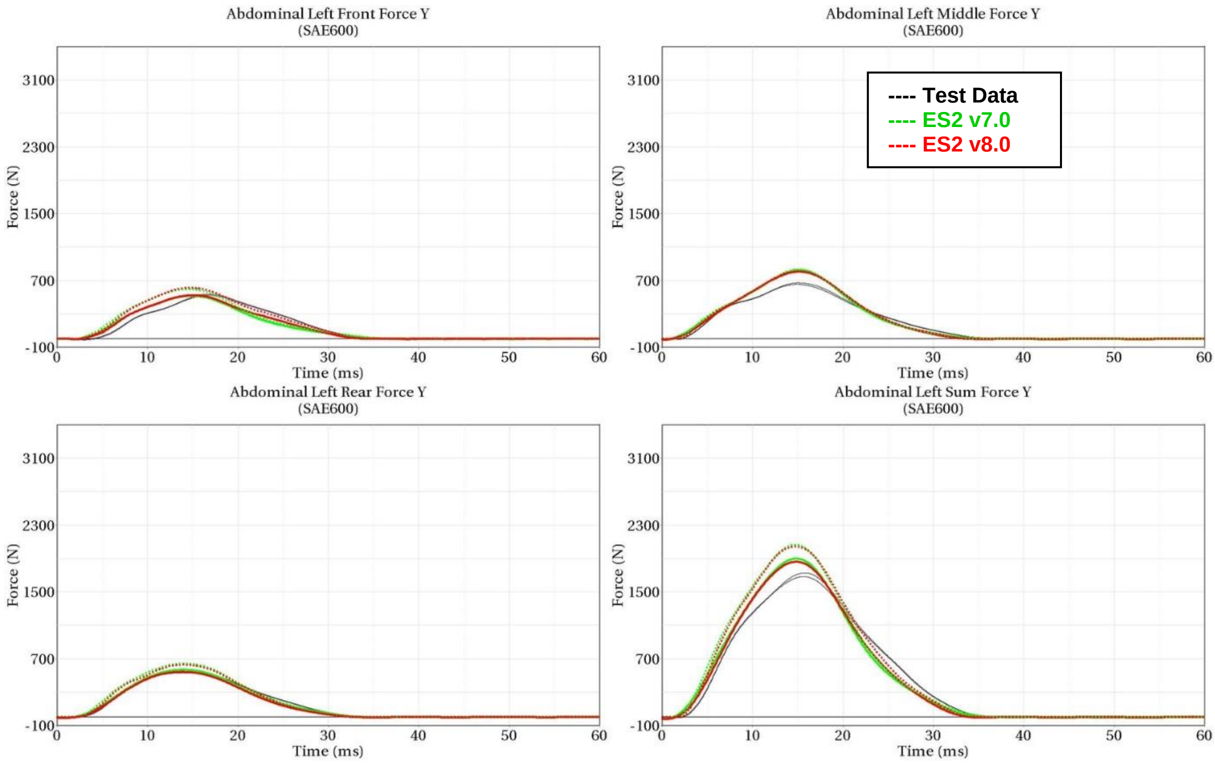
Results for 90° orientation, top impact, medium velocity



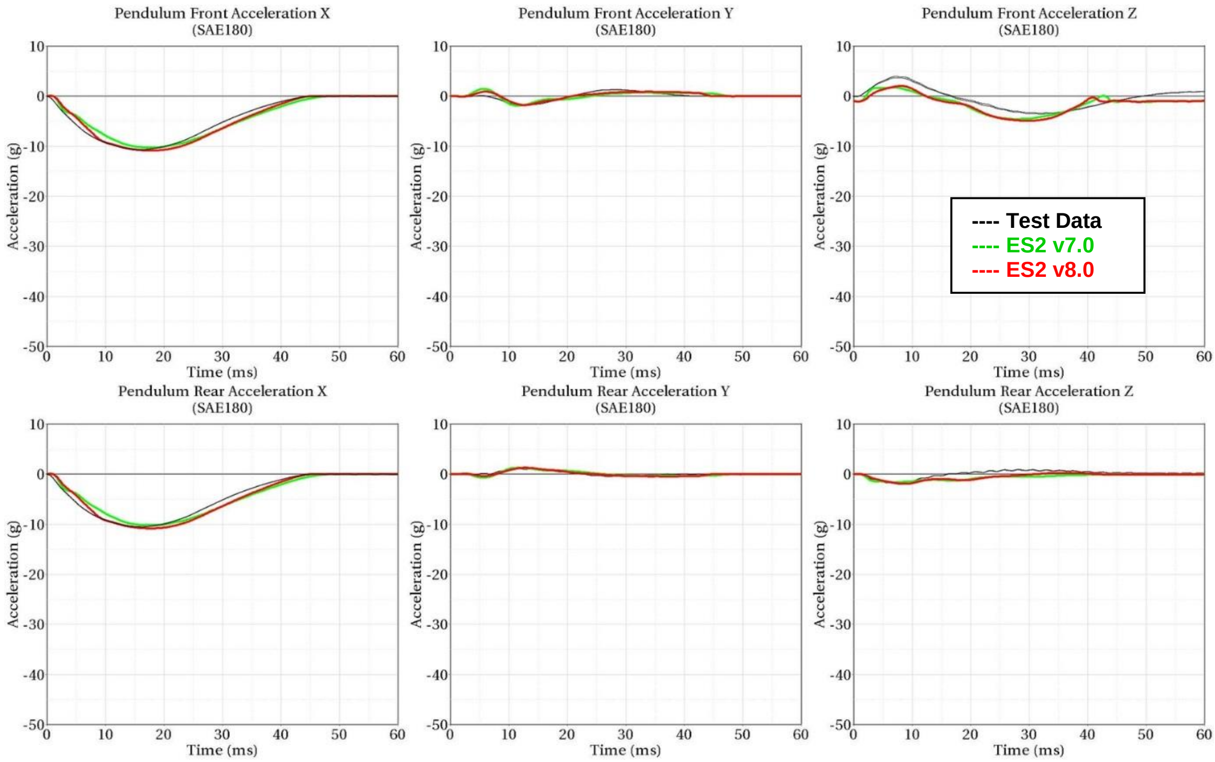


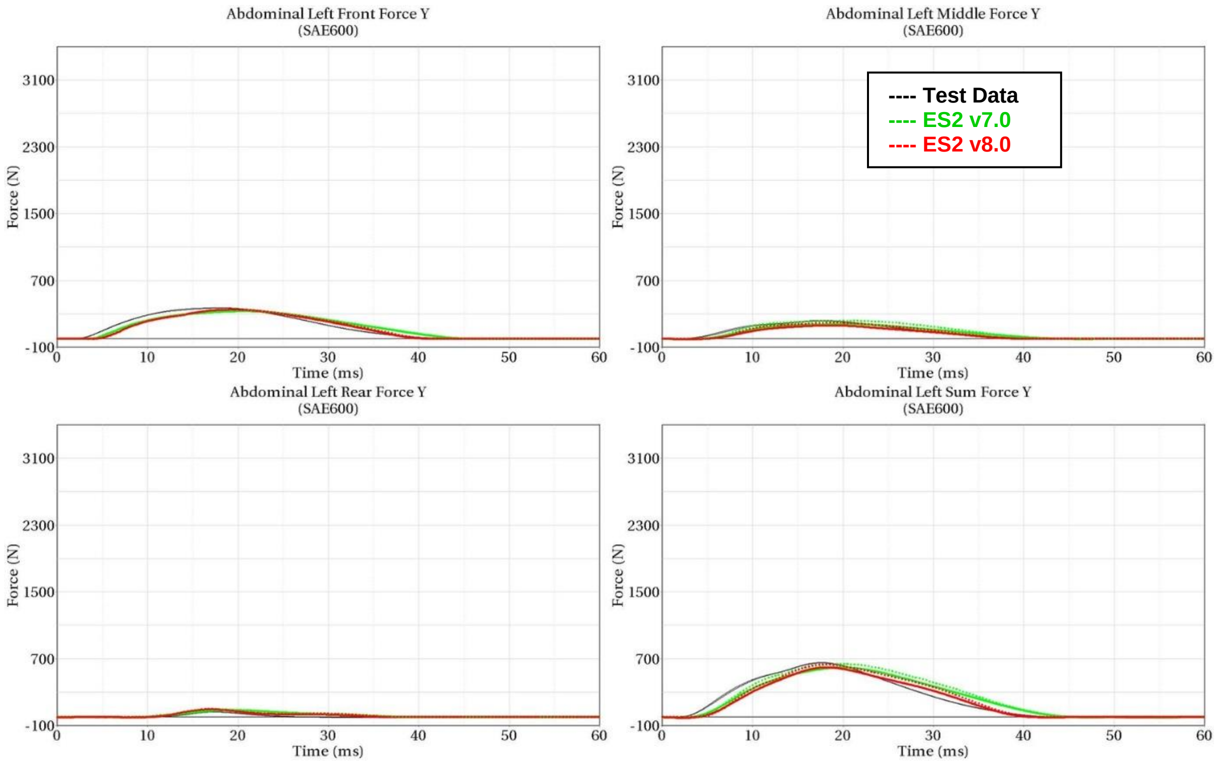
Results for 90° orientation, top impact, high velocity



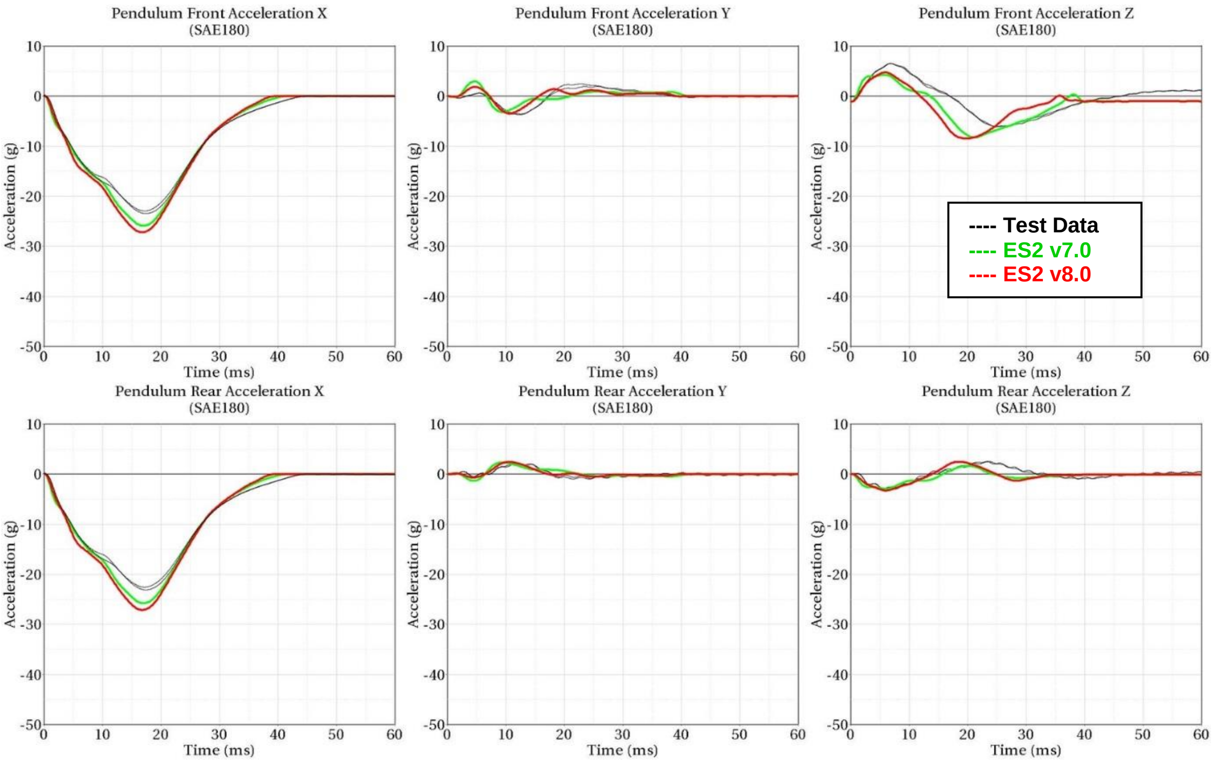


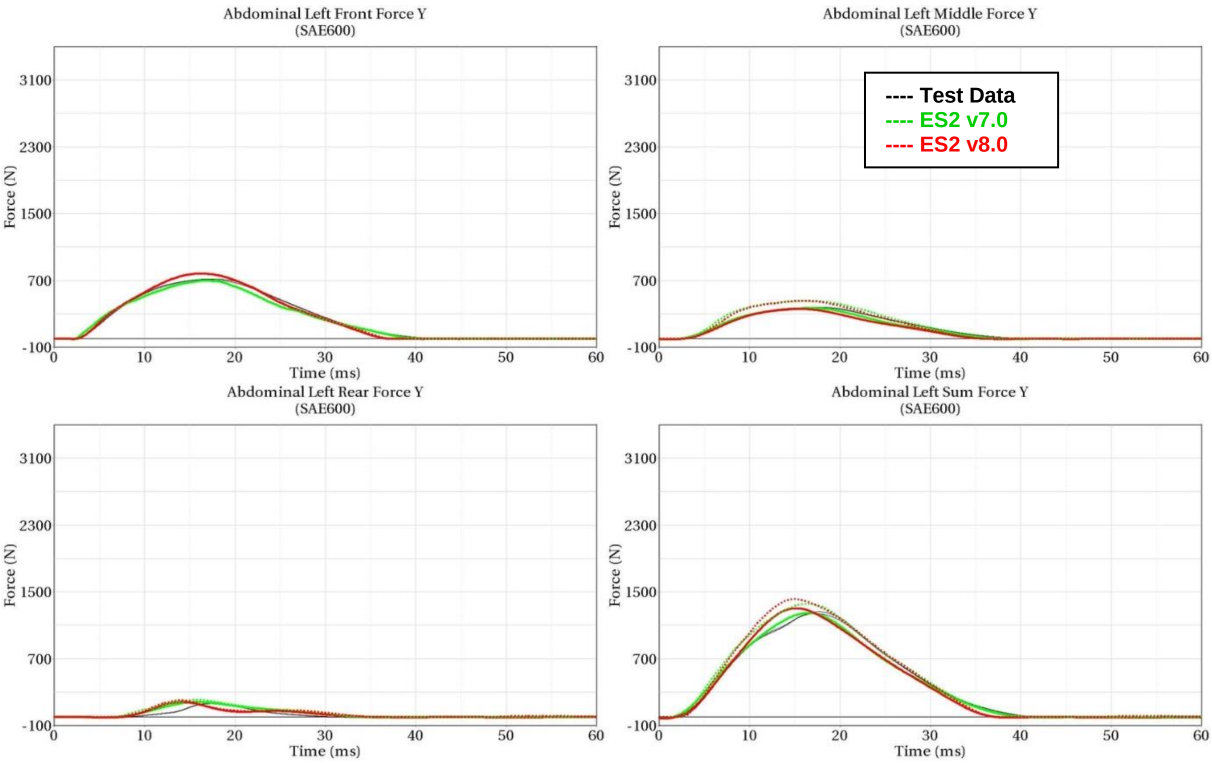
Results for 60° orientation, top impact, low velocity



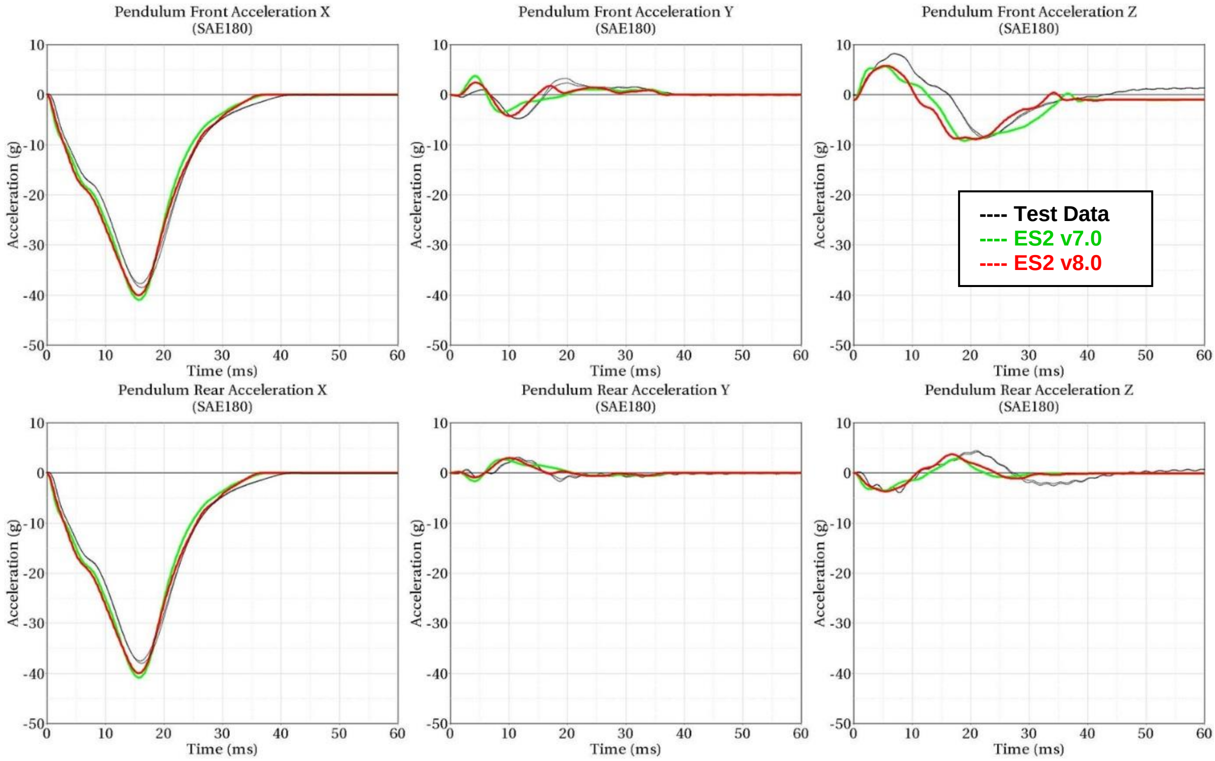


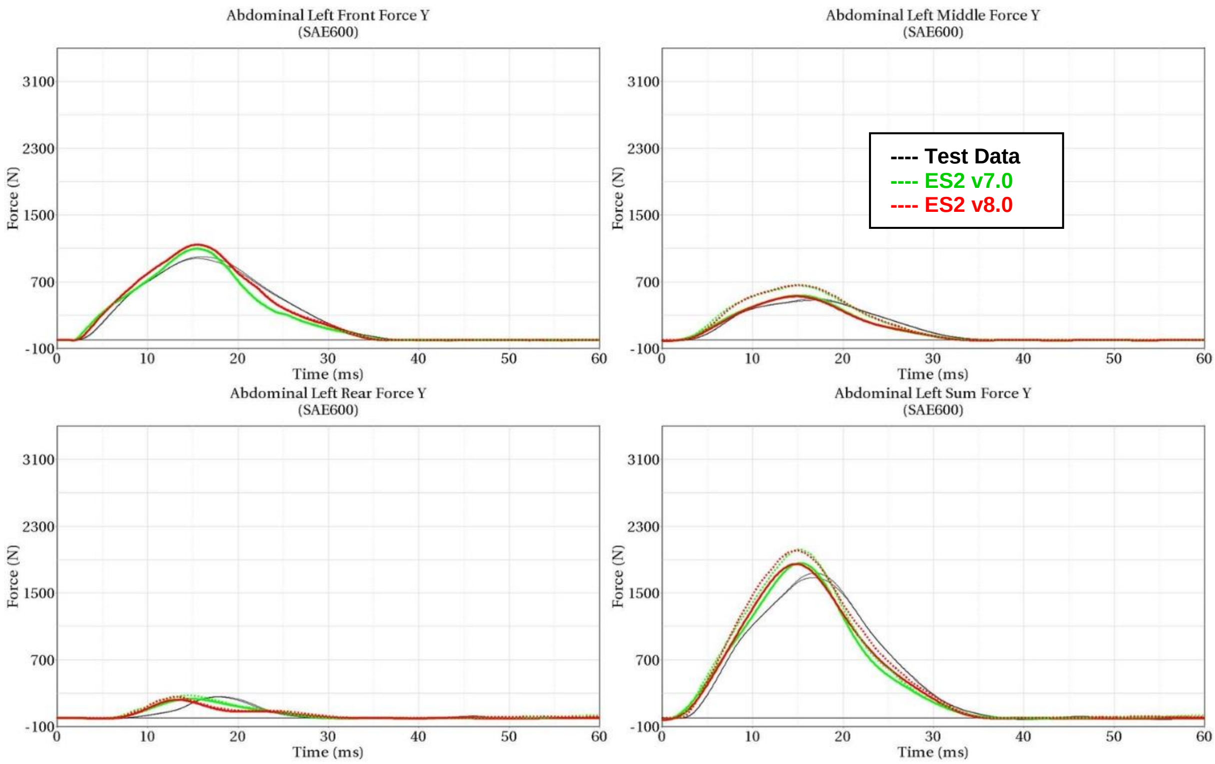
Results for 60° orientation, top impact, medium velocity



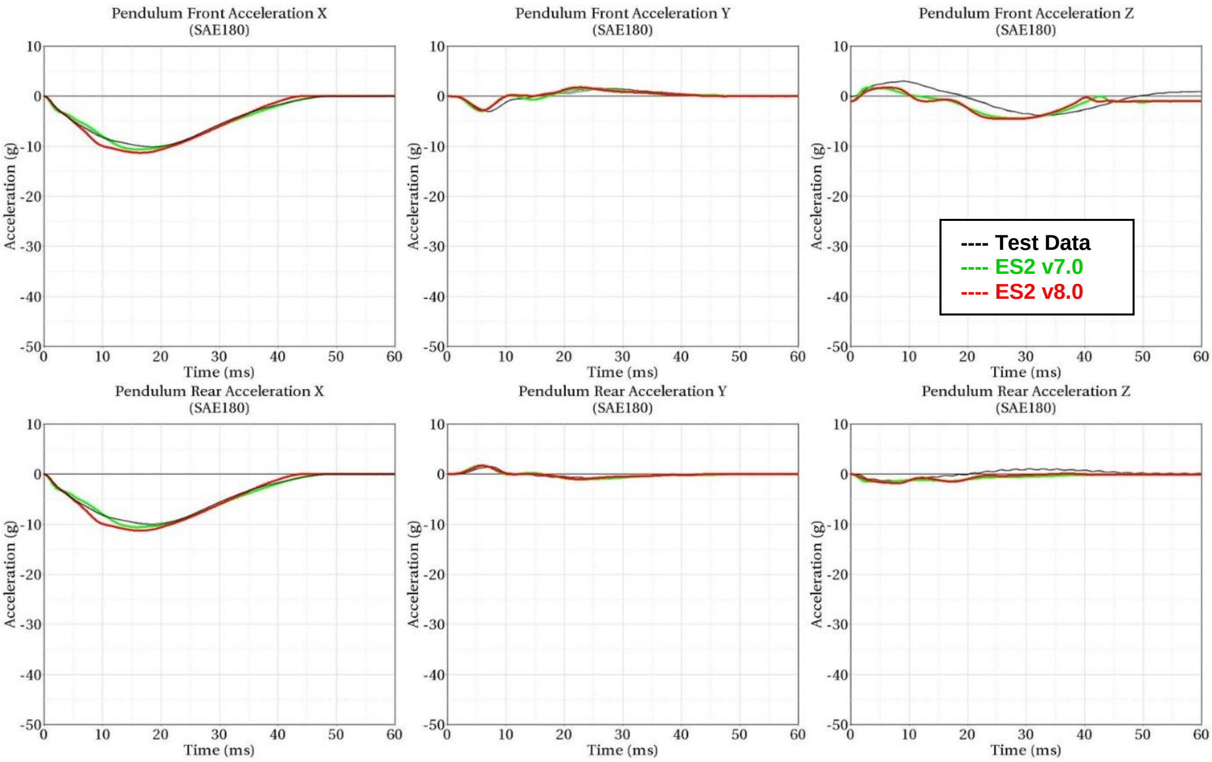


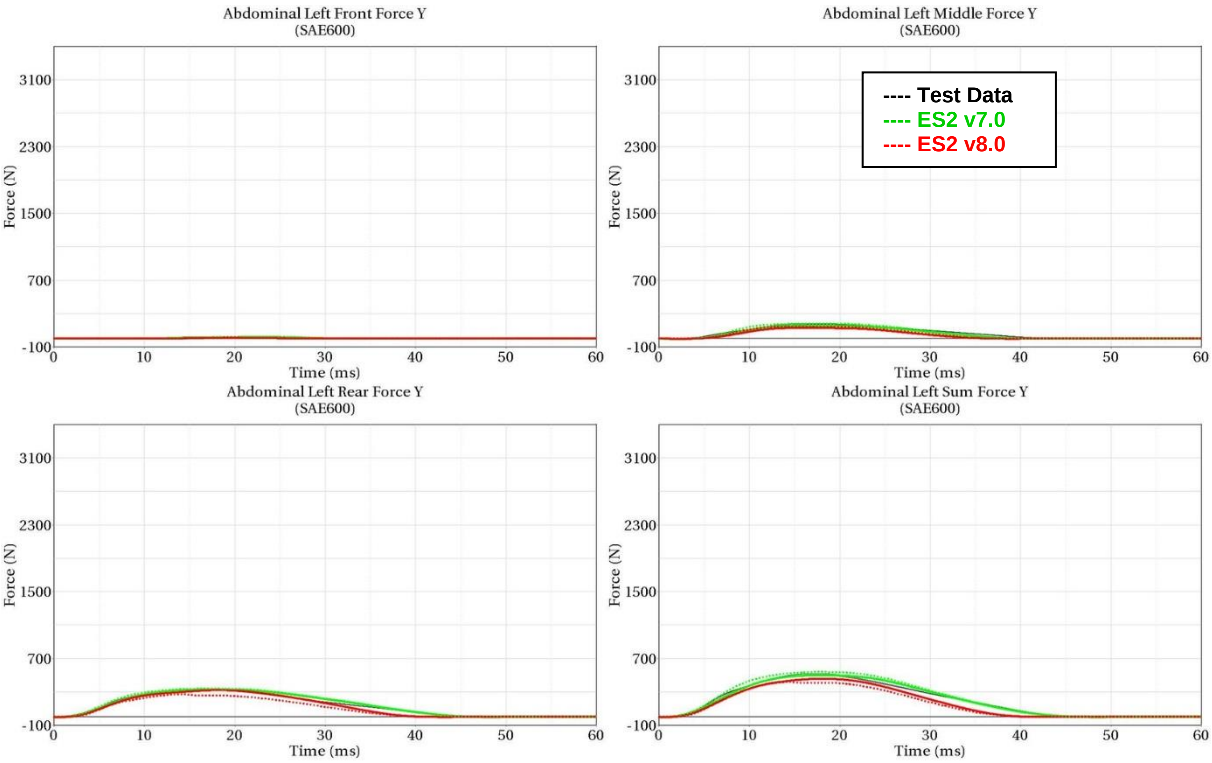
Results for 60° orientation, top impact, high velocity



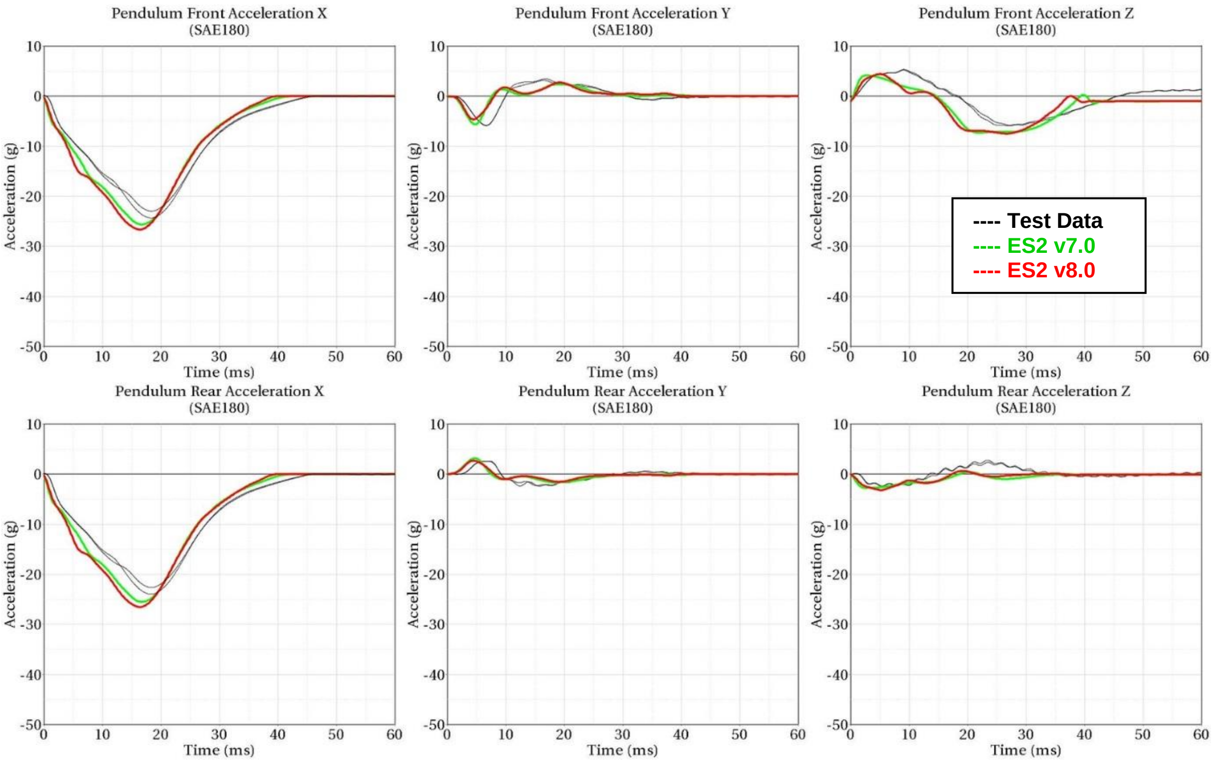


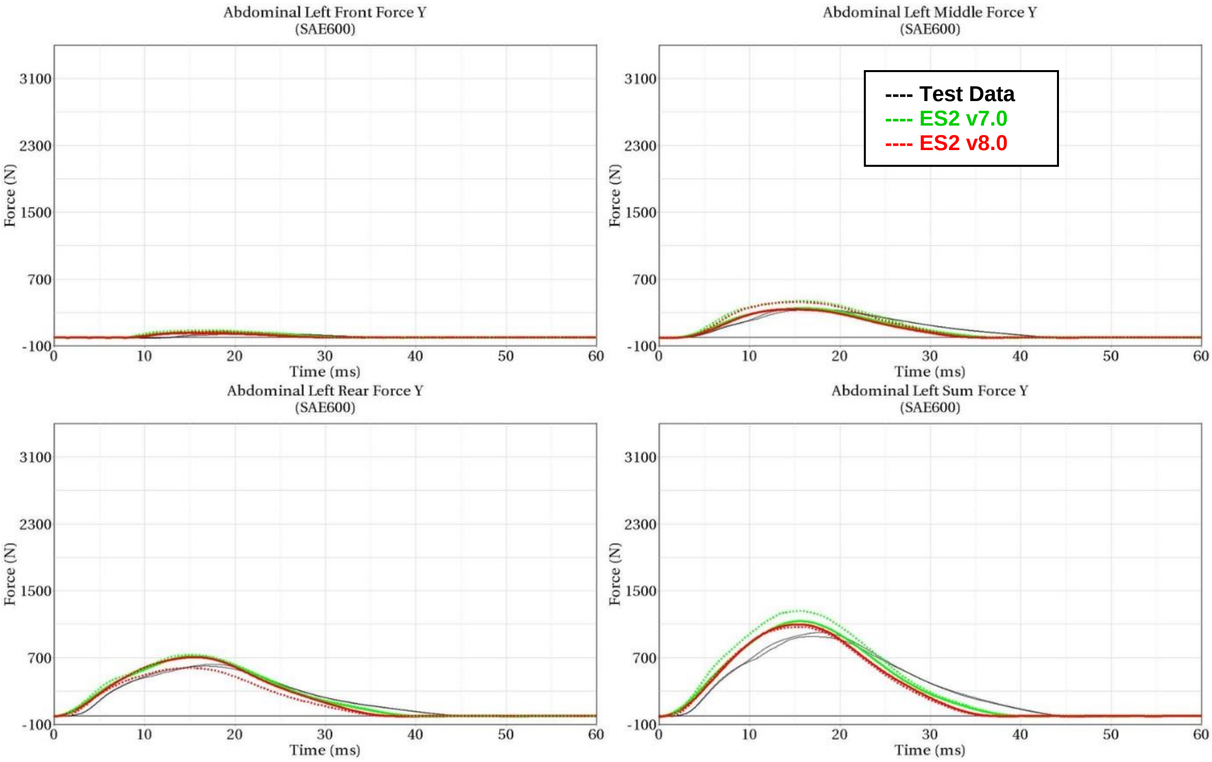
Results for 120° orientation, top impact, low velocity



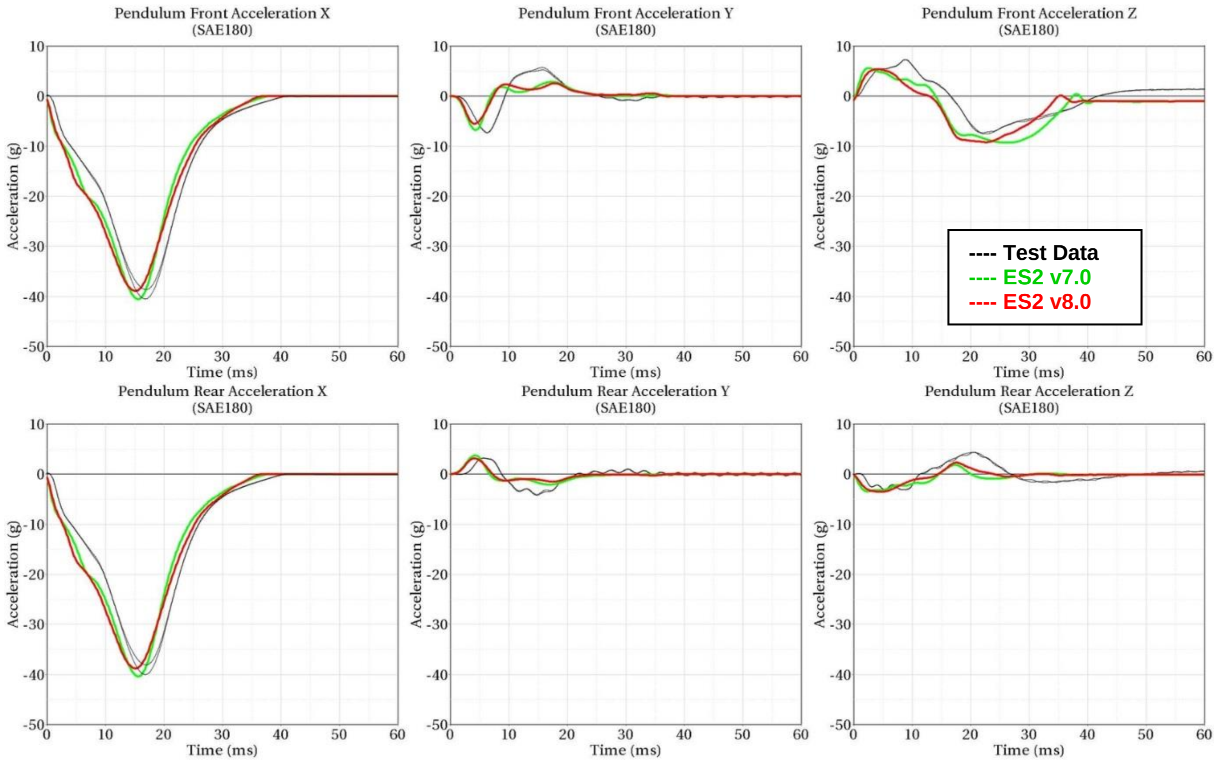


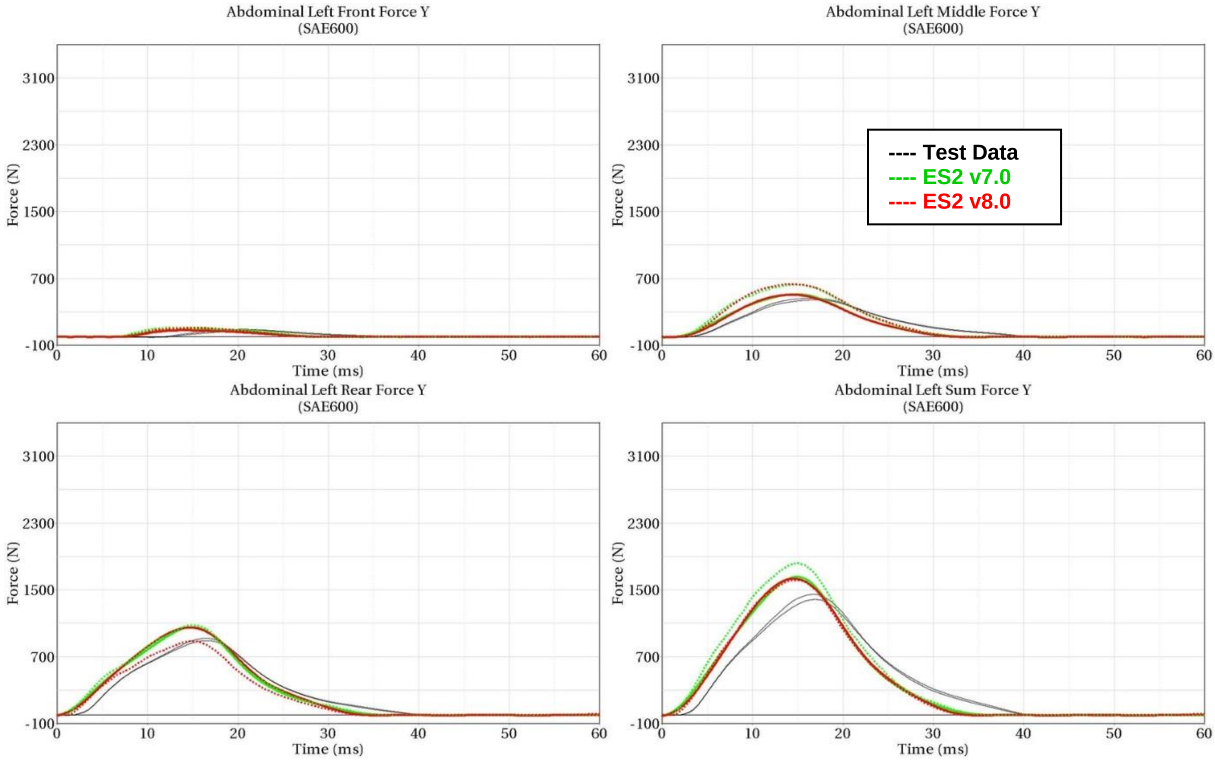
Results for 120° orientation, top impact, medium velocity





Results for 120° orientation, top impact, high velocity





10.1.6 Lumbar spine test

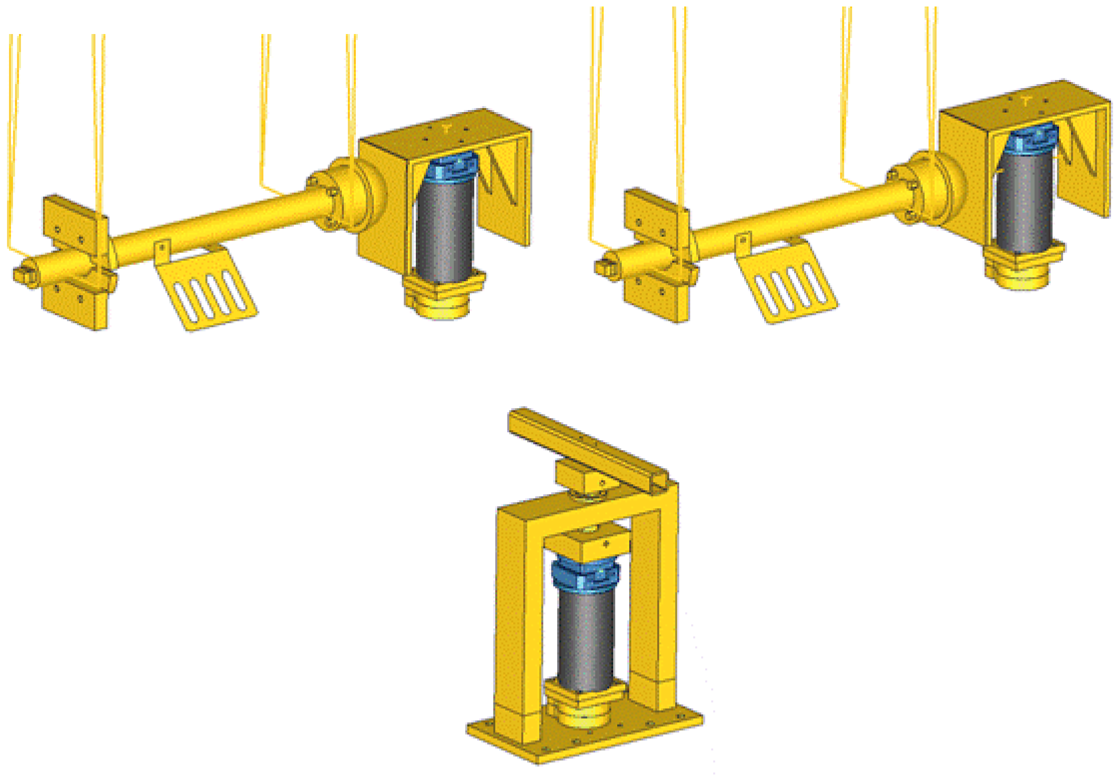
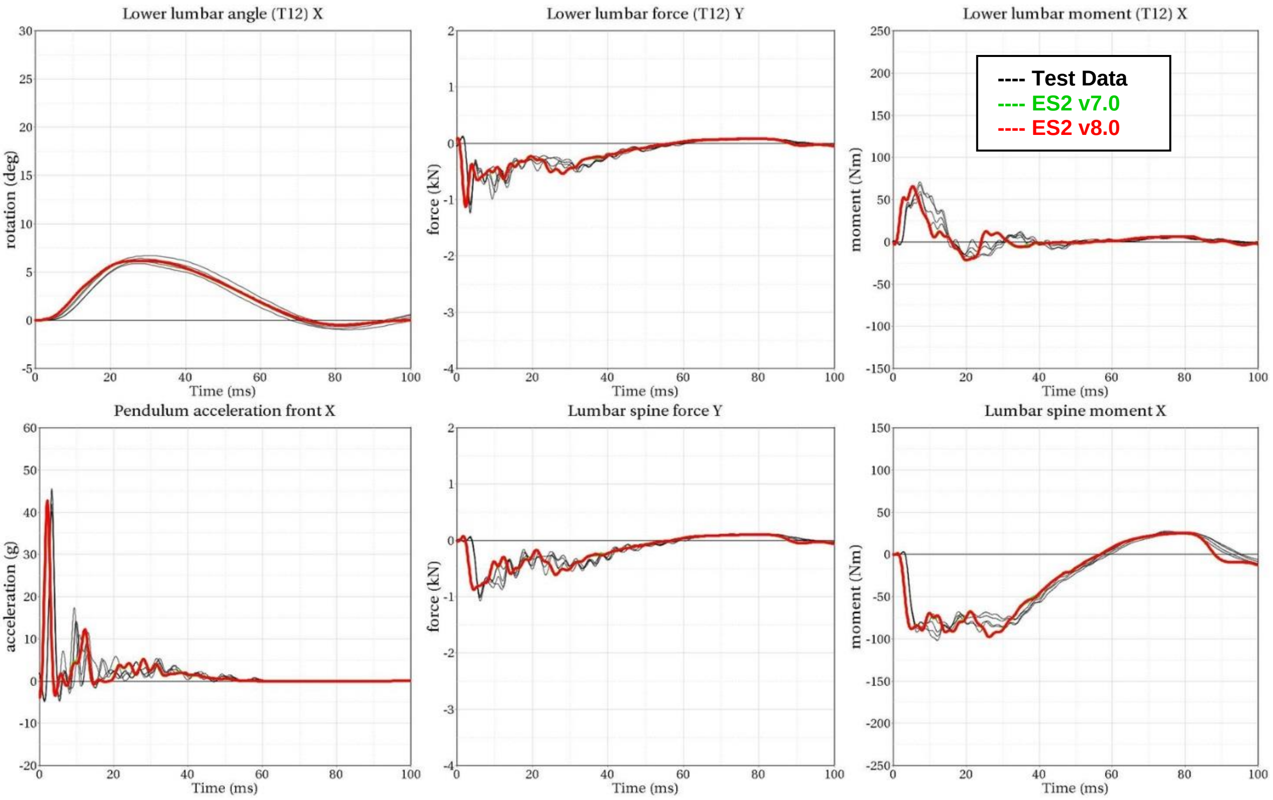


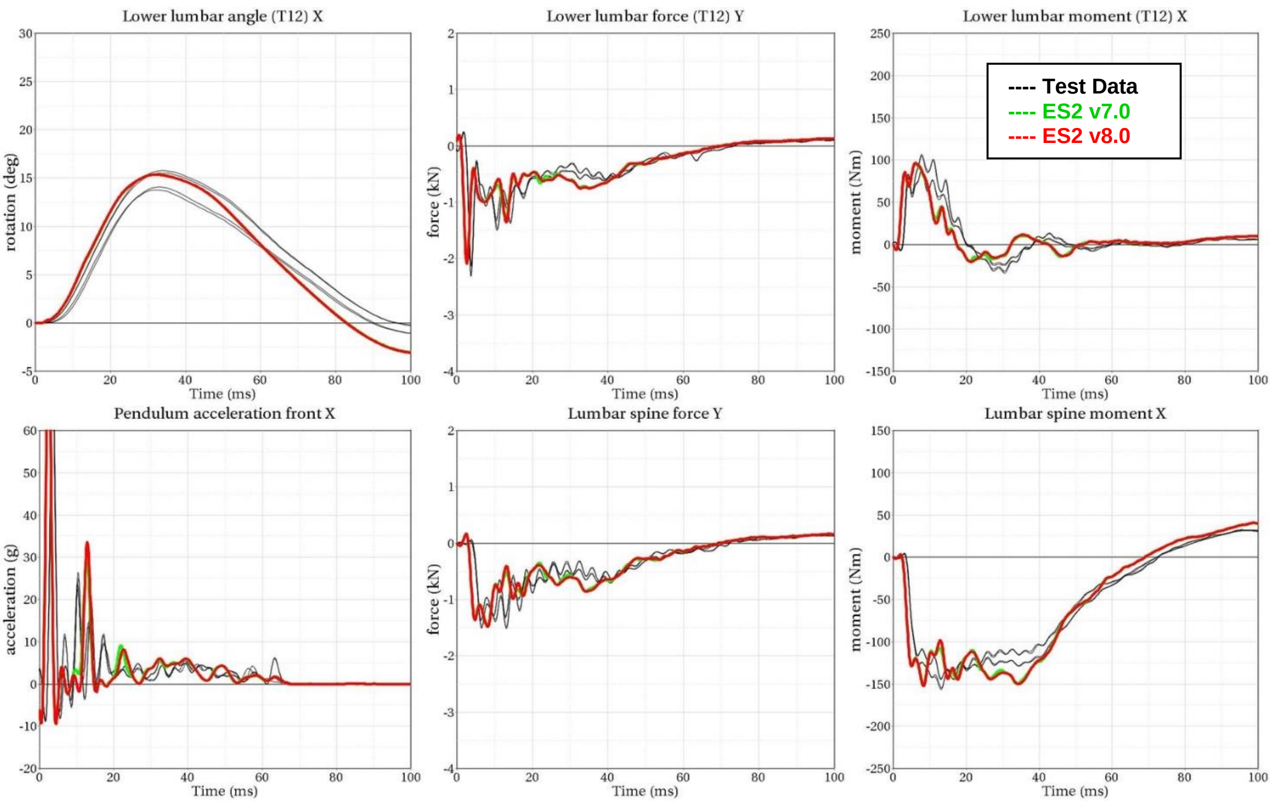
Figure 34: Setups for bending, shear and torsion tests on lumbar spine

The T12 load cell in the lumbar spine has been remodeled. A new spherical joint has been modeled at the bottom of the lumbar spine. Materials for the lumbar spine are from the EMI material tests. The test setups for bending, shear and torsion tests on the lumbar spine are shown in the figure above.

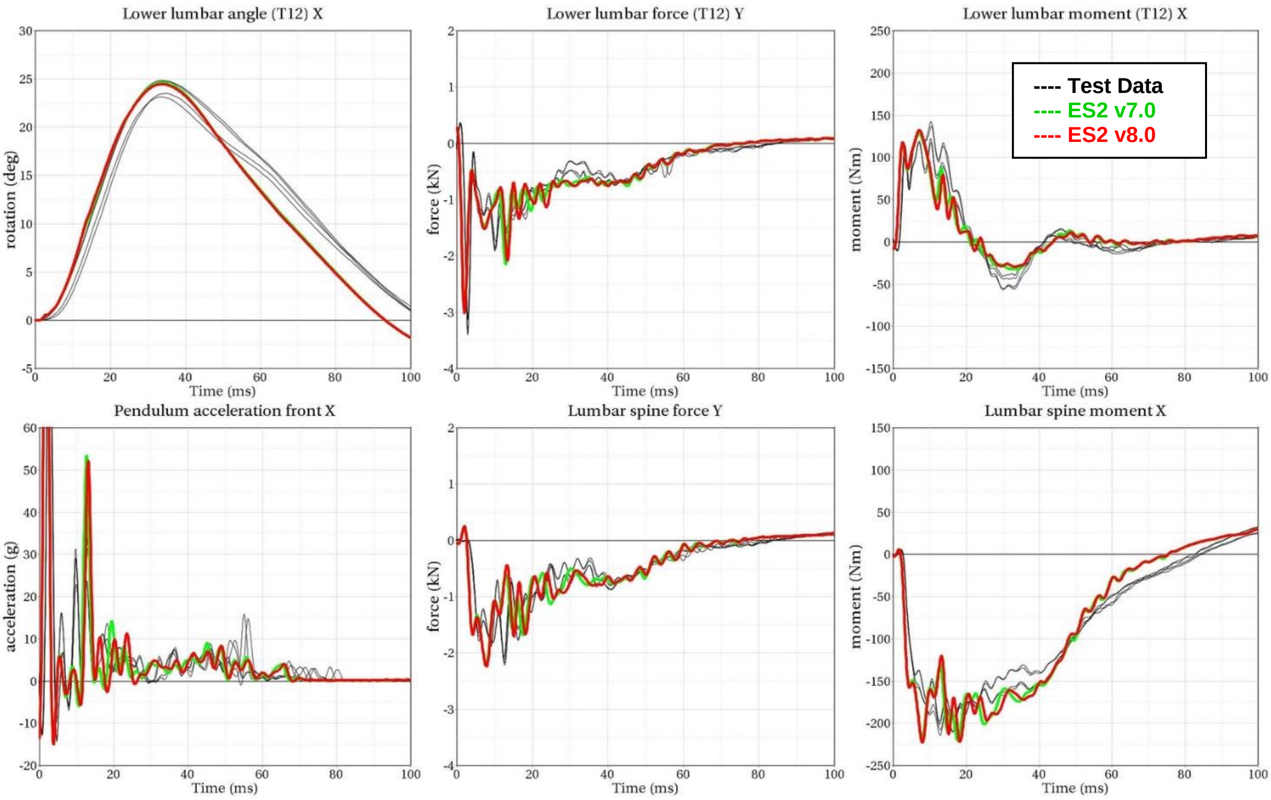
Results for bending low velocity



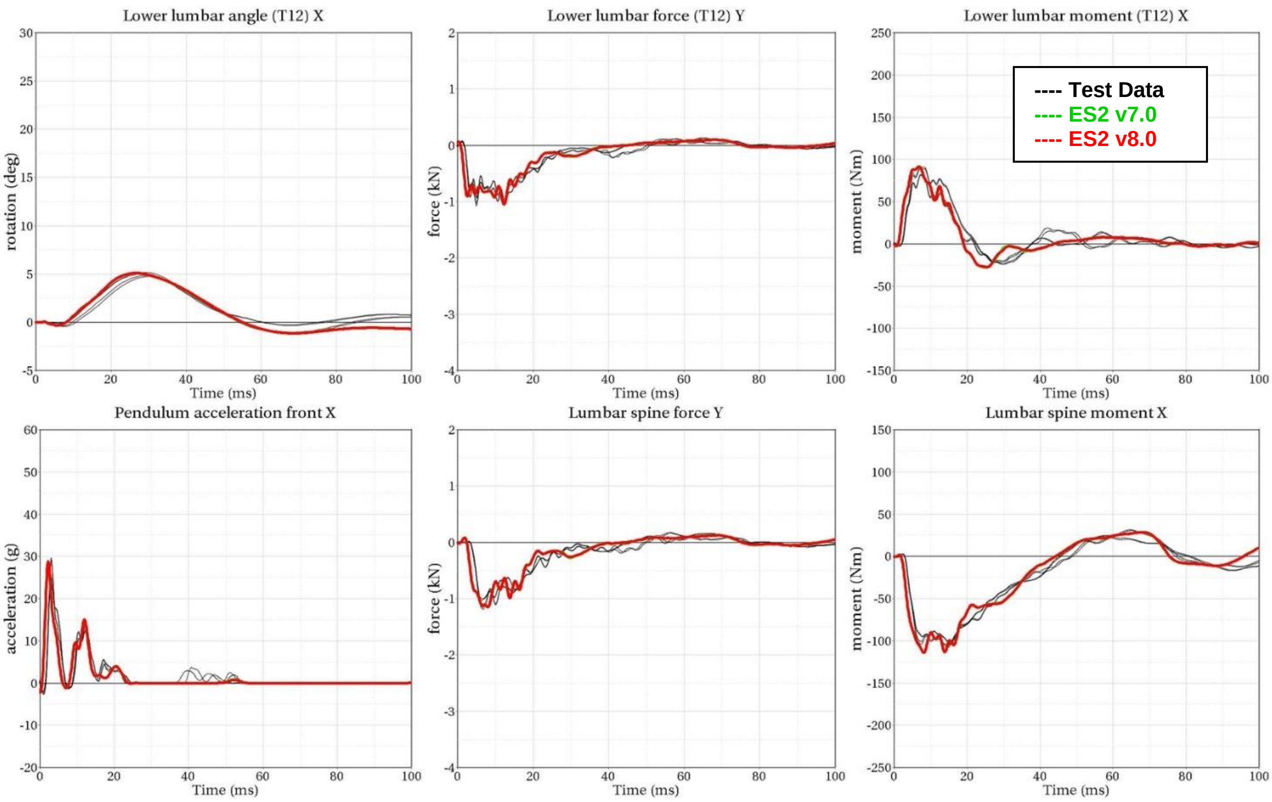
Results for bending medium velocity



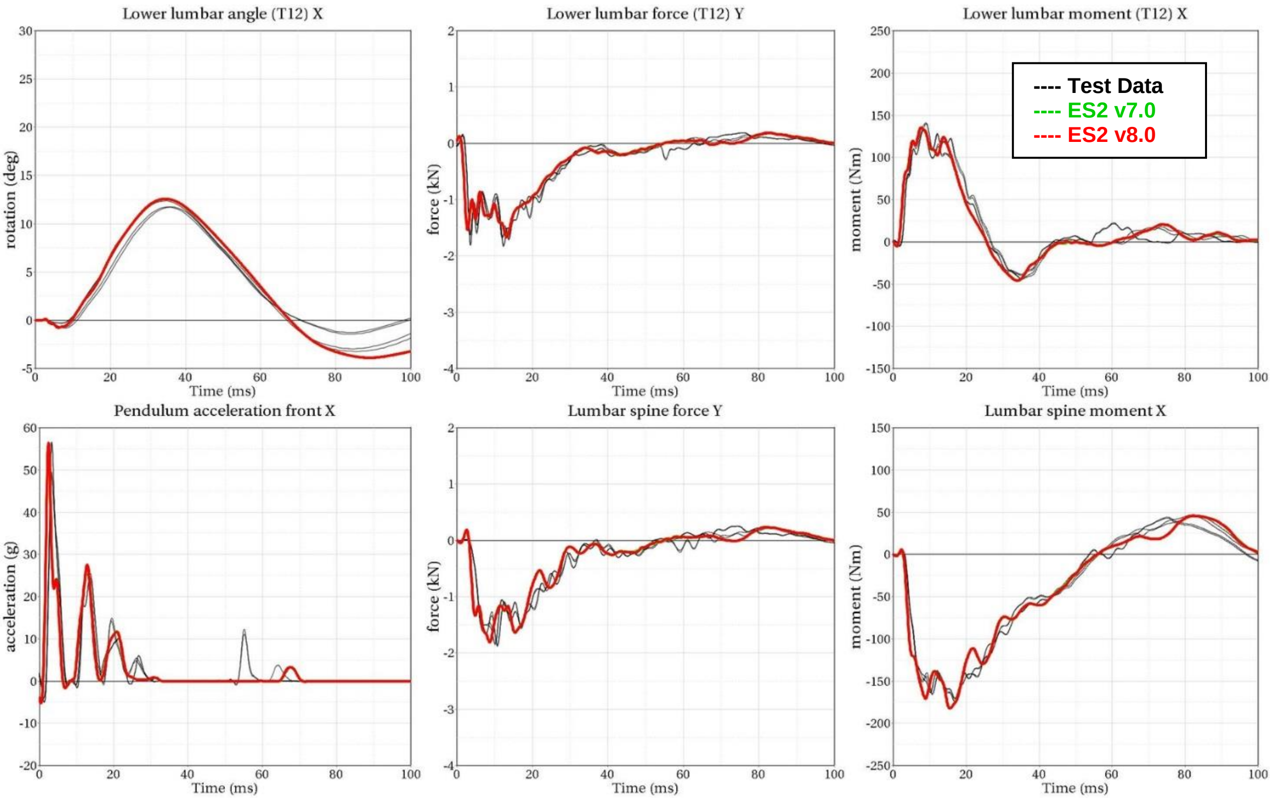
Results for bending high velocity



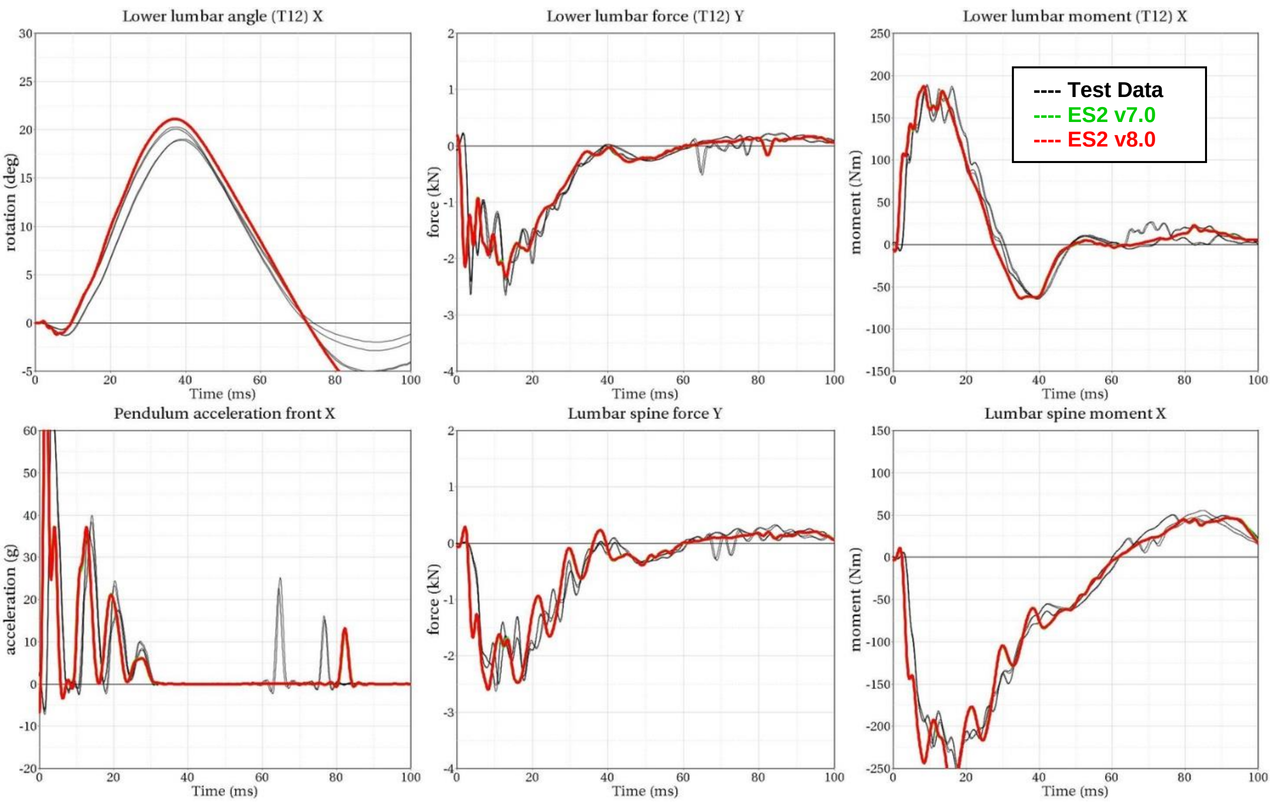
Results for shear low velocity



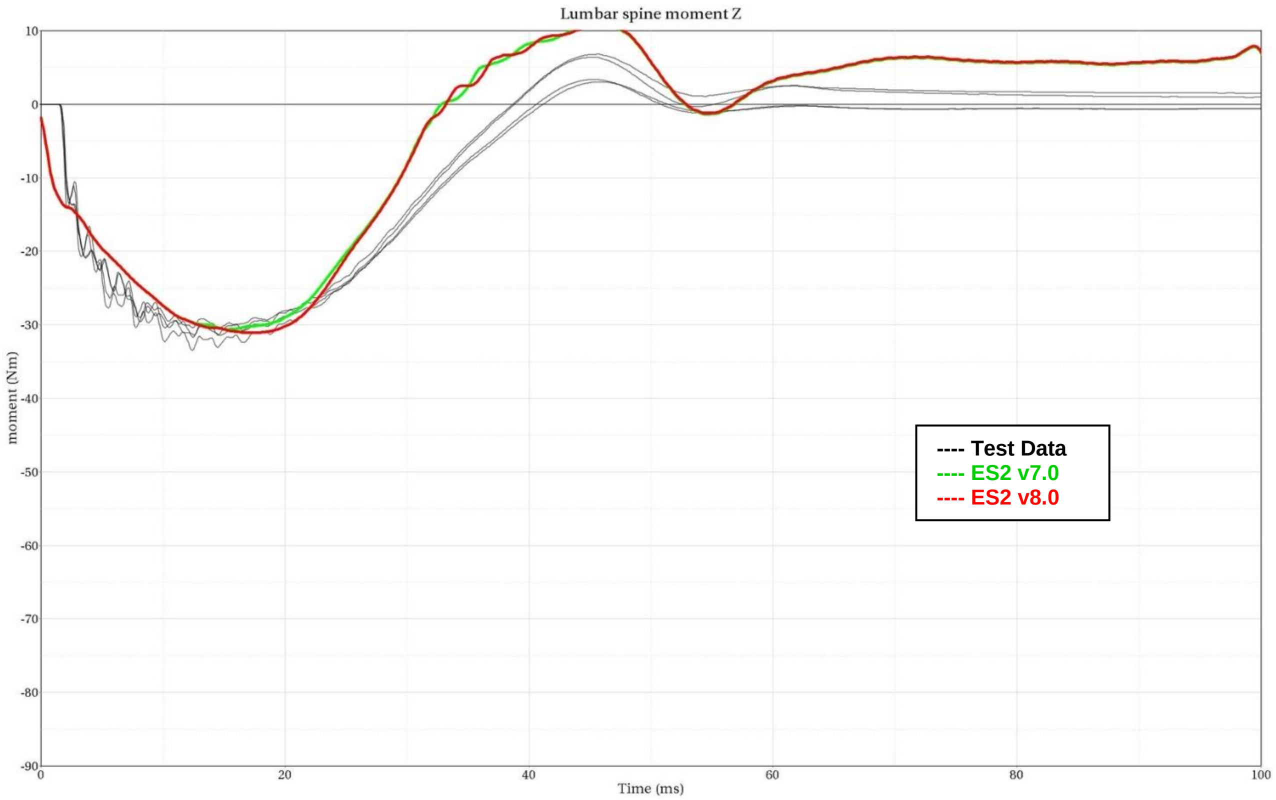
Results for shear medium velocity



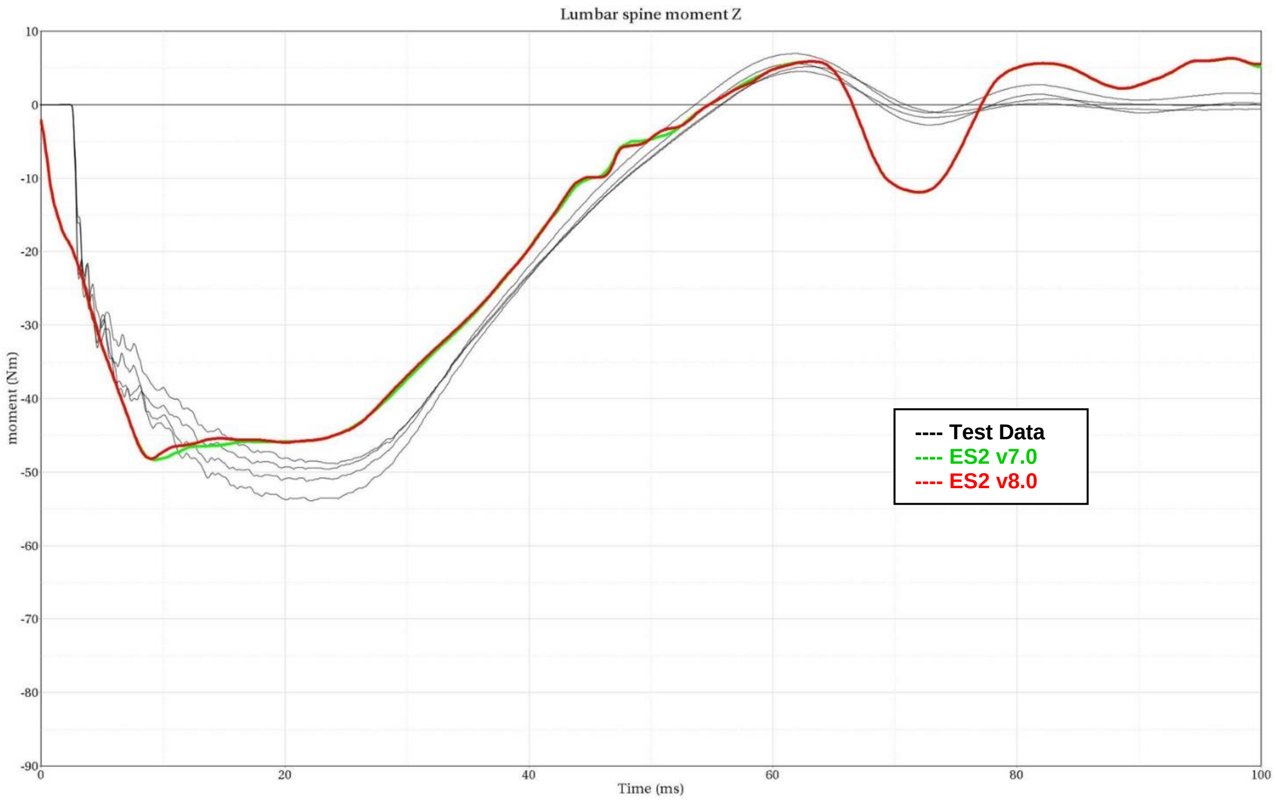
Results for shear high velocity



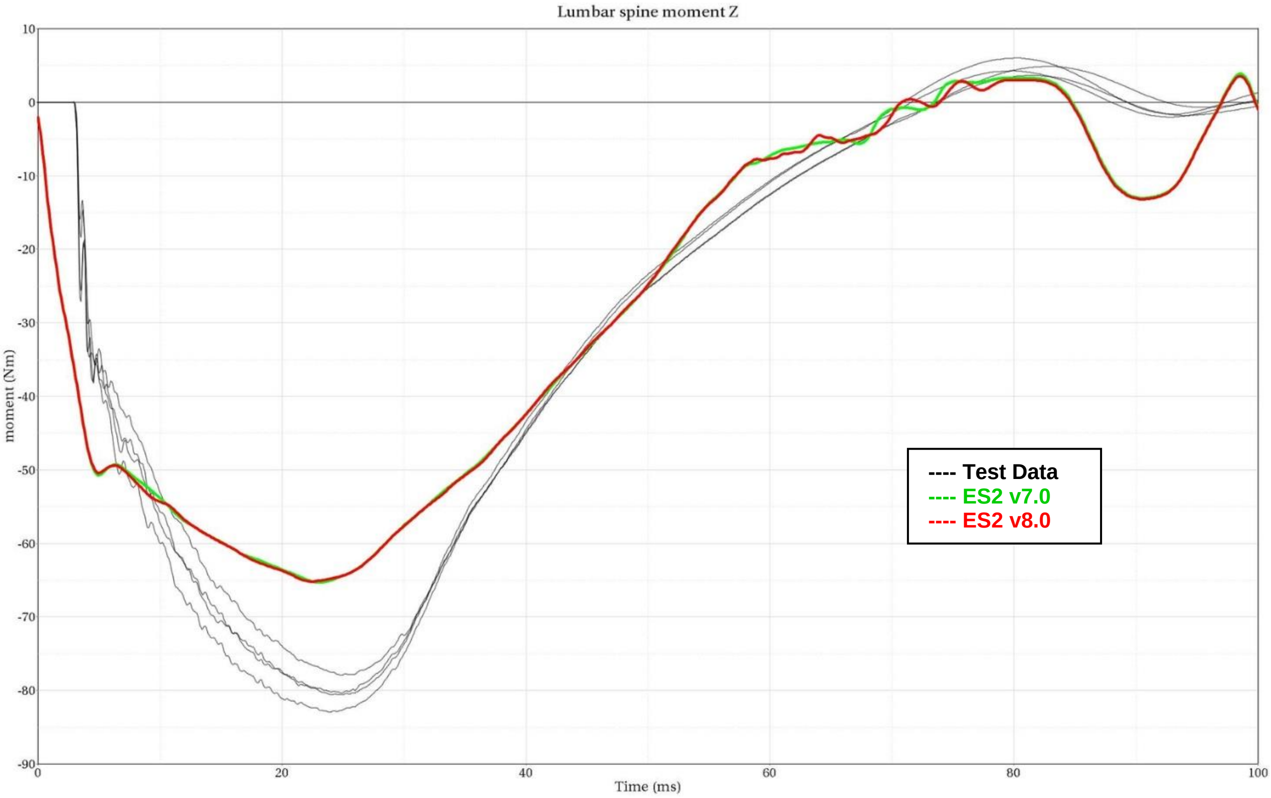
Results for torsion low velocity



Results for torsion medium velocity



Results for torsion high velocity



10.1.7 Iliac wing test

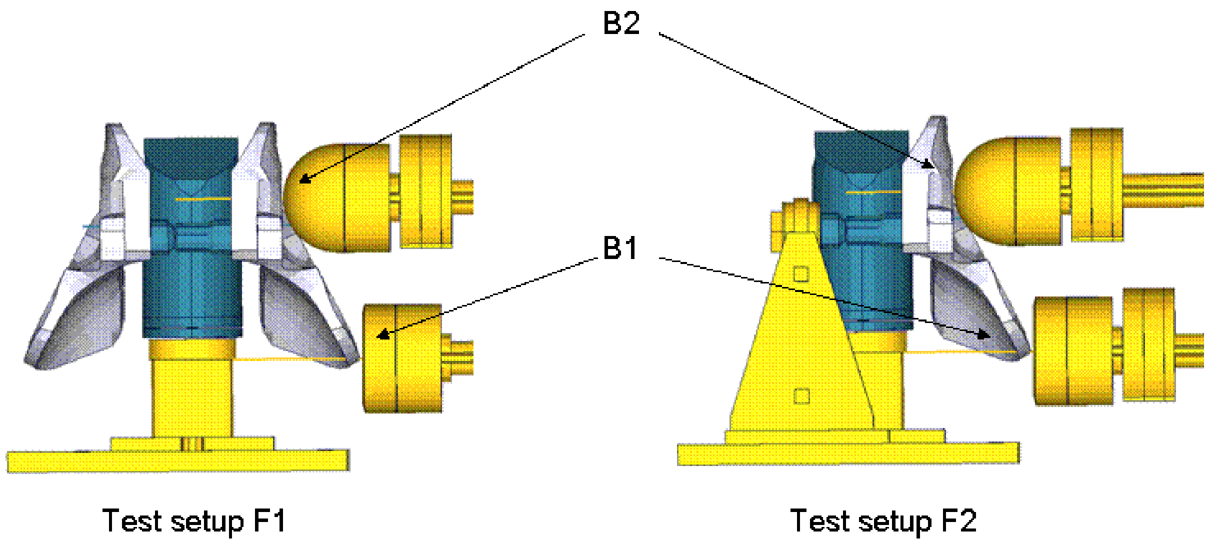
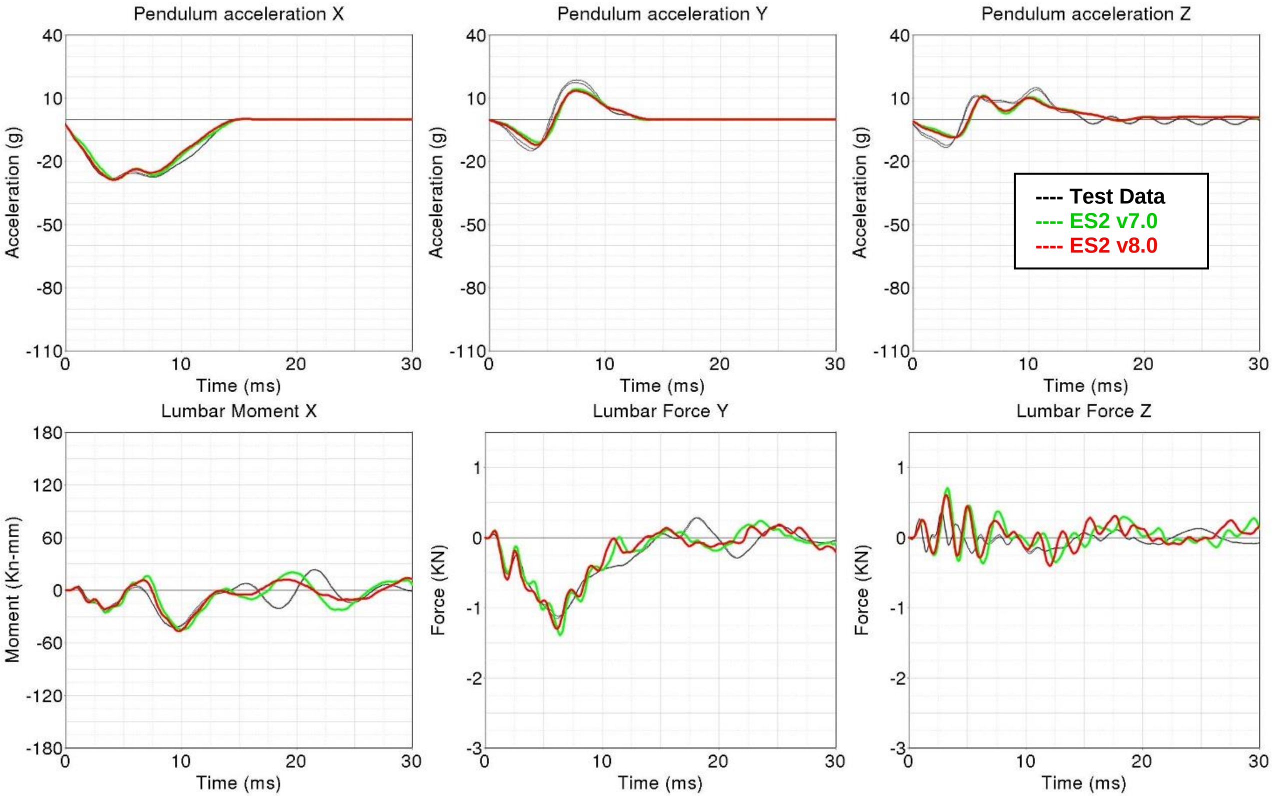
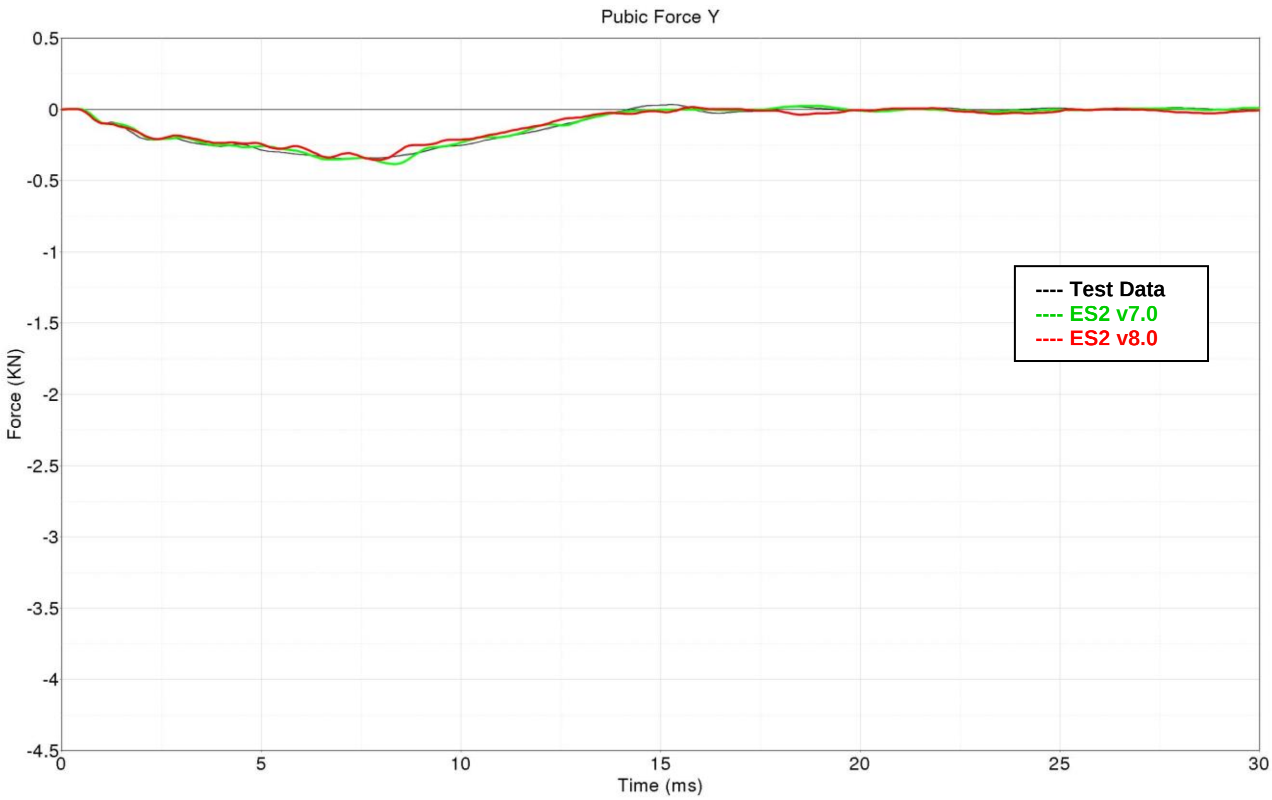


Figure 35: Test setup for iliac wing test

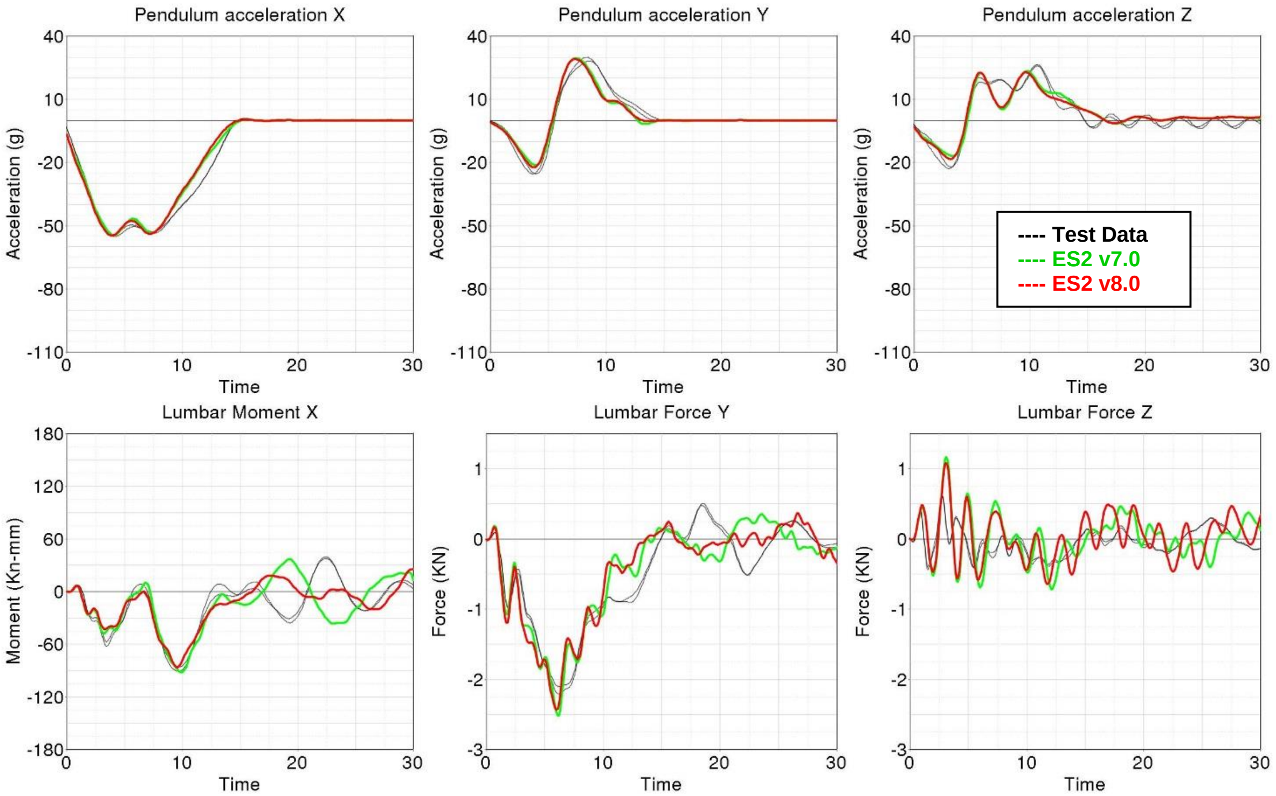
The Iliac wing assembly is mounted on a test block as shown in the figure above. The Iliac wings are impacted by a hemispherical-headed pendulum and a cylindrical-headed pendulum at two different points as indicated in the figure. The pendulum masses are varied for different configurations and the test is carried out at two velocities.

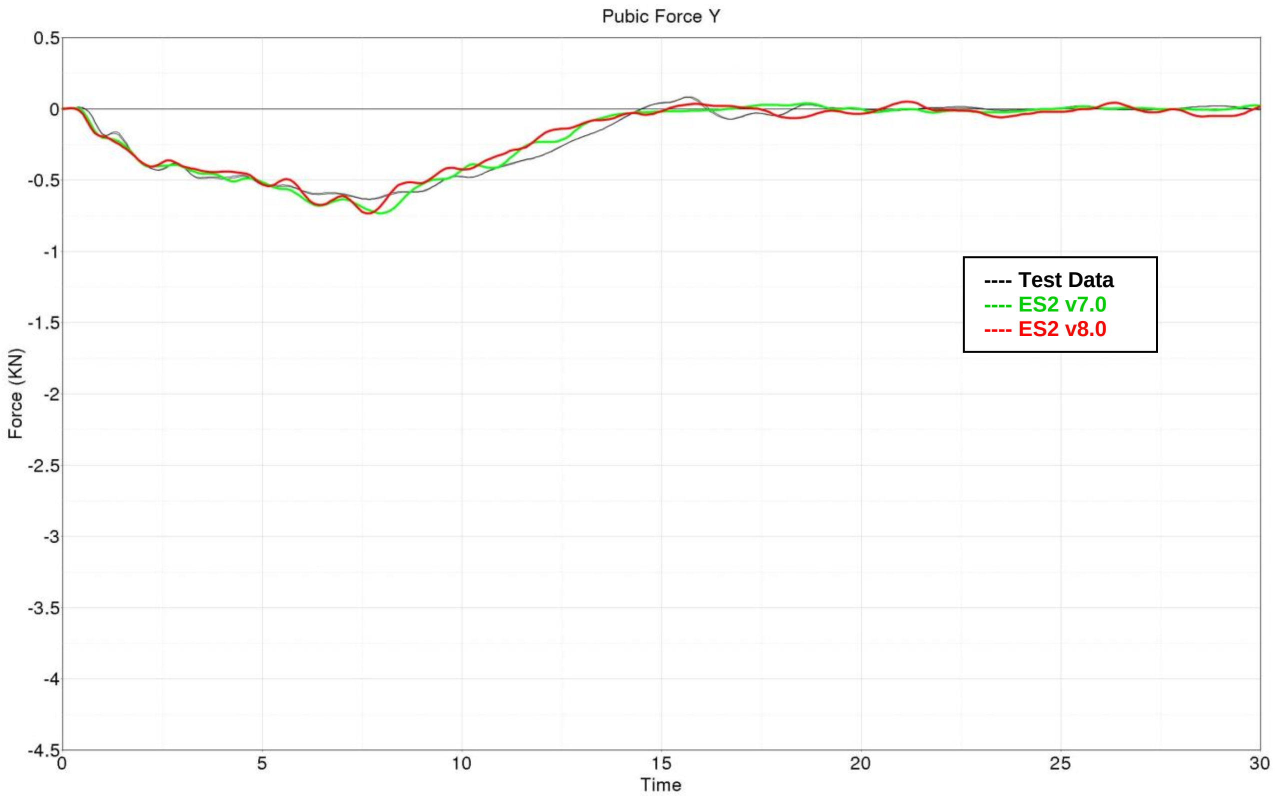
Results for configuration F1B1M1, low velocity



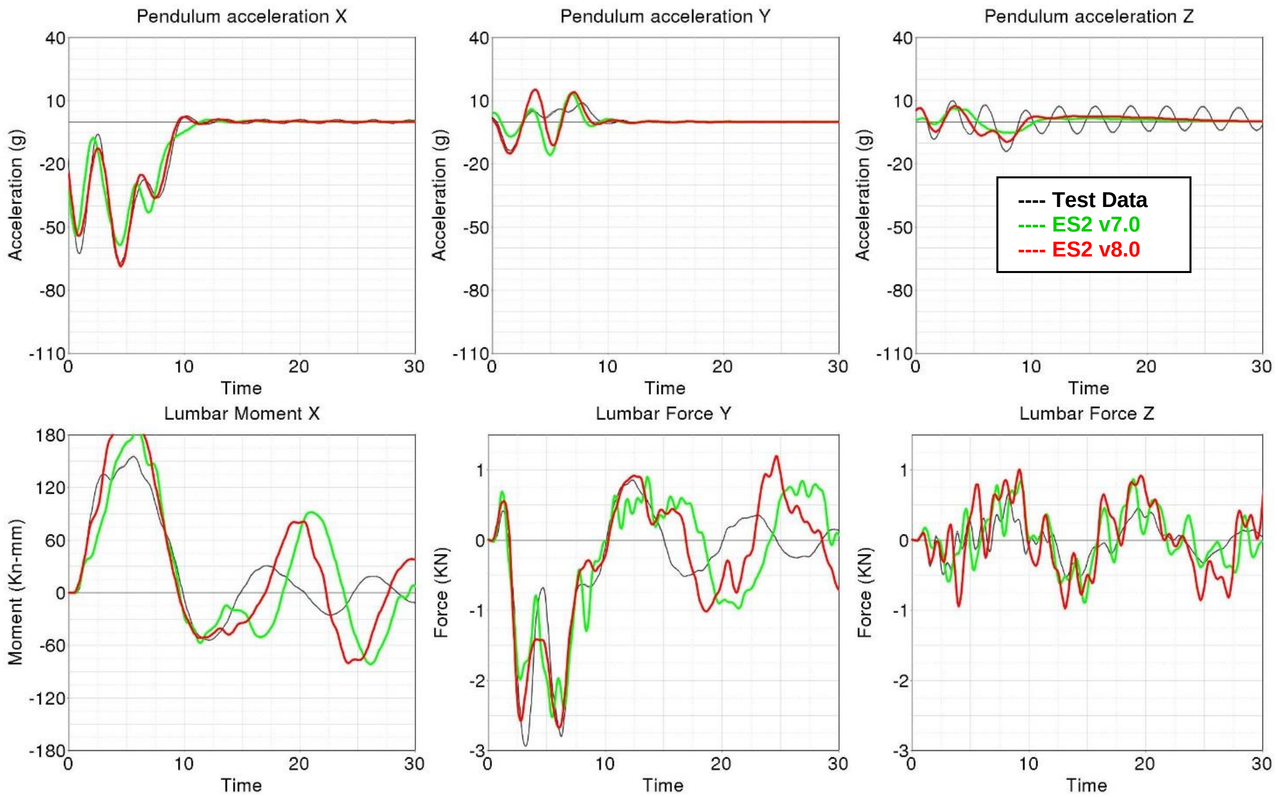


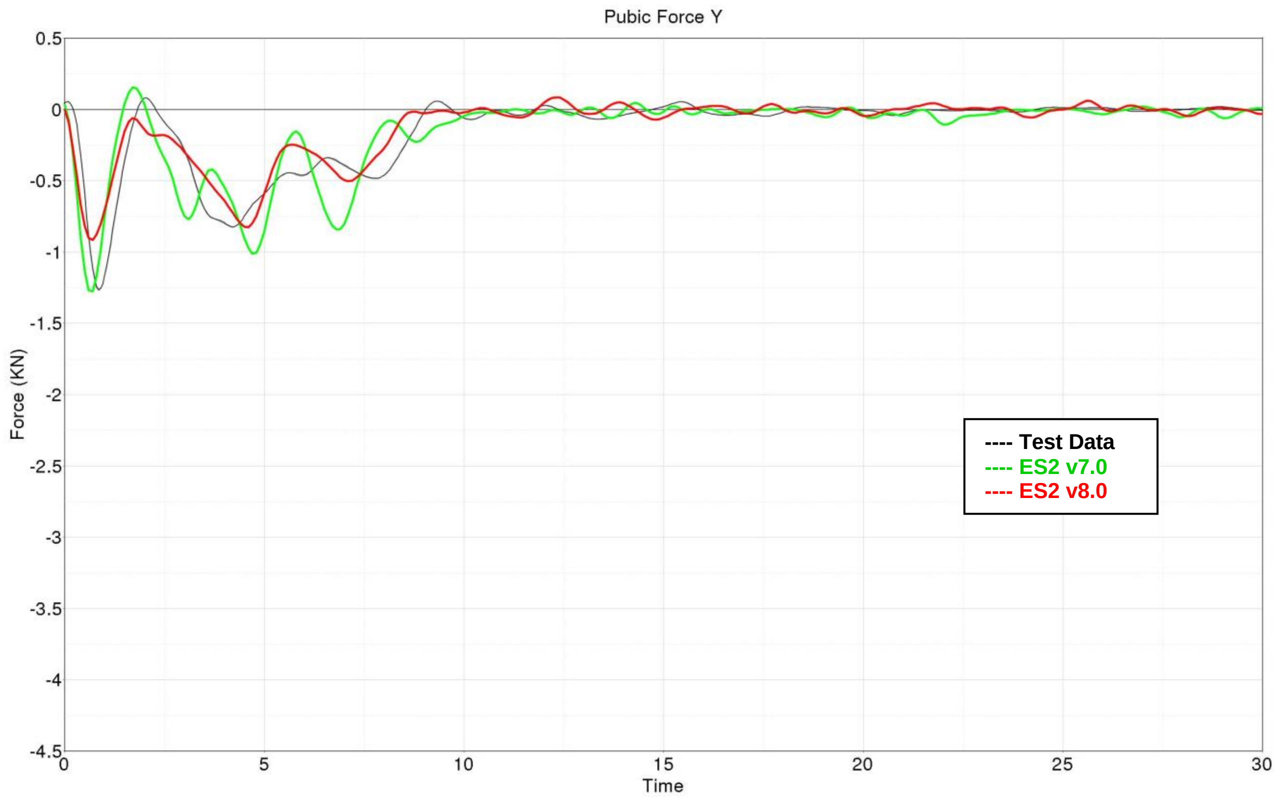
Results for configuration F1B1M1, high velocity



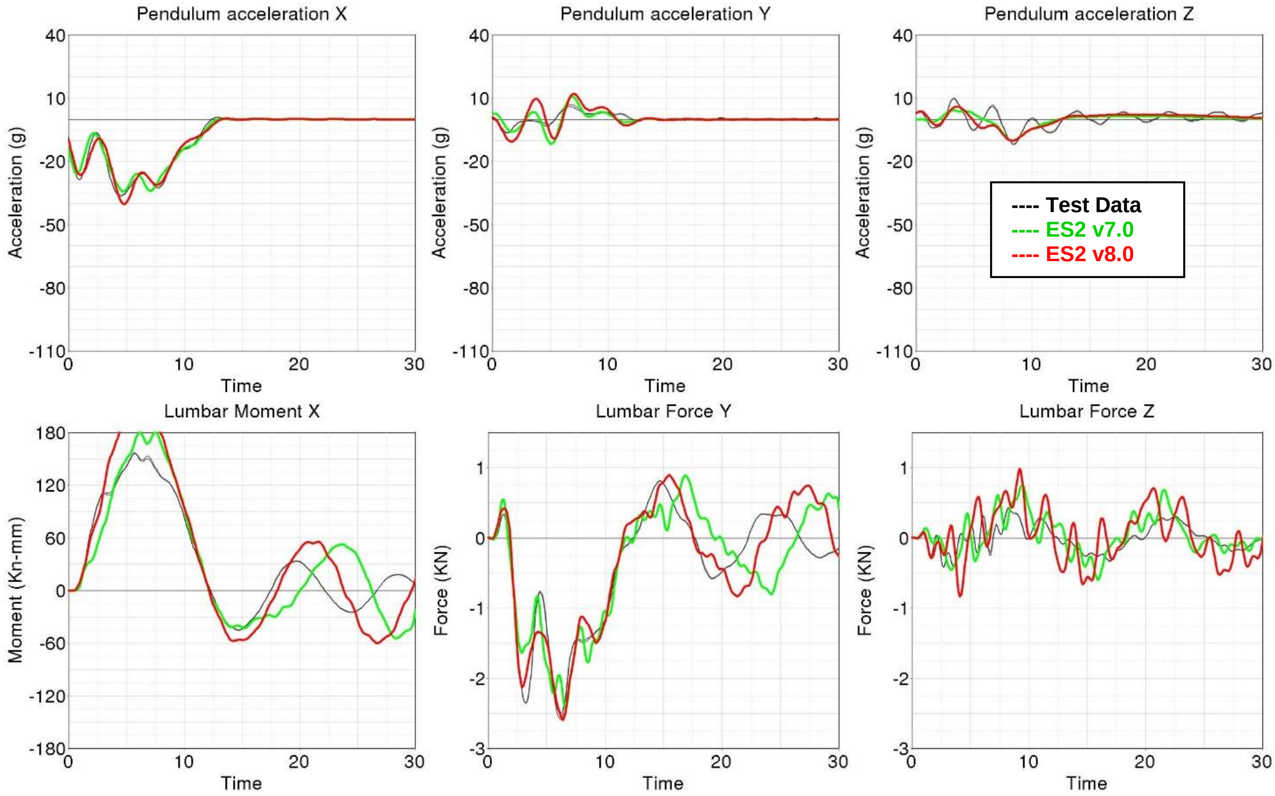


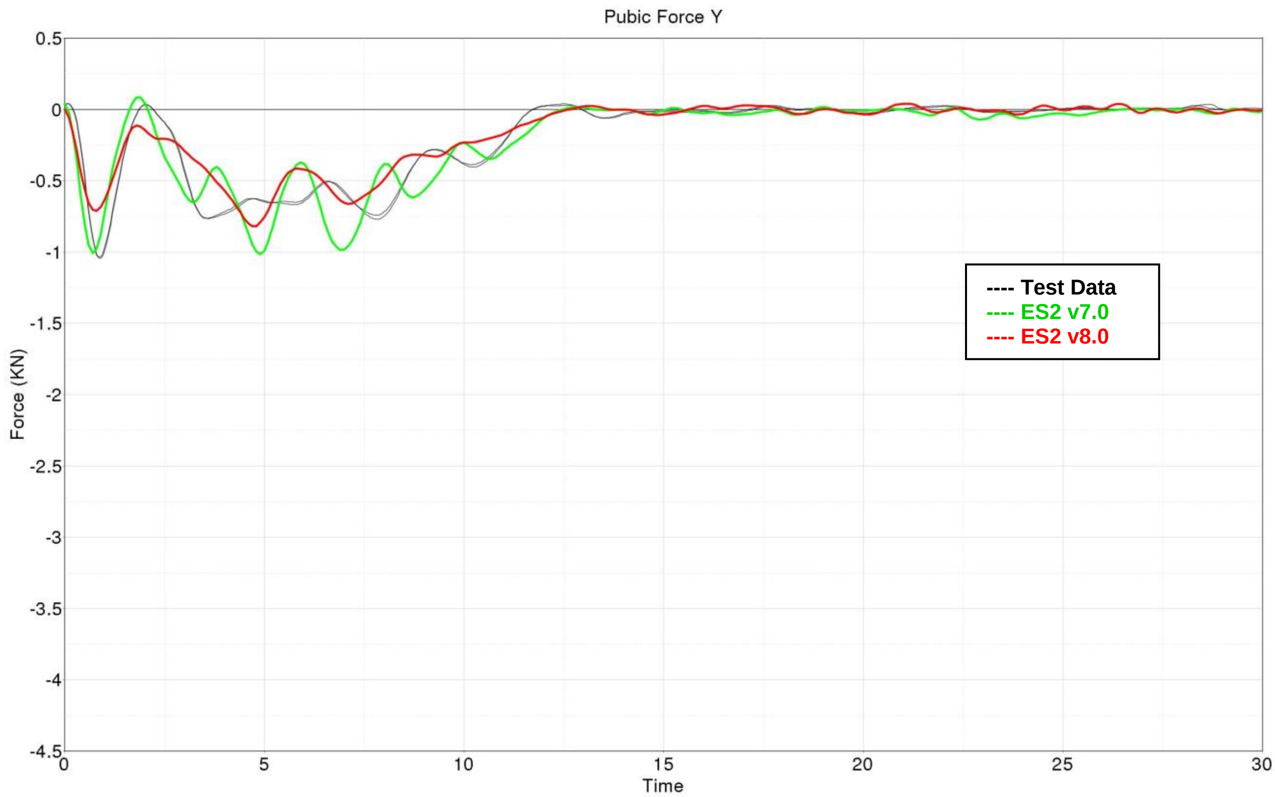
Results for configuration F1B2M1, high velocity



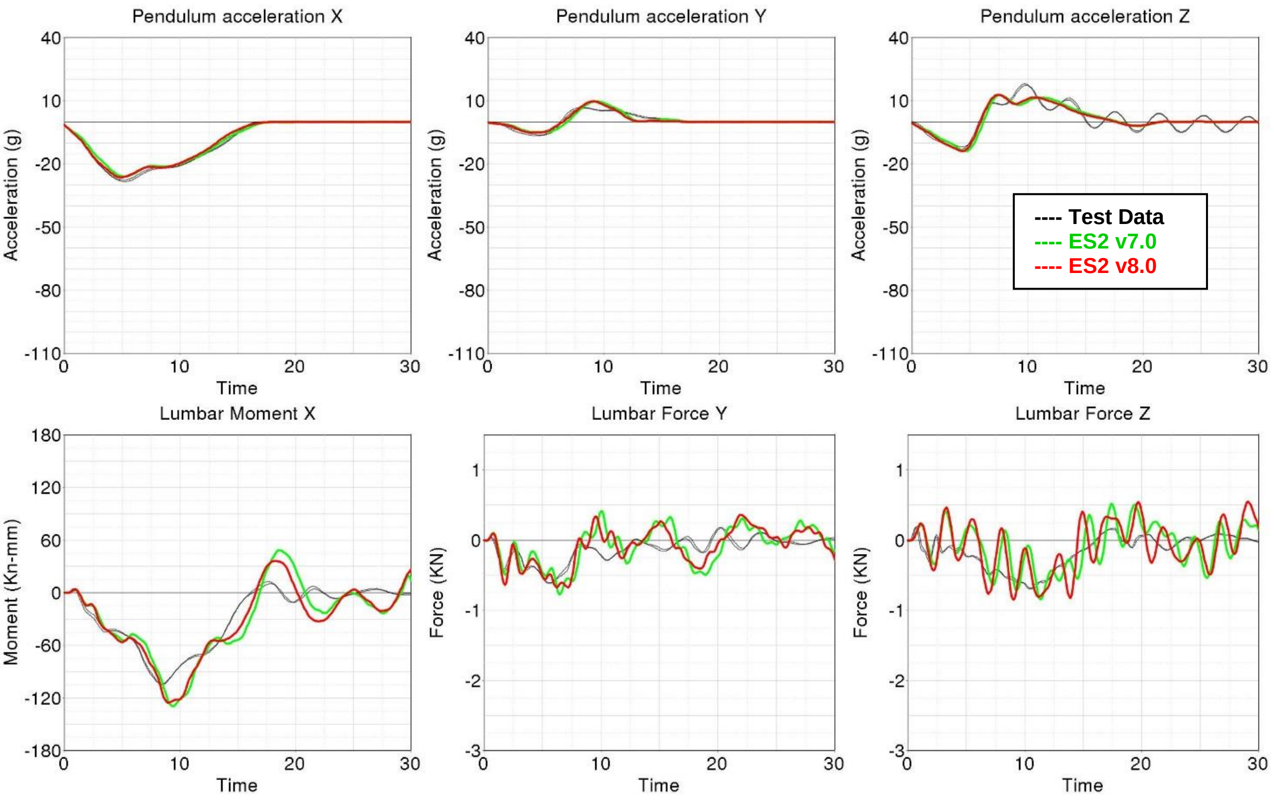


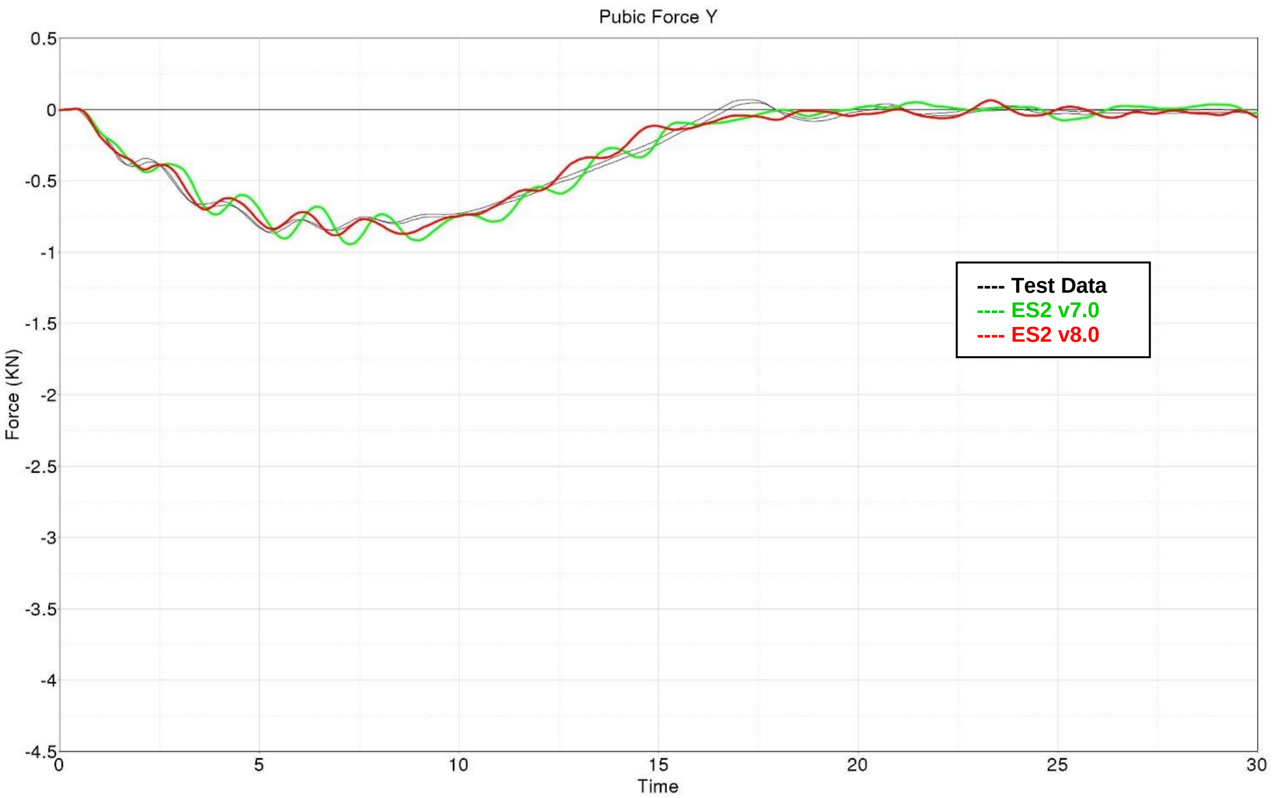
Results for configuration F1B2M2, low velocity



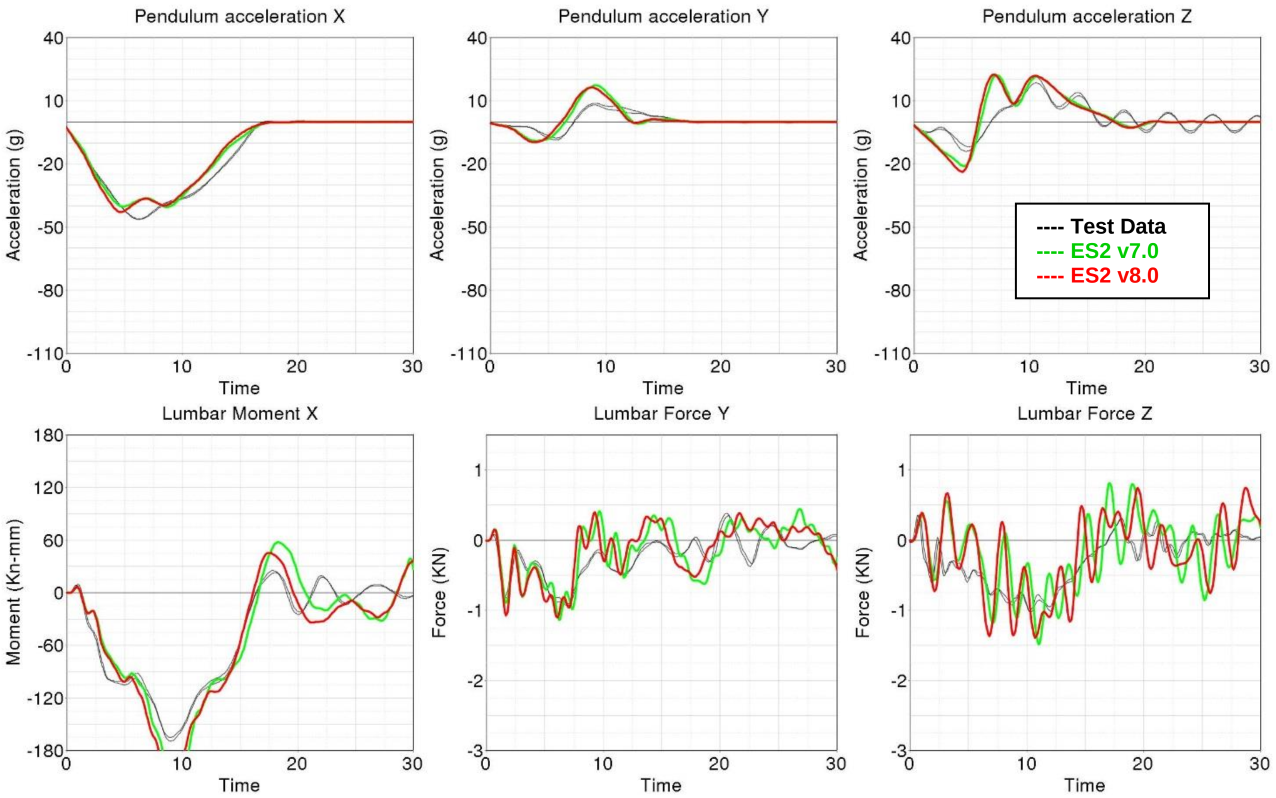


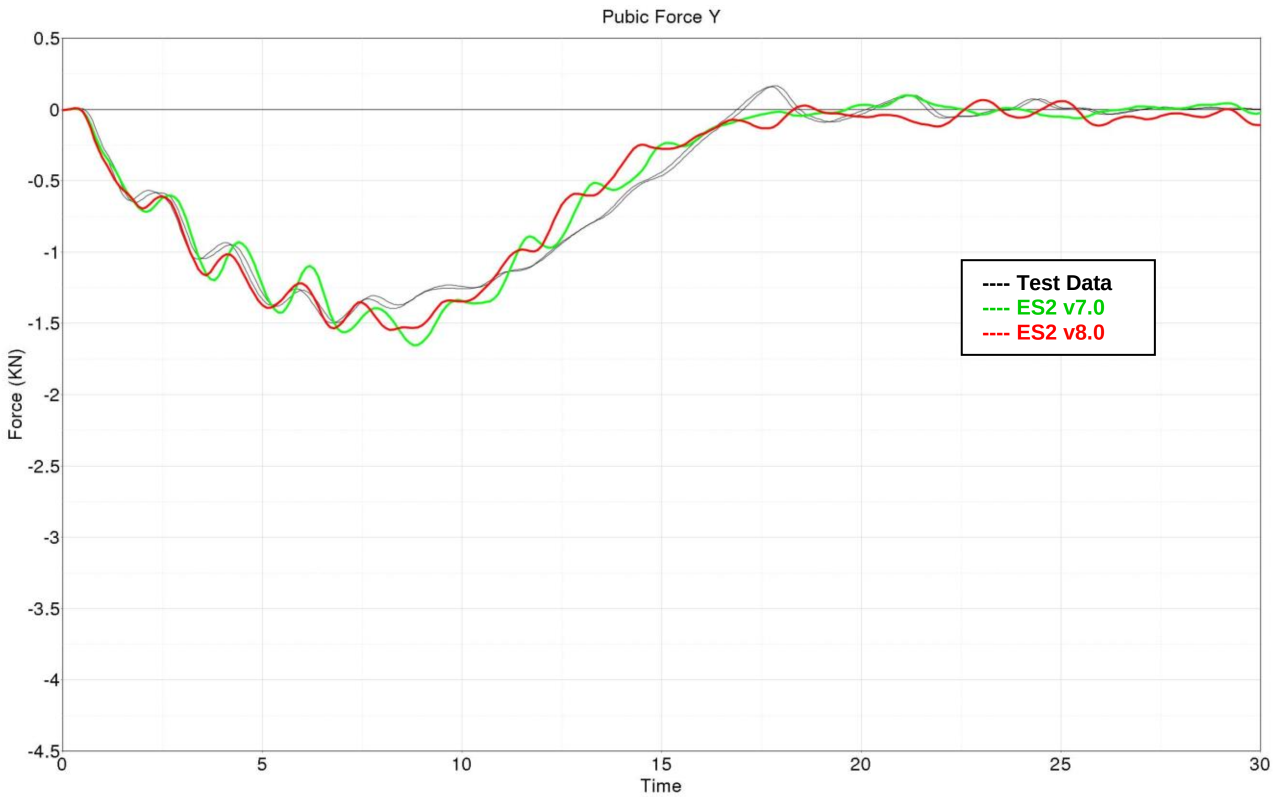
Results for configuration F2B1M2, low velocity



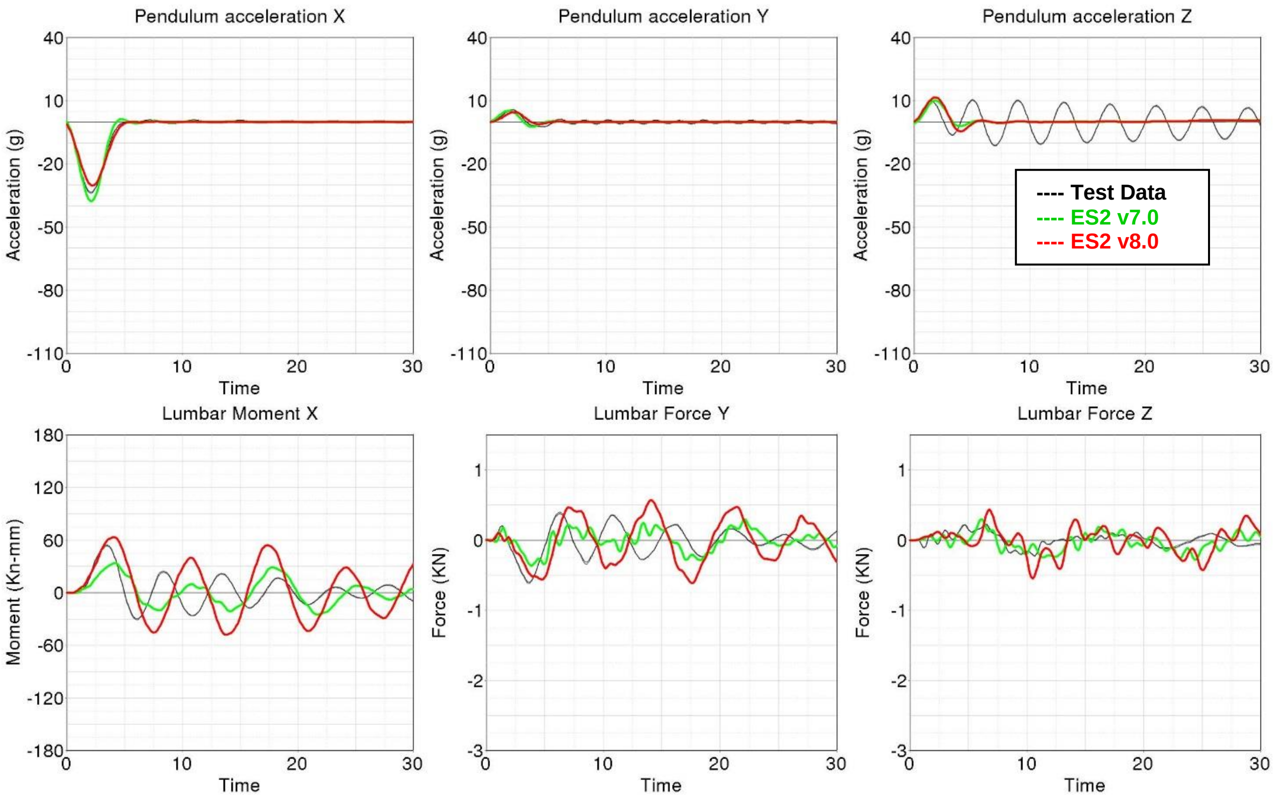


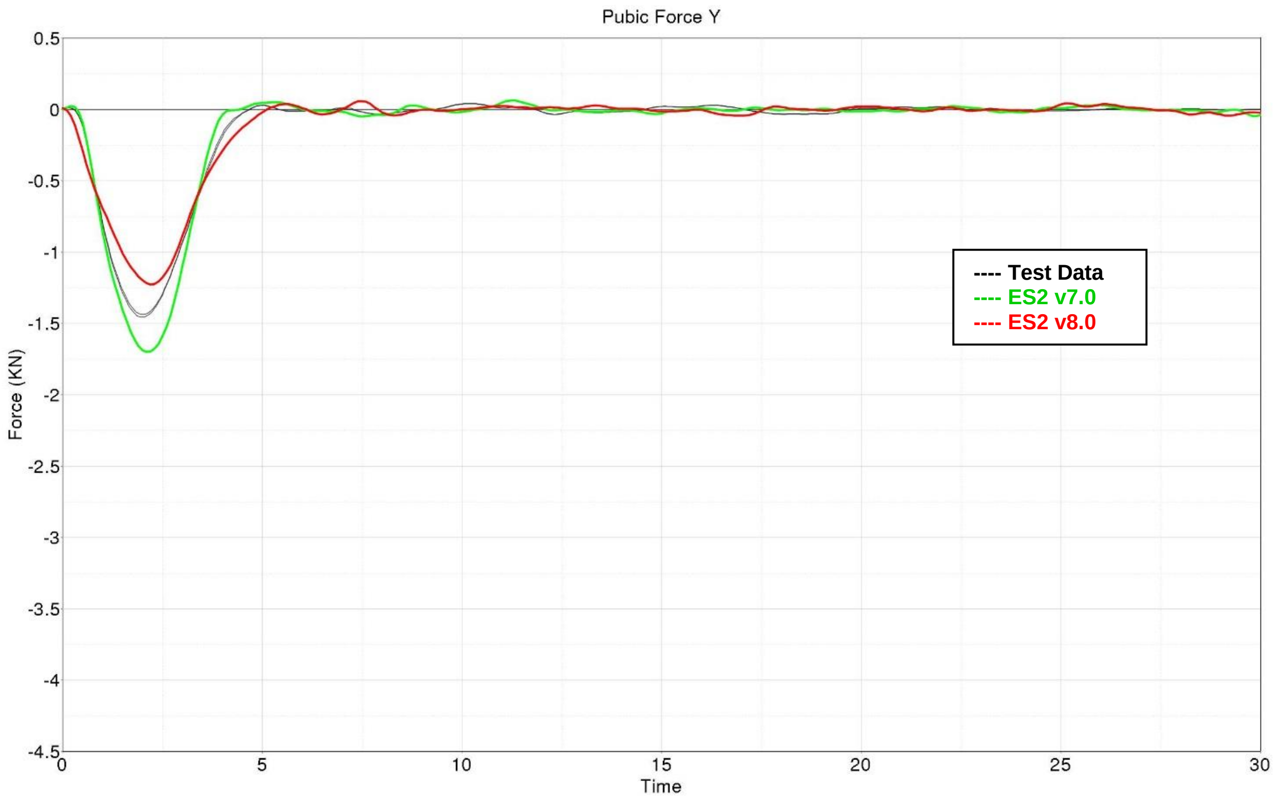
Results for configuration F2B1M2, high velocity



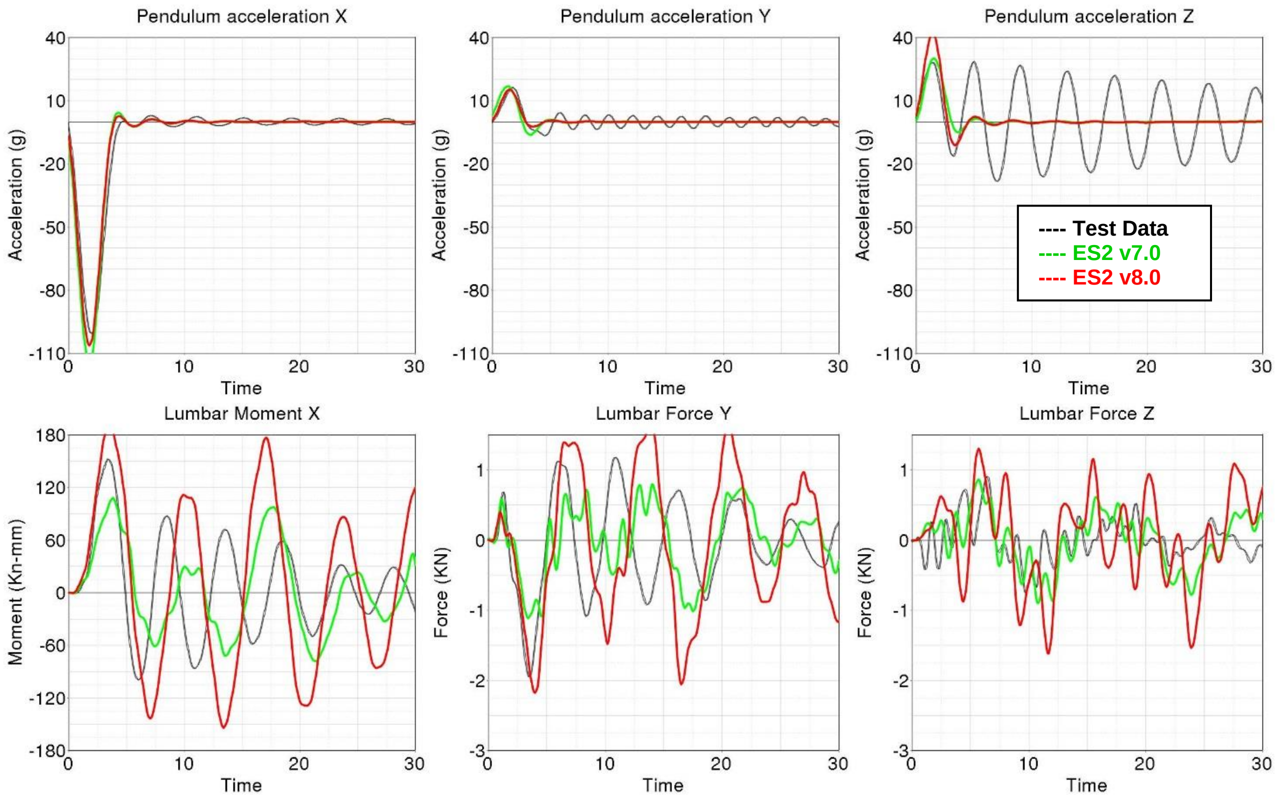


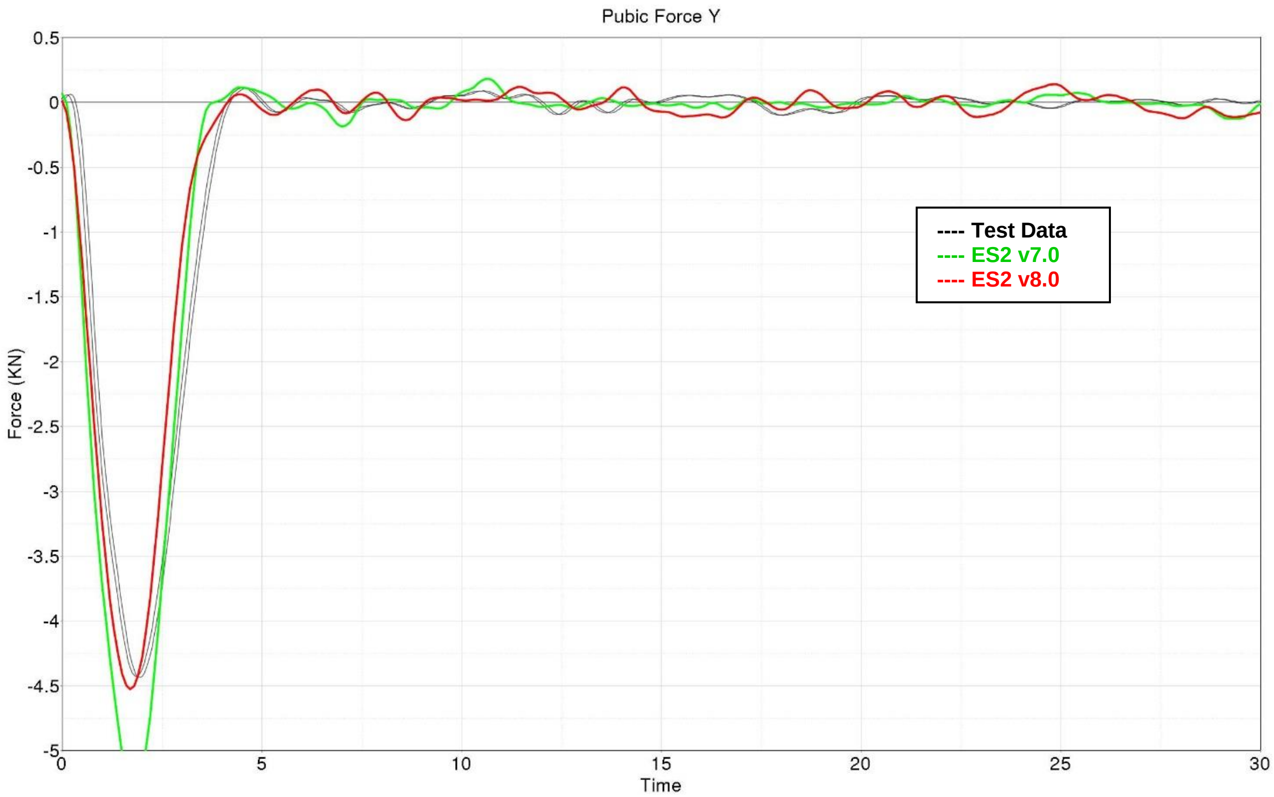
Results for configuration F2B2M2, low velocity





Results for configuration F2B2M2, high velocity





10.1.8 Femur stopper test

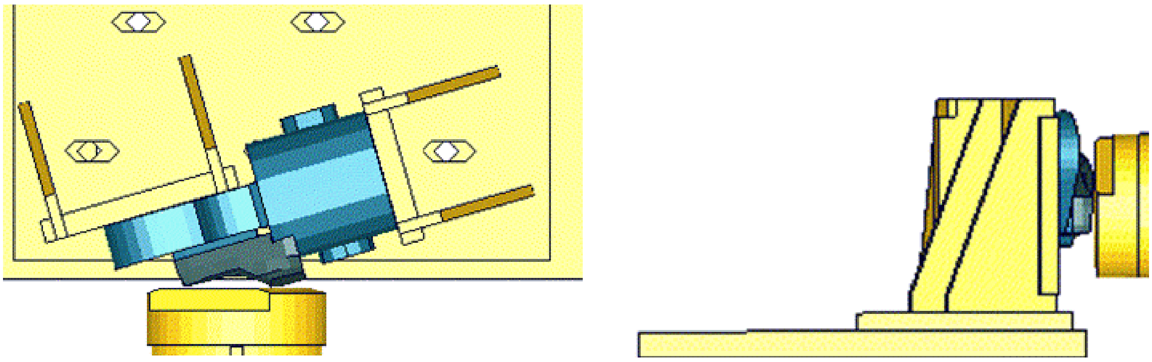
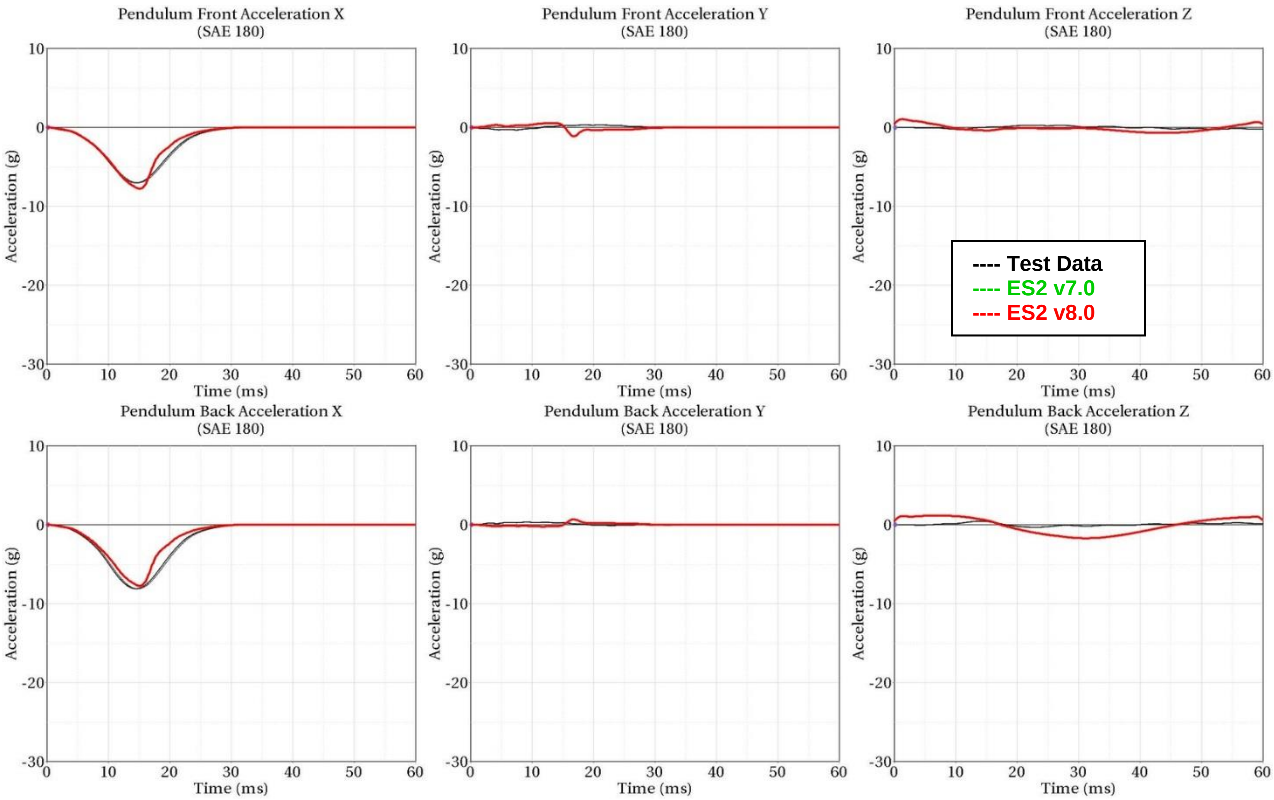


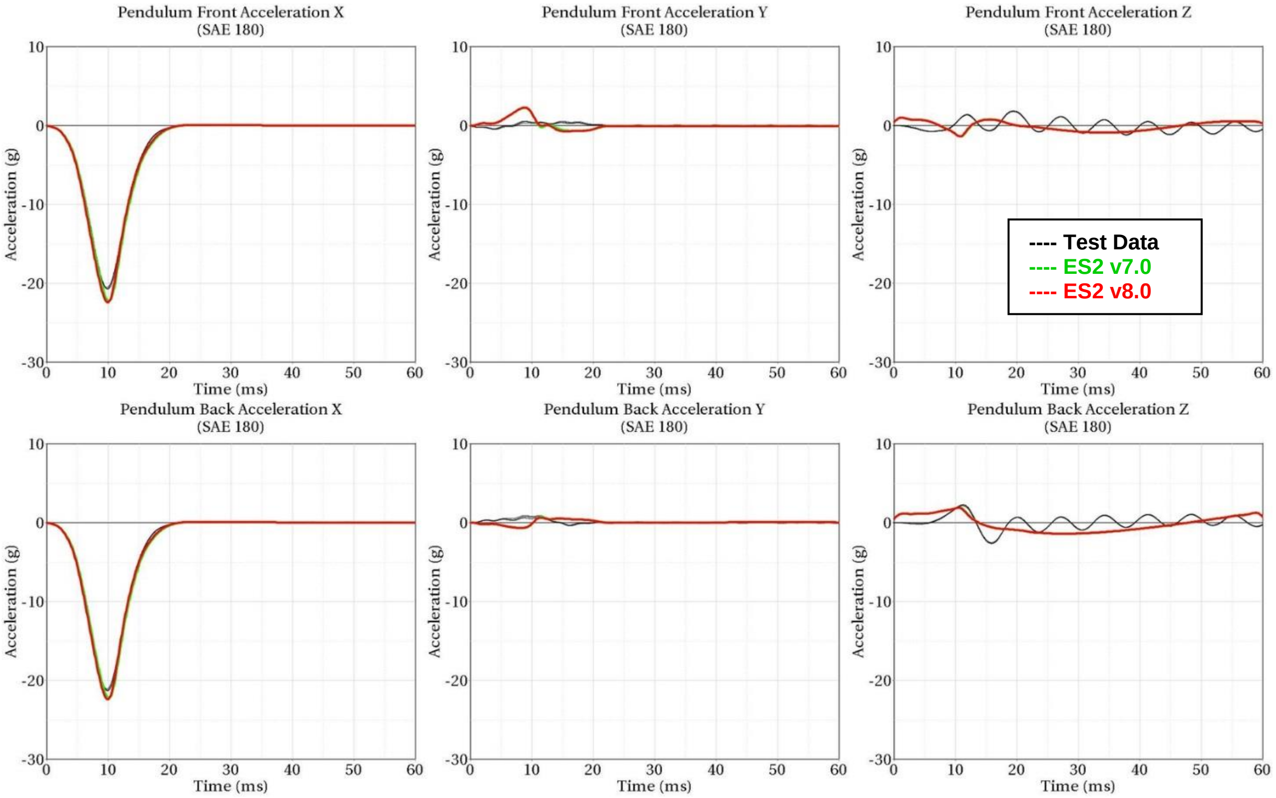
Figure 36: Femur stopper test

The femur stopper is fixed on a test block as shown in the figure above. It is impacted by a pendulum with two velocities.

Results low velocity



Results high velocity



10.2 Rib module tests

10.2.1 Test setup 1

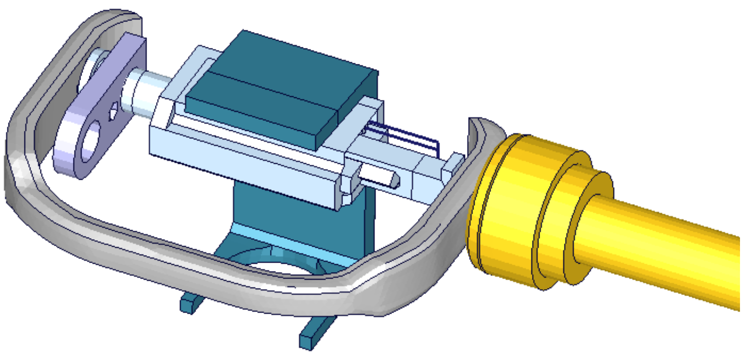
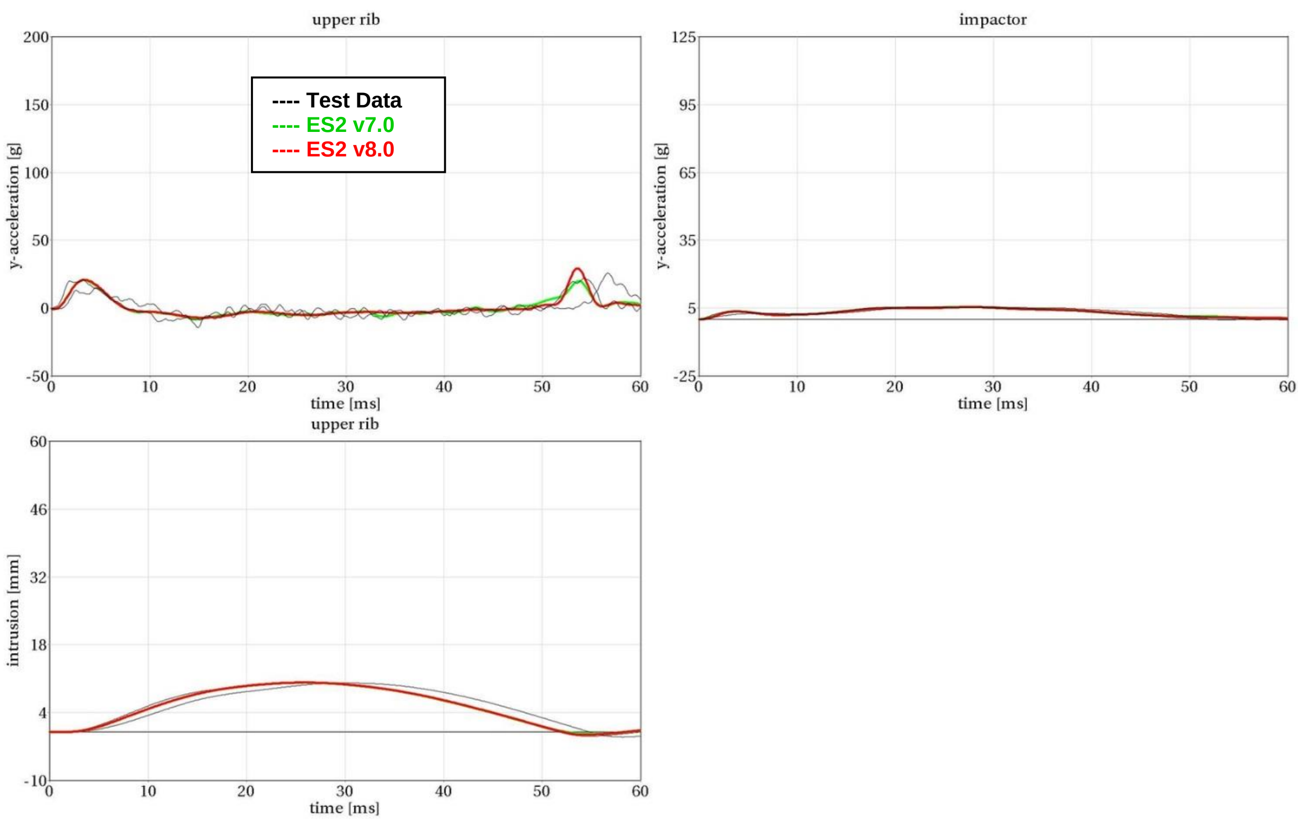


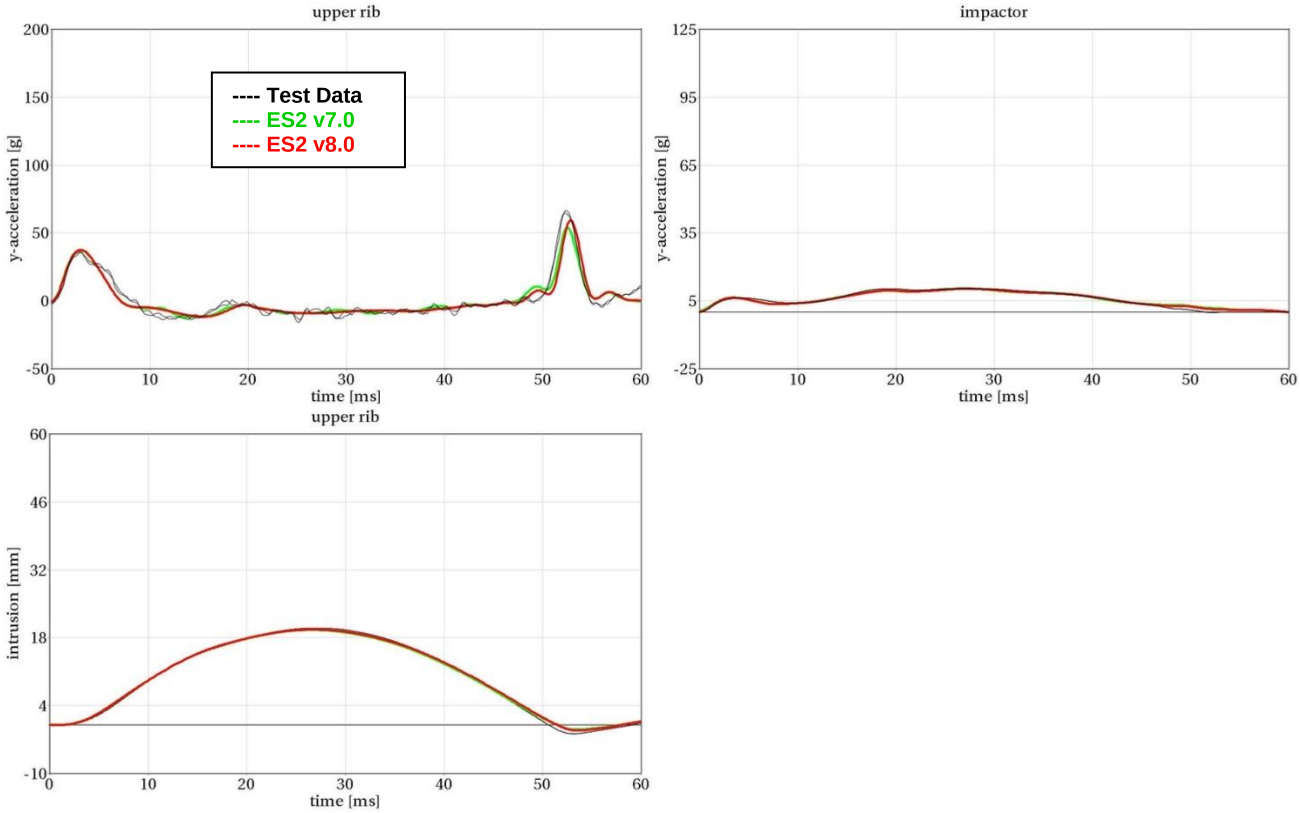
Figure 37: ES-2 rib module test setup 1

- Pendulum impacting the assembly at the rib guidance
- five impact velocities
- Damper assembly is removed

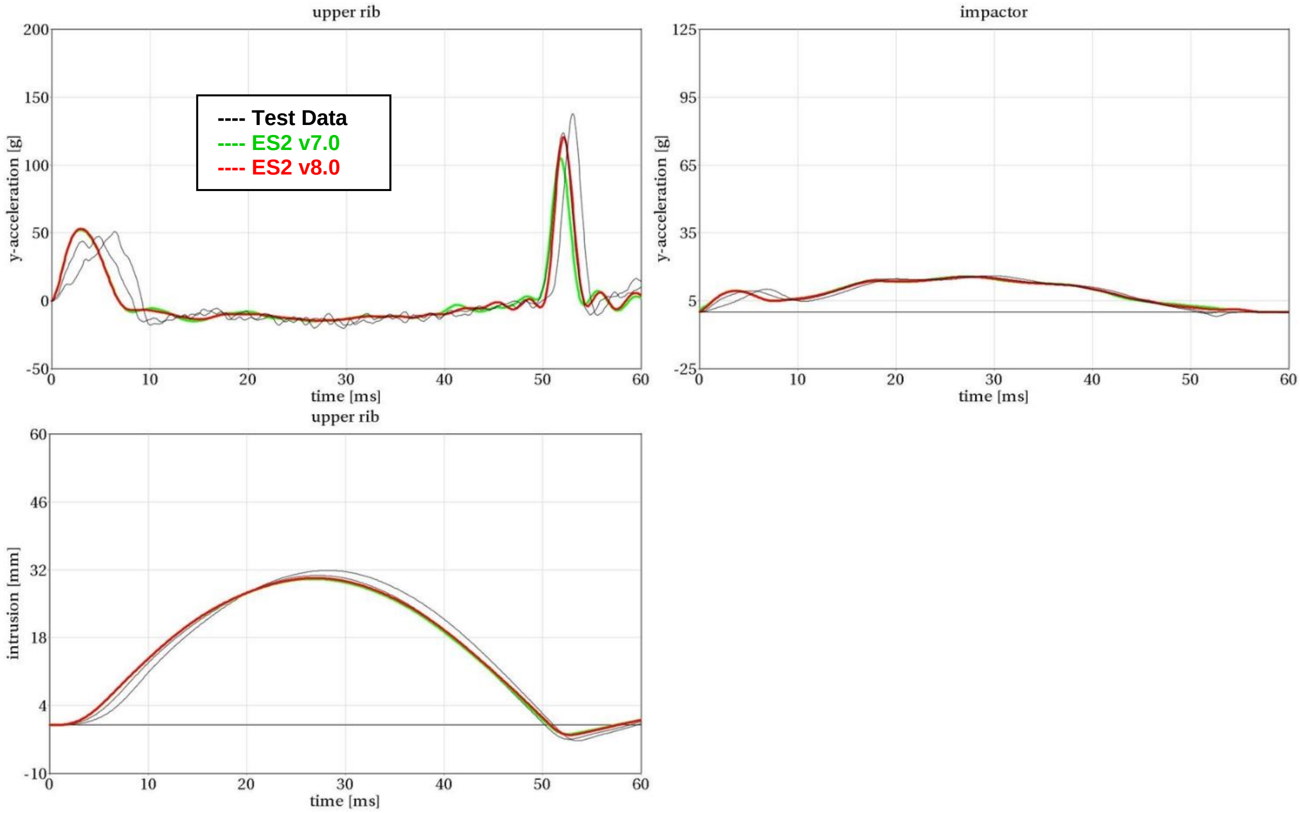
10.2.2 Test setup 1: velocity 1



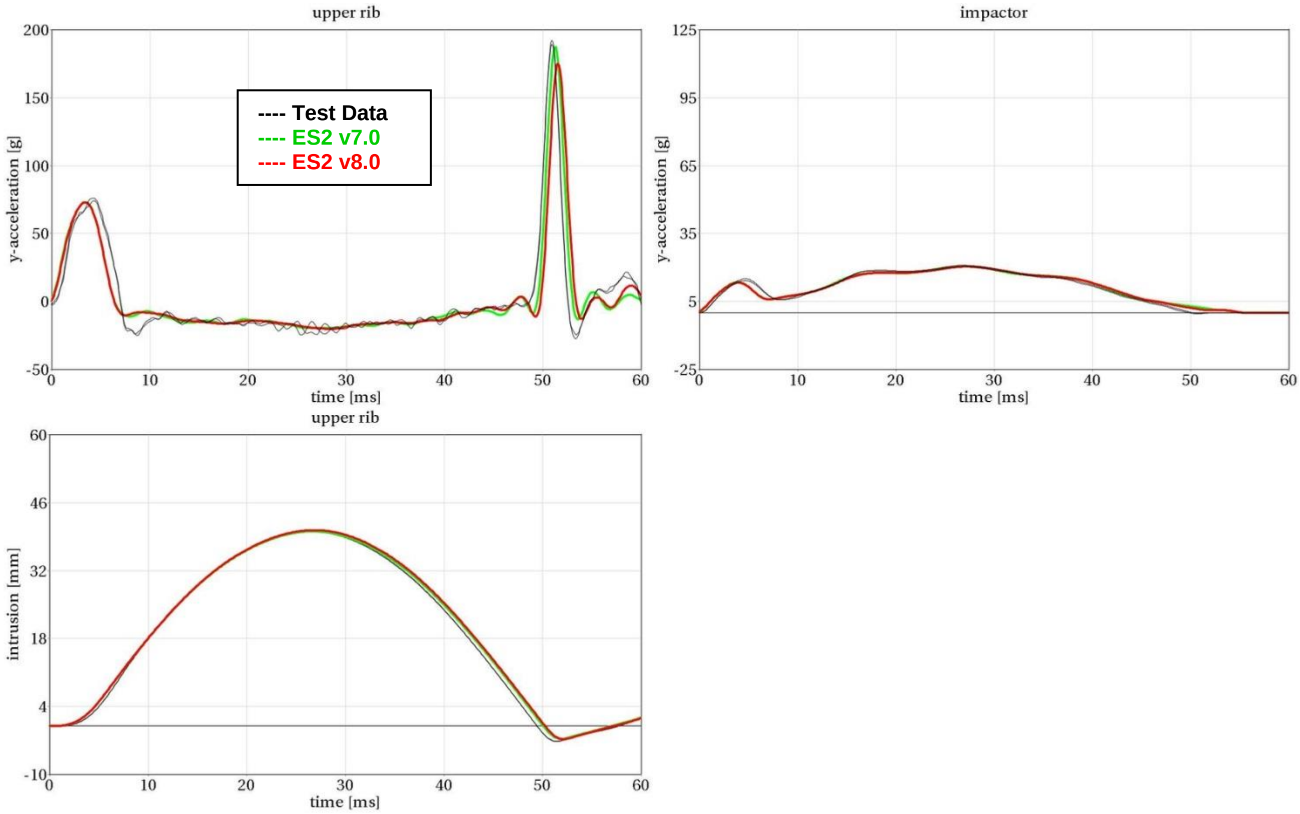
10.2.3 Test setup 1: velocity 2



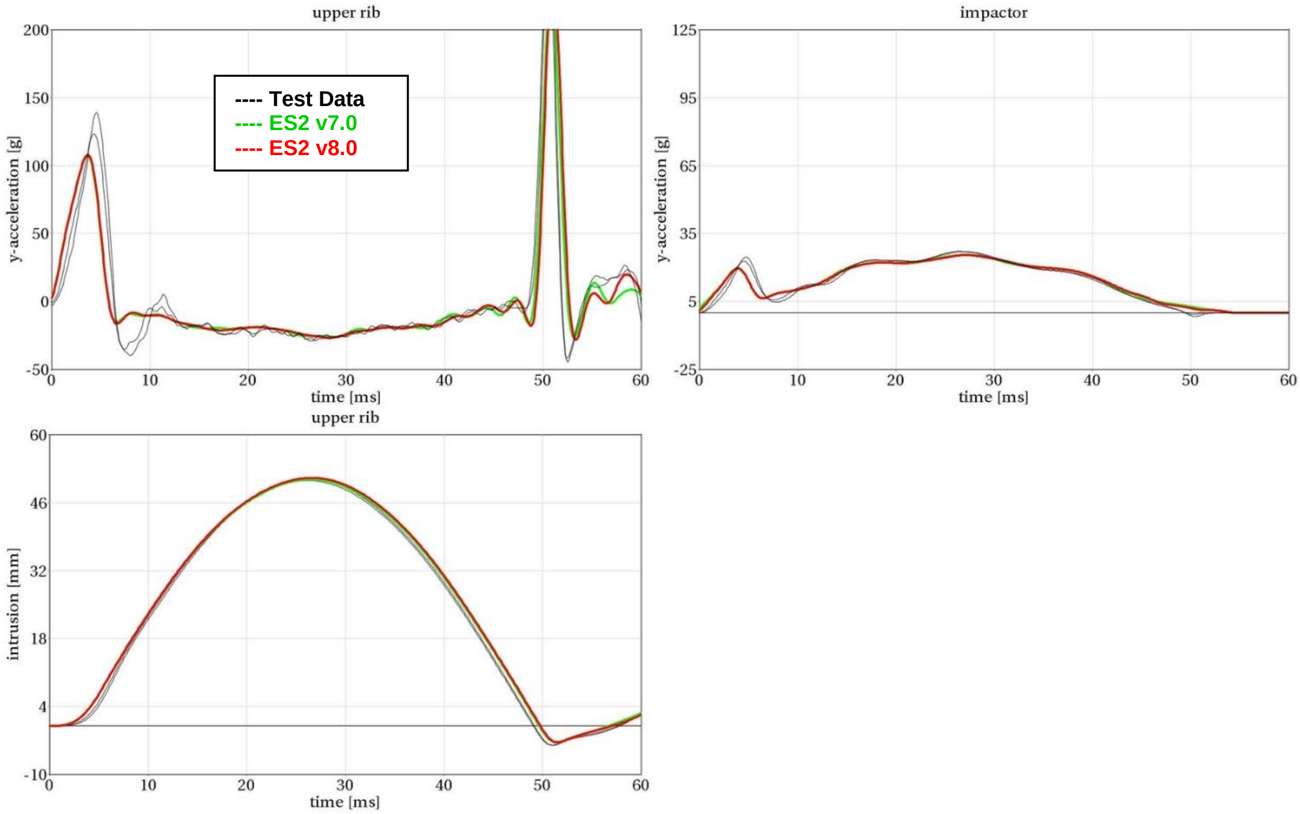
10.2.4 Test setup 1: velocity 3



10.2.5 Test setup 1: velocity 4



10.2.6 Test setup 1: velocity 5



10.2.7 Test setup 2

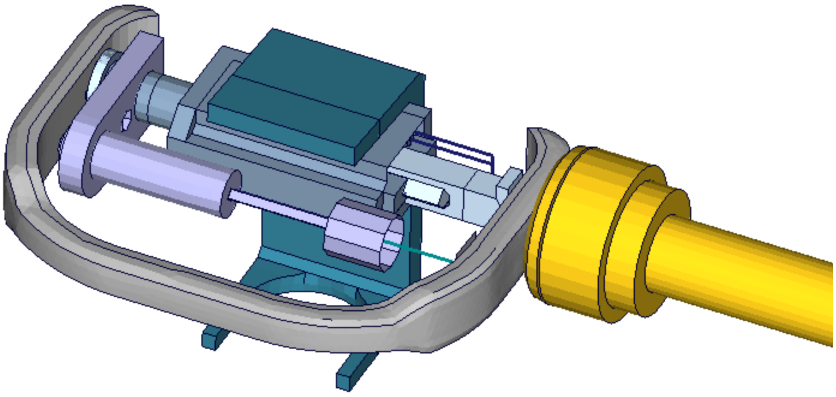
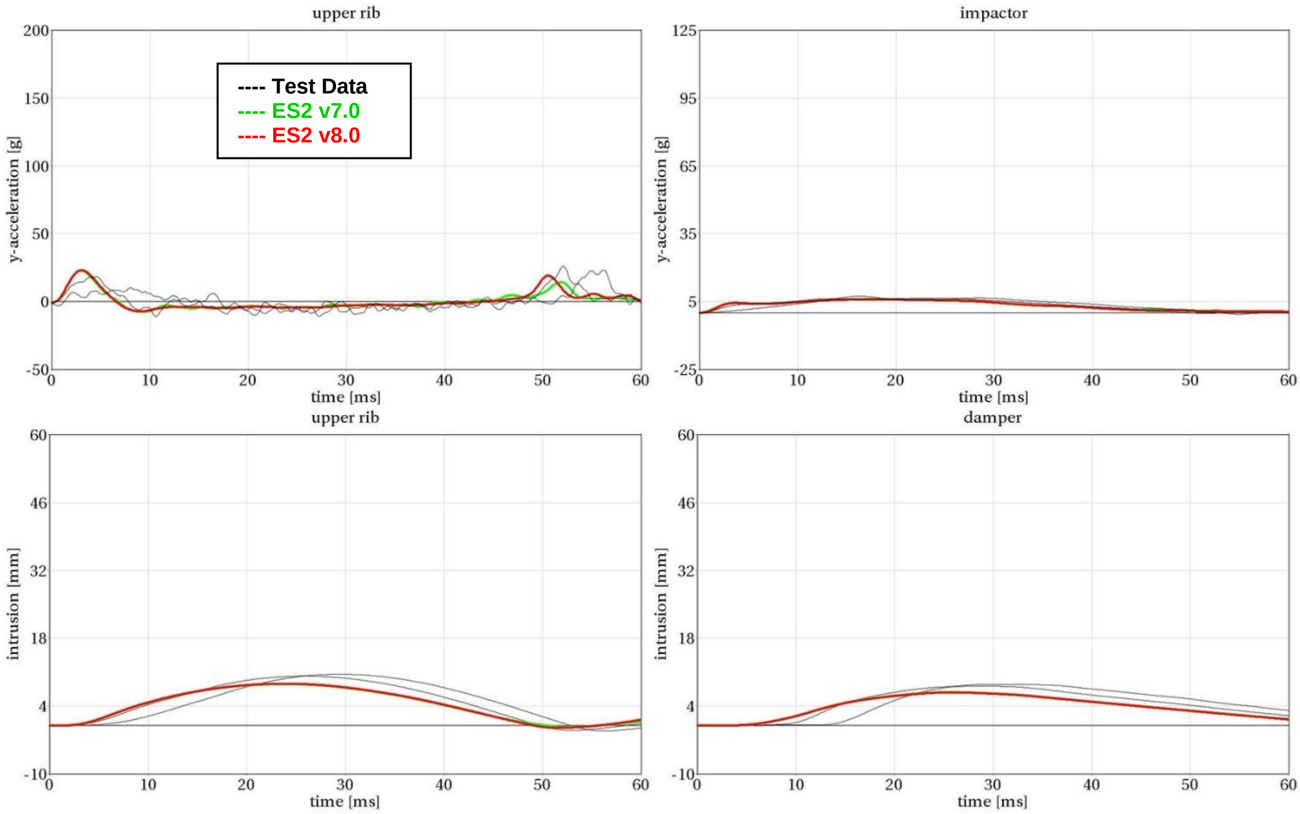


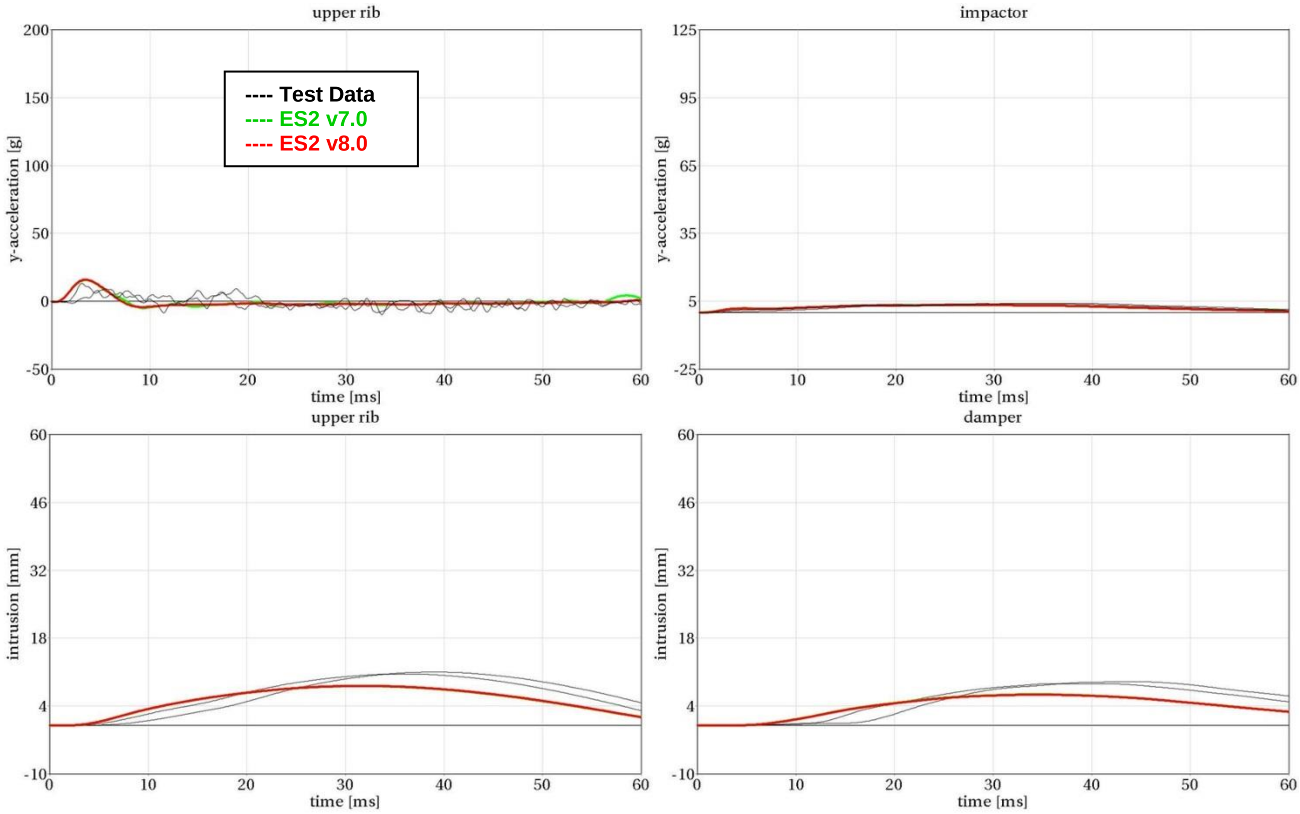
Figure 38: ES-2 rib module test setup 2

- Pendulum impacting the assembly at the rib guidance
- five impact velocities
- Damper assembly is included

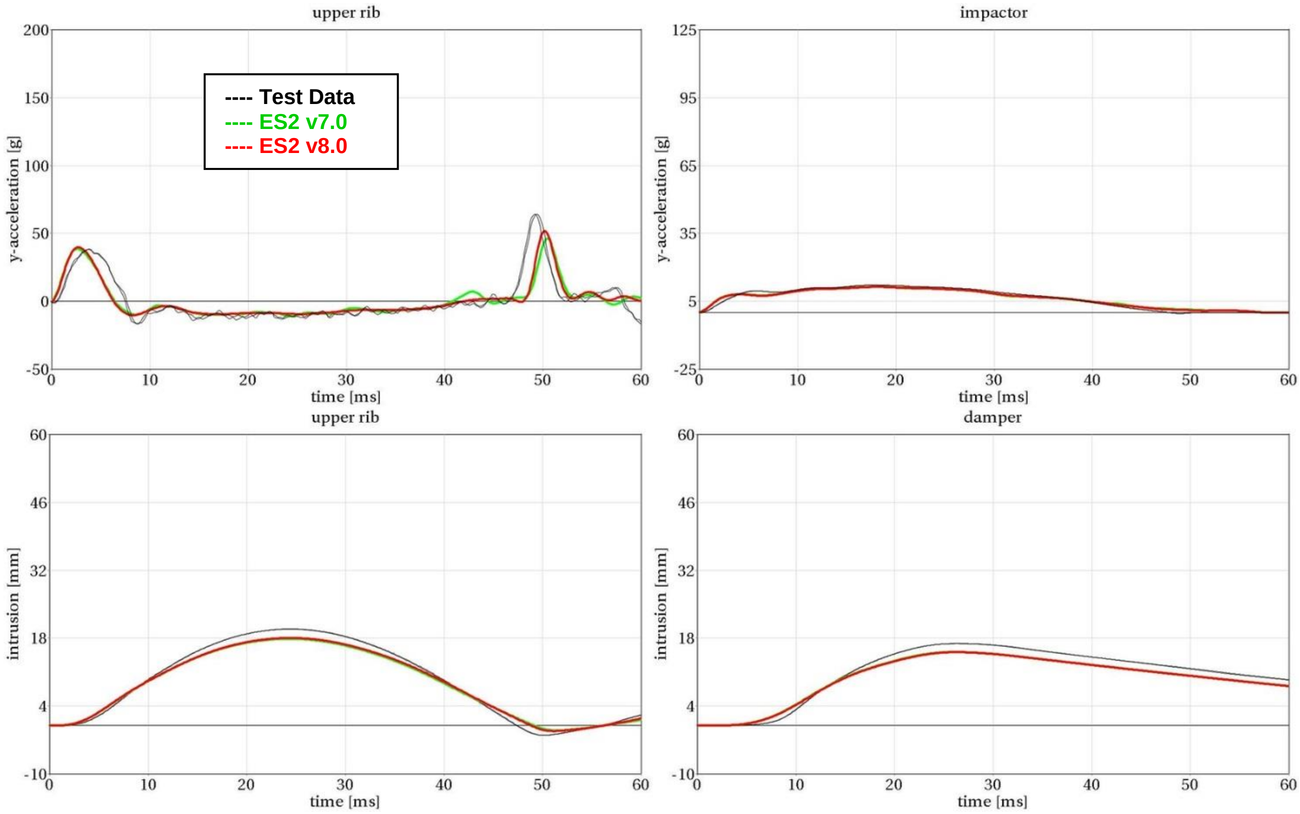
10.2.8 Test setup 2: velocity 1 low mass



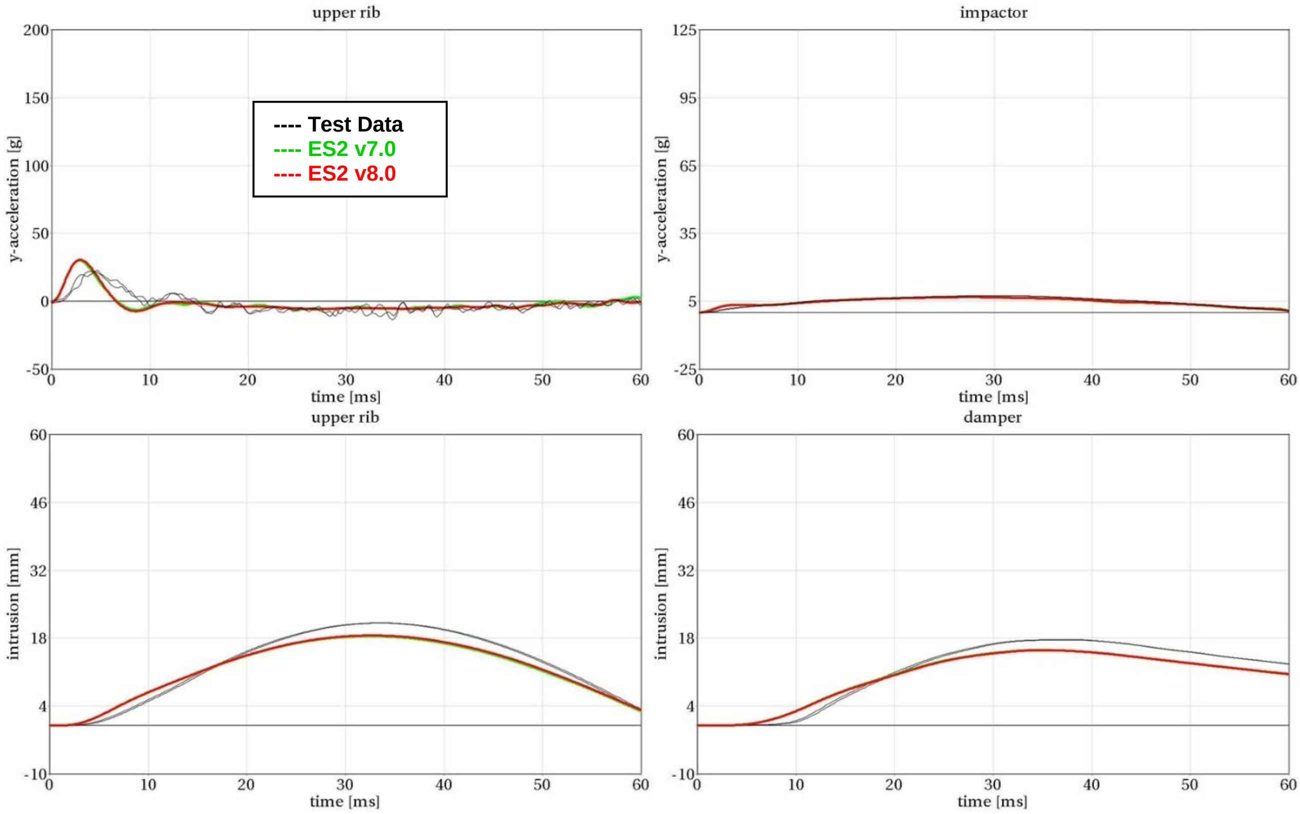
10.2.9 Test setup 2: velocity 1 high mass



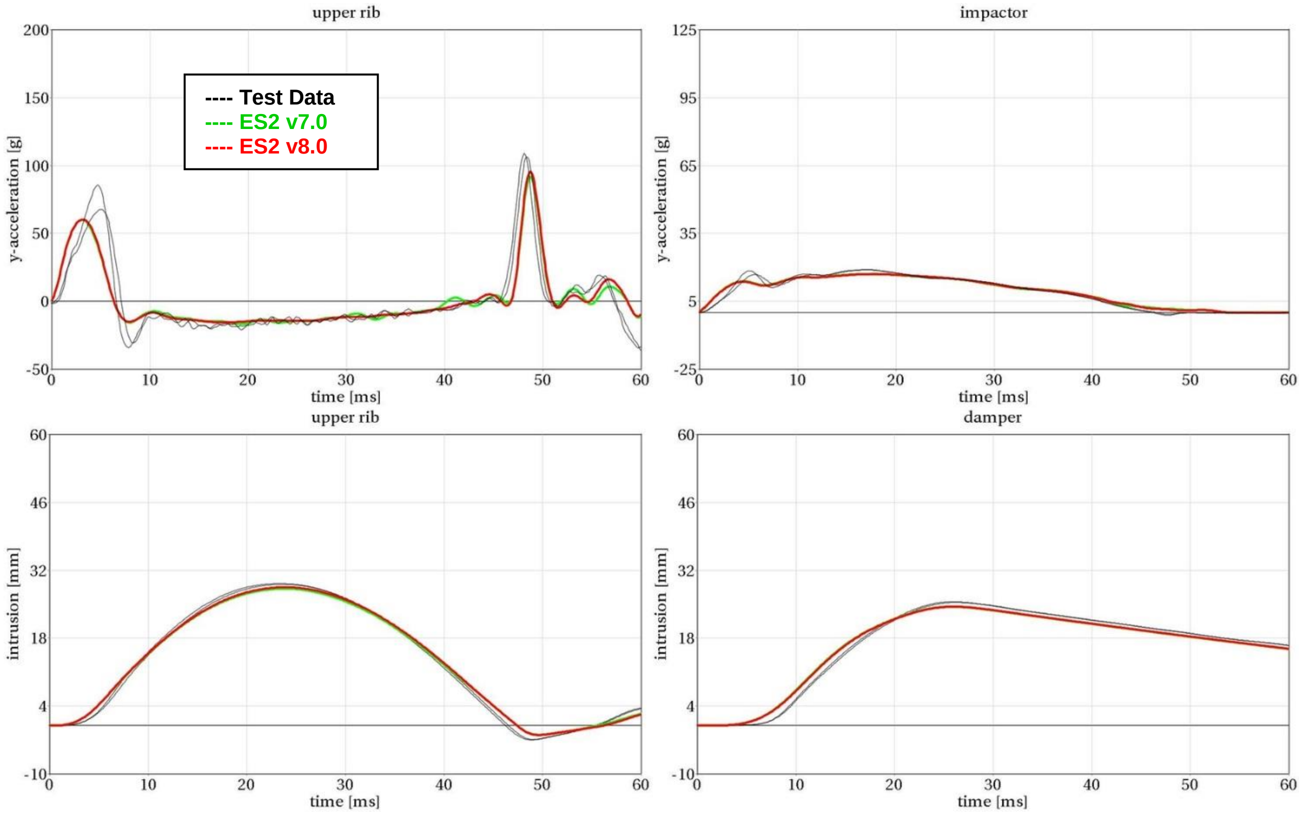
10.2.10 Test setup 2: velocity 2 low mass



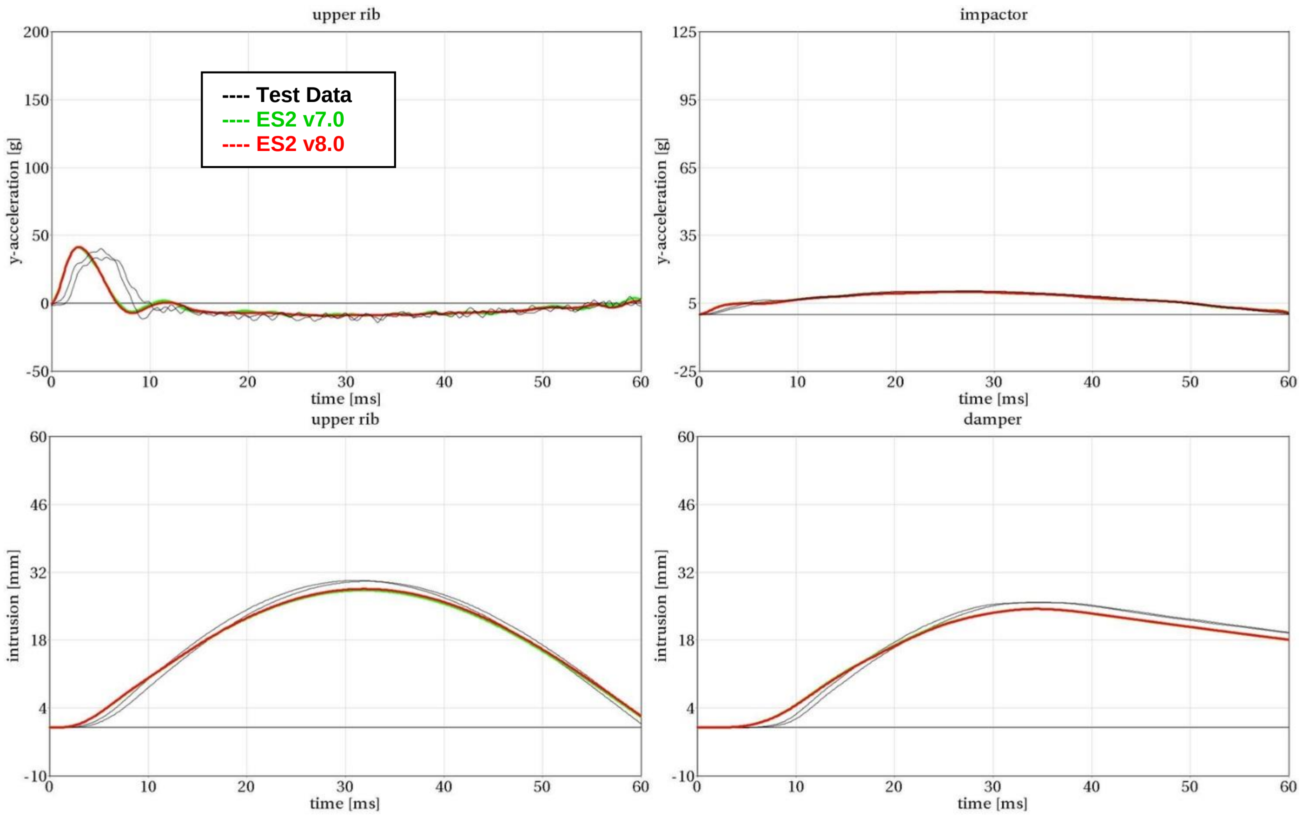
10.2.11 Test setup 2: velocity 2 high mass



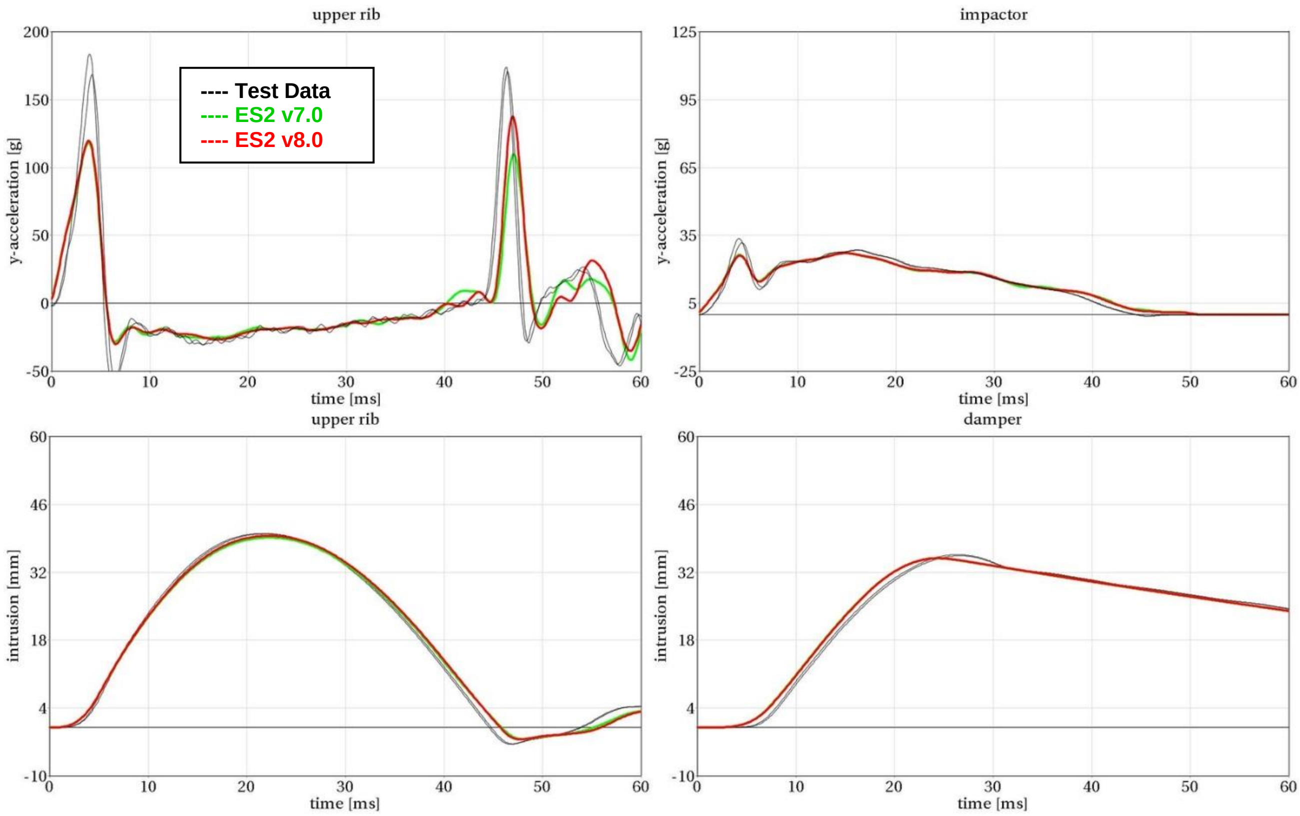
10.2.12 Test setup 2: velocity 3 low mass



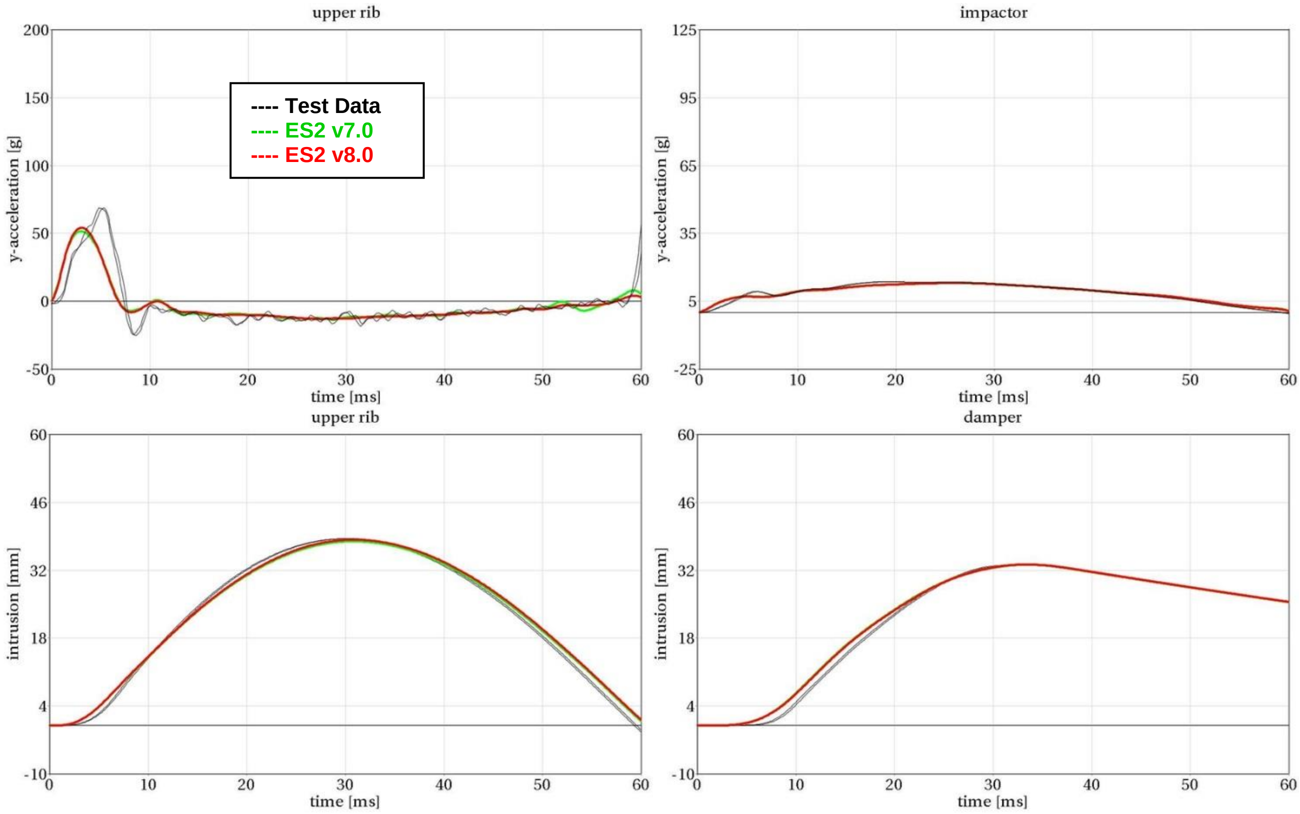
10.2.13 Test setup 2: velocity 3 high mass



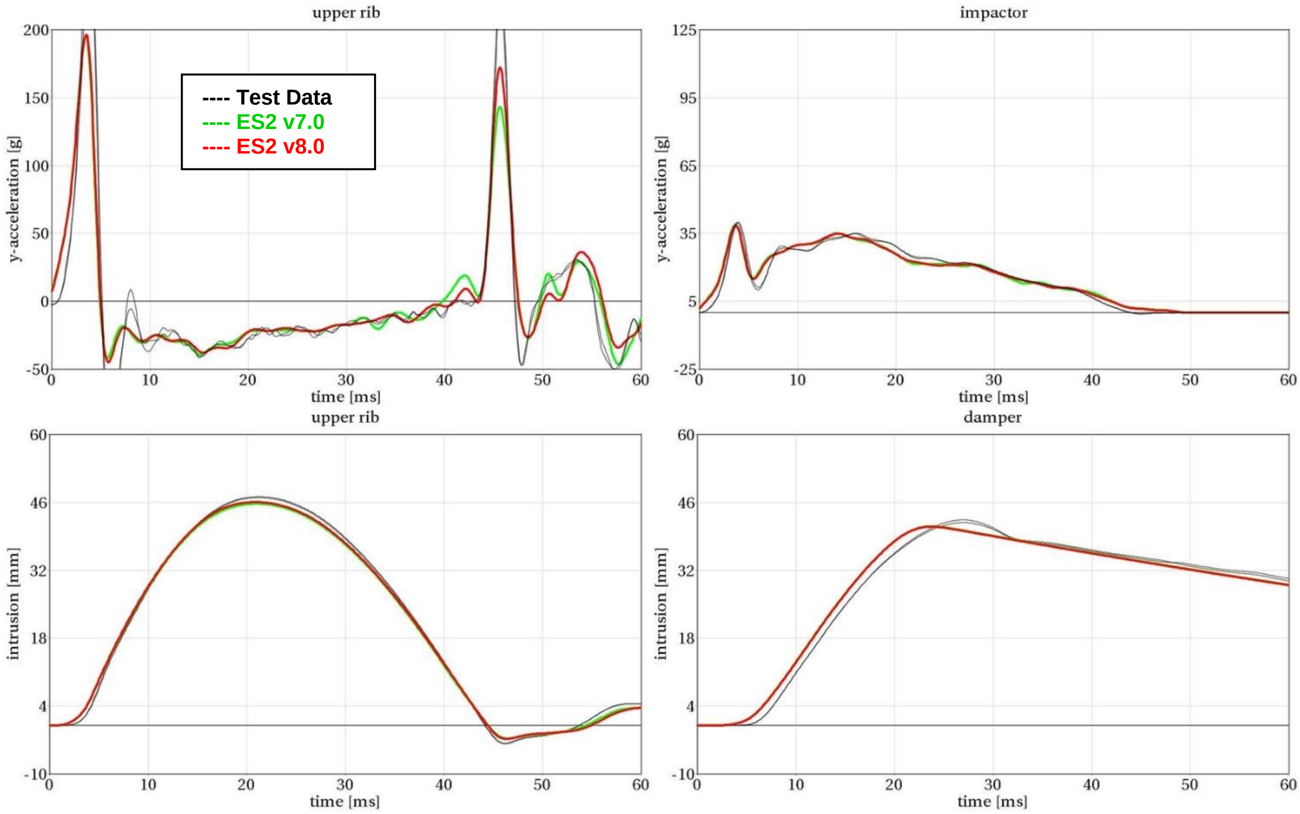
10.2.14 Test setup 2: velocity 4 low mass



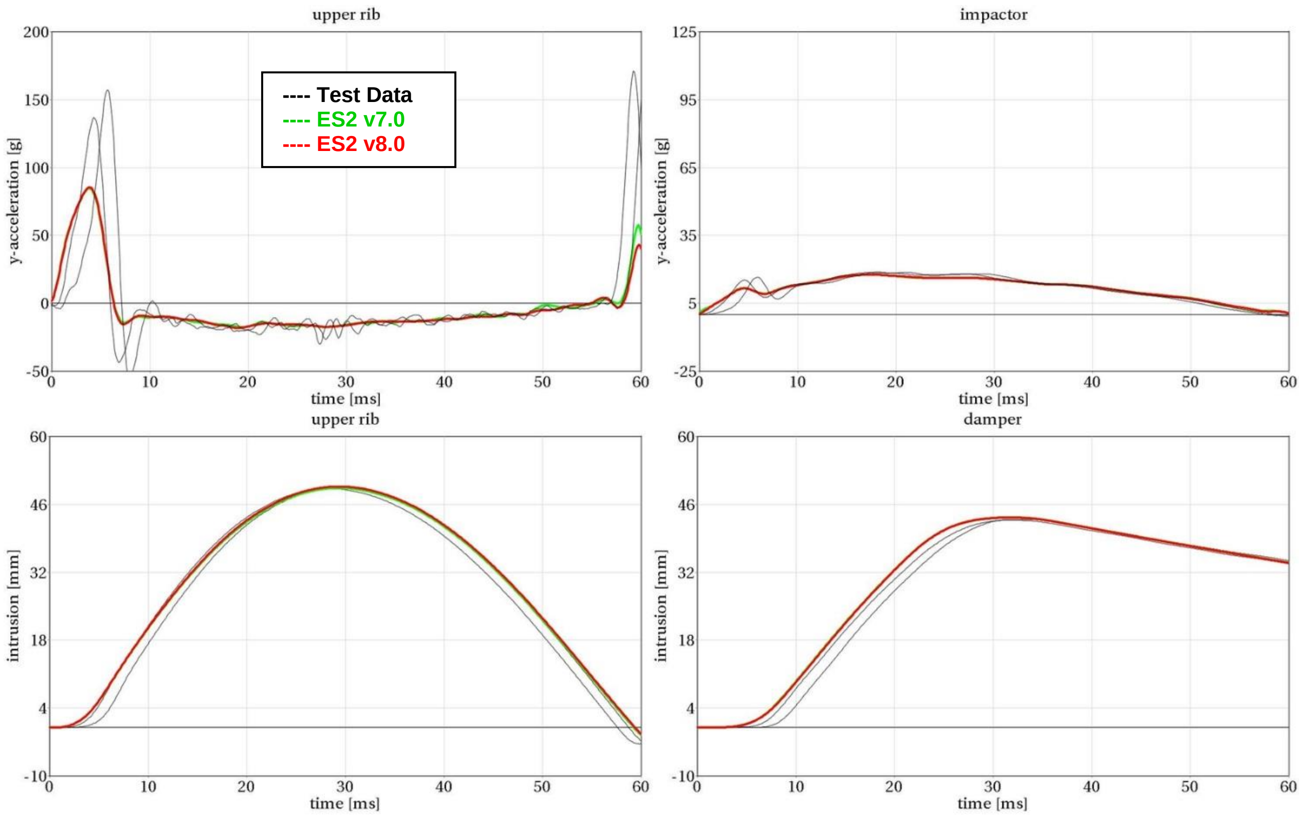
10.2.15 Test setup 2: velocity 4 high mass



10.2.16 Test setup 2: velocity 5 low mass



10.2.17 Test setup 2: velocity 5 high mass



10.2.18 Test setup 3

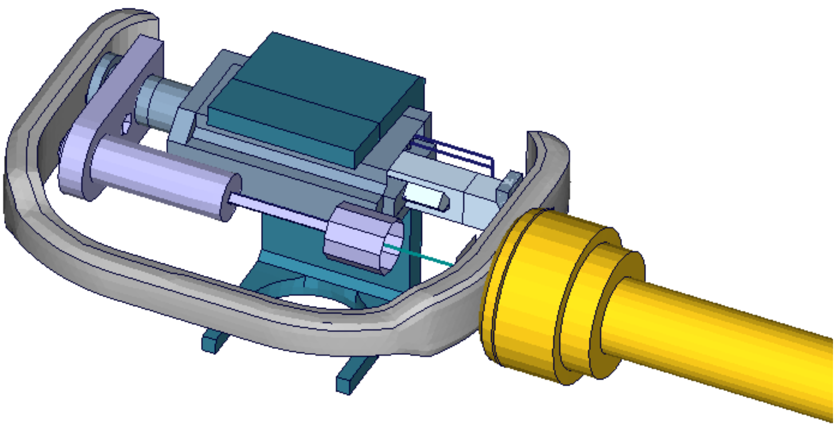
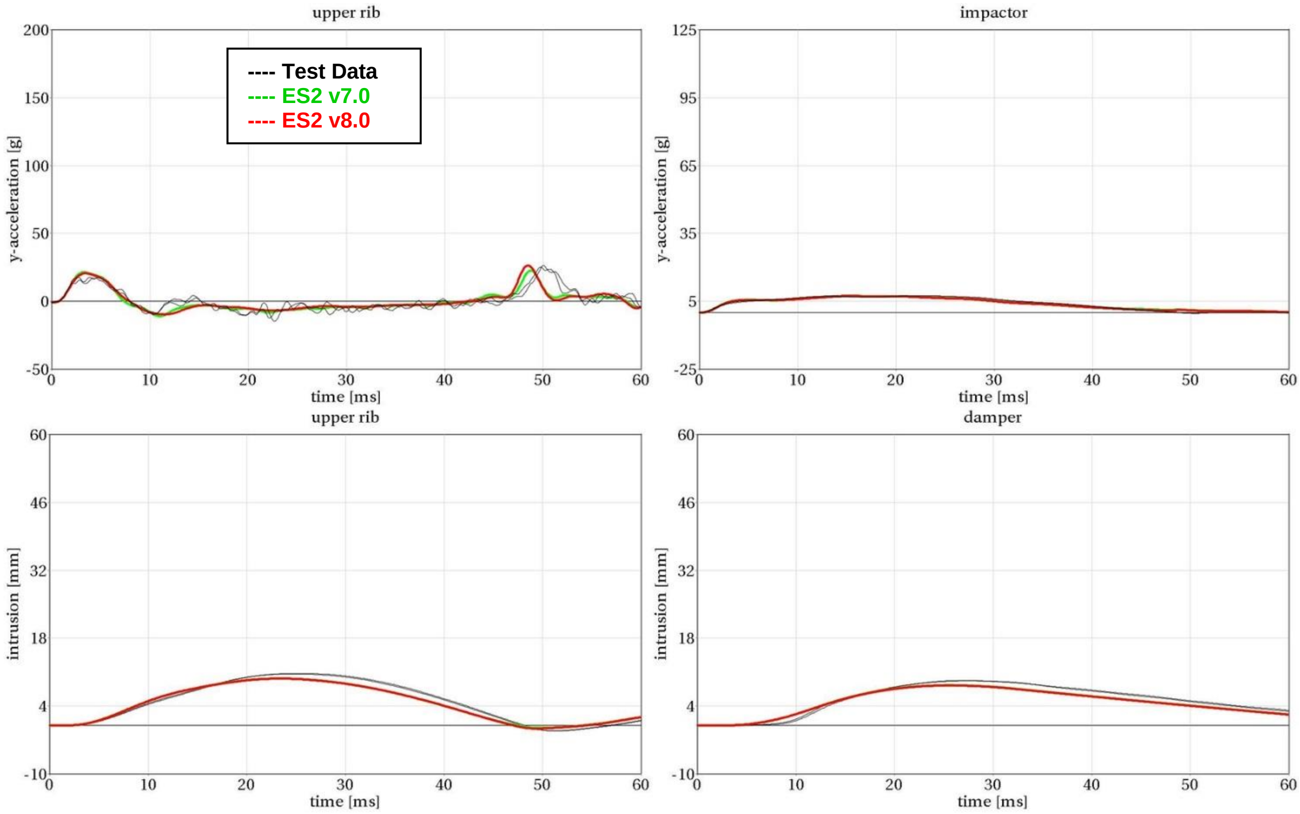


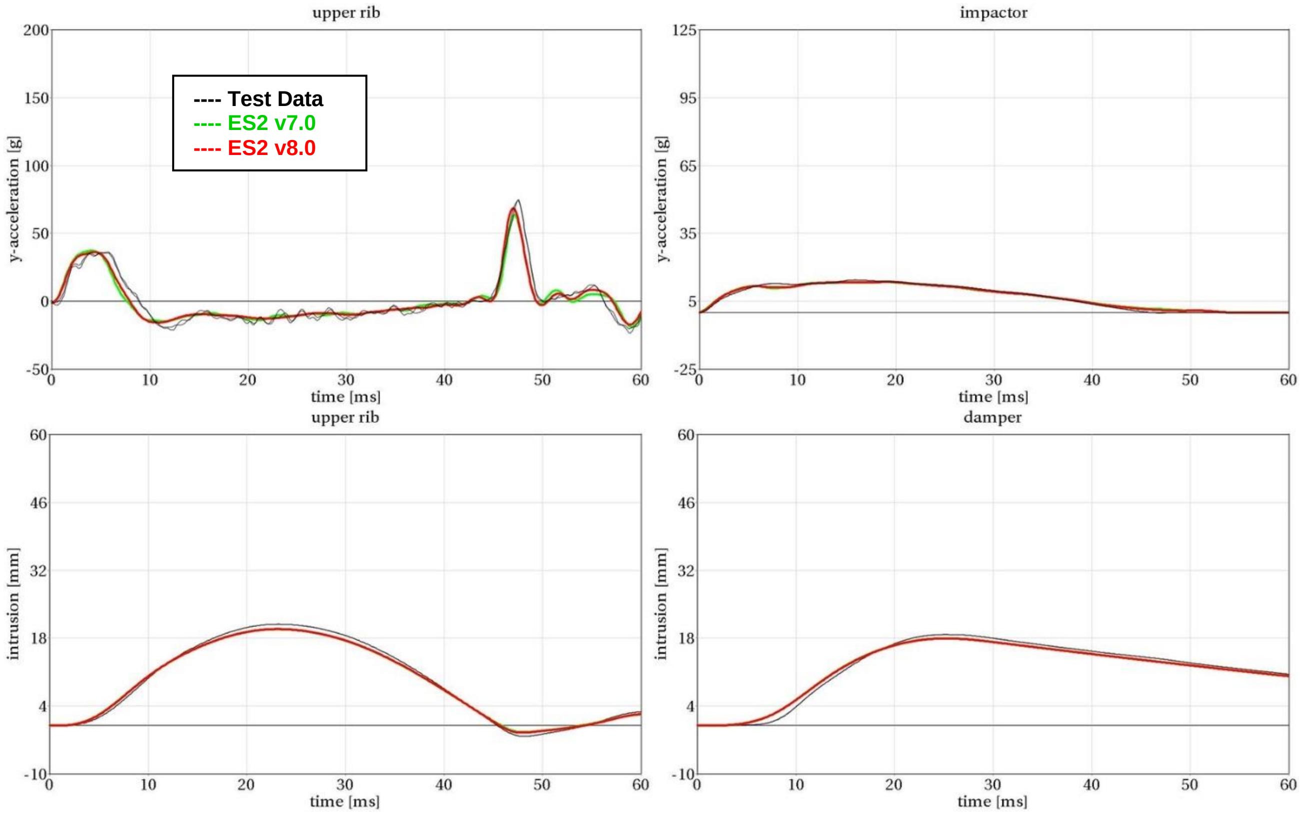
Figure 39: ES-2 rib module test setup 3

- Pendulum impacting the assembly at the damper connection
- five impact velocities
- Damper assembly is included

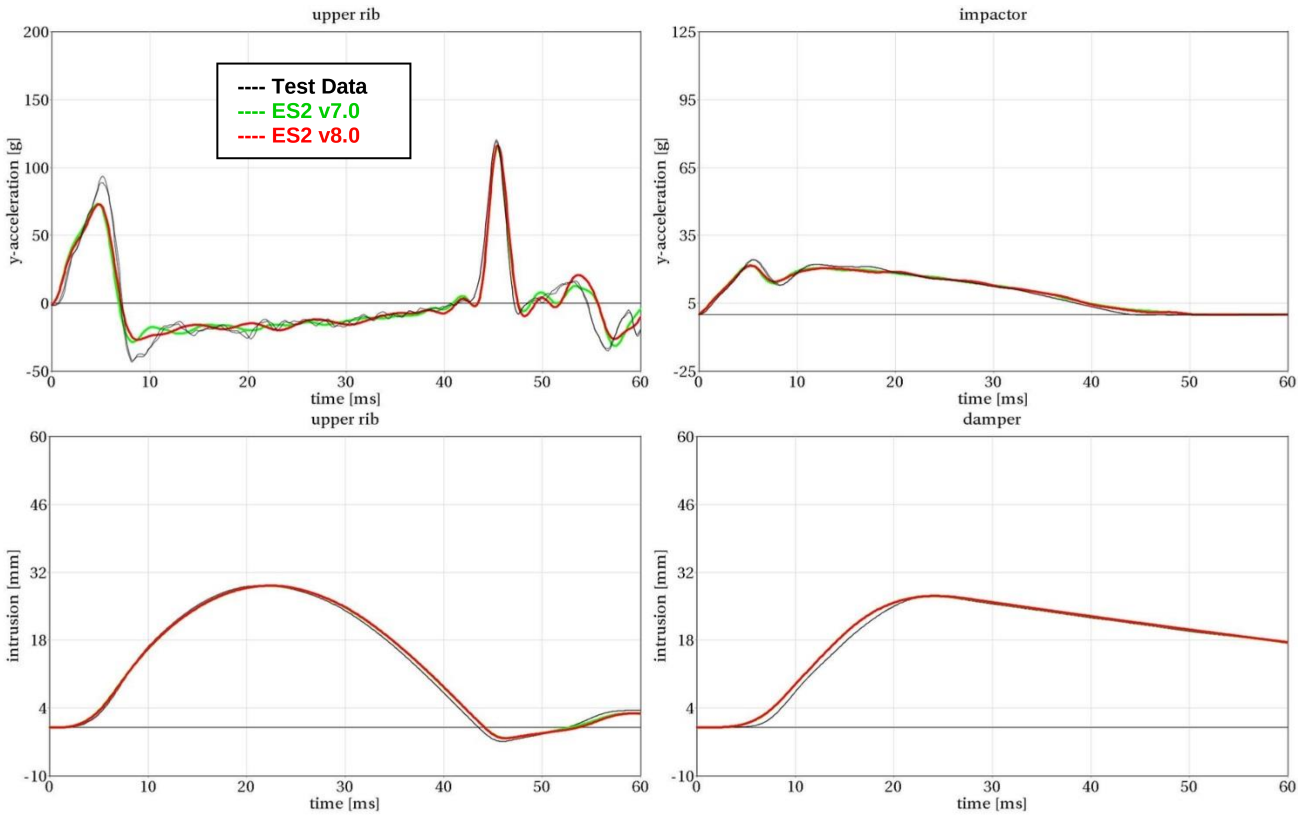
10.2.19 Test setup 3: velocity 1



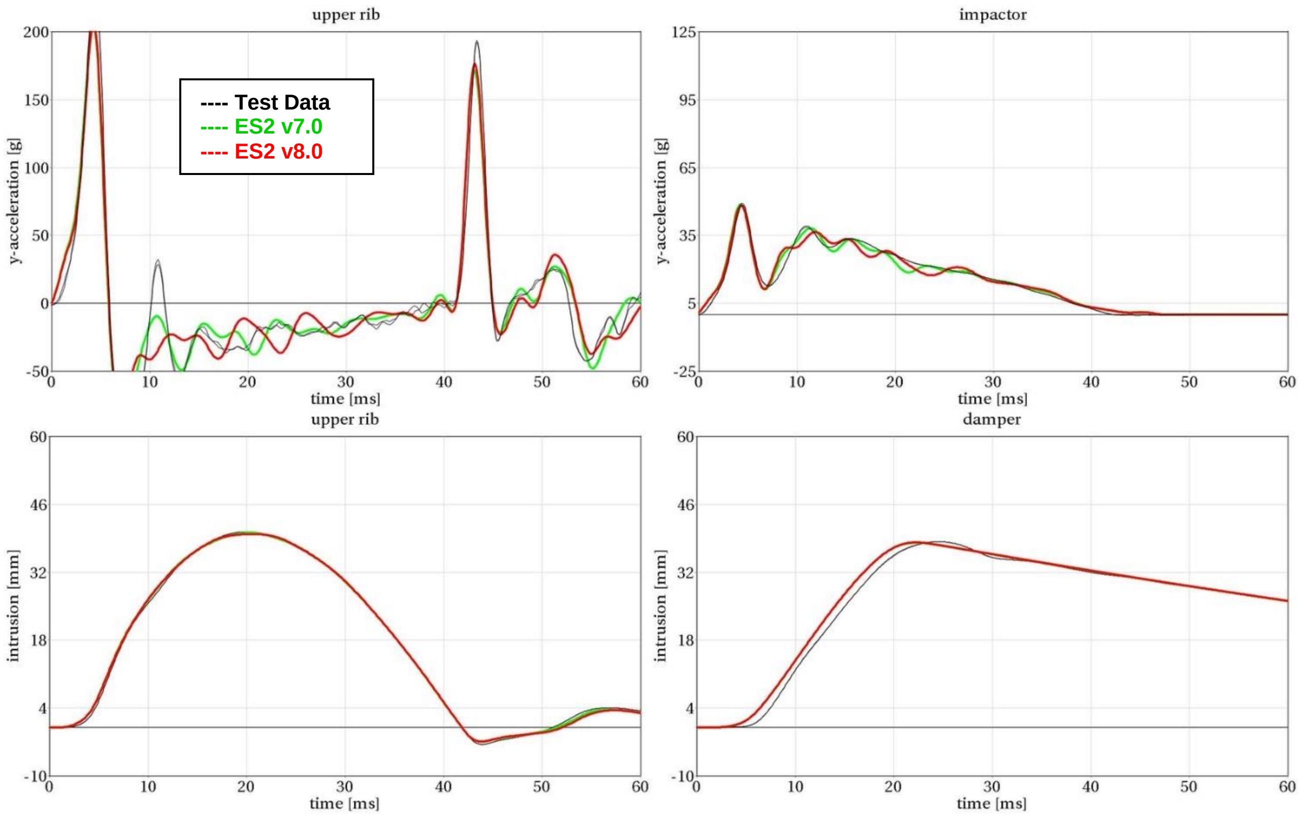
10.2.20 Test setup 3: velocity 2



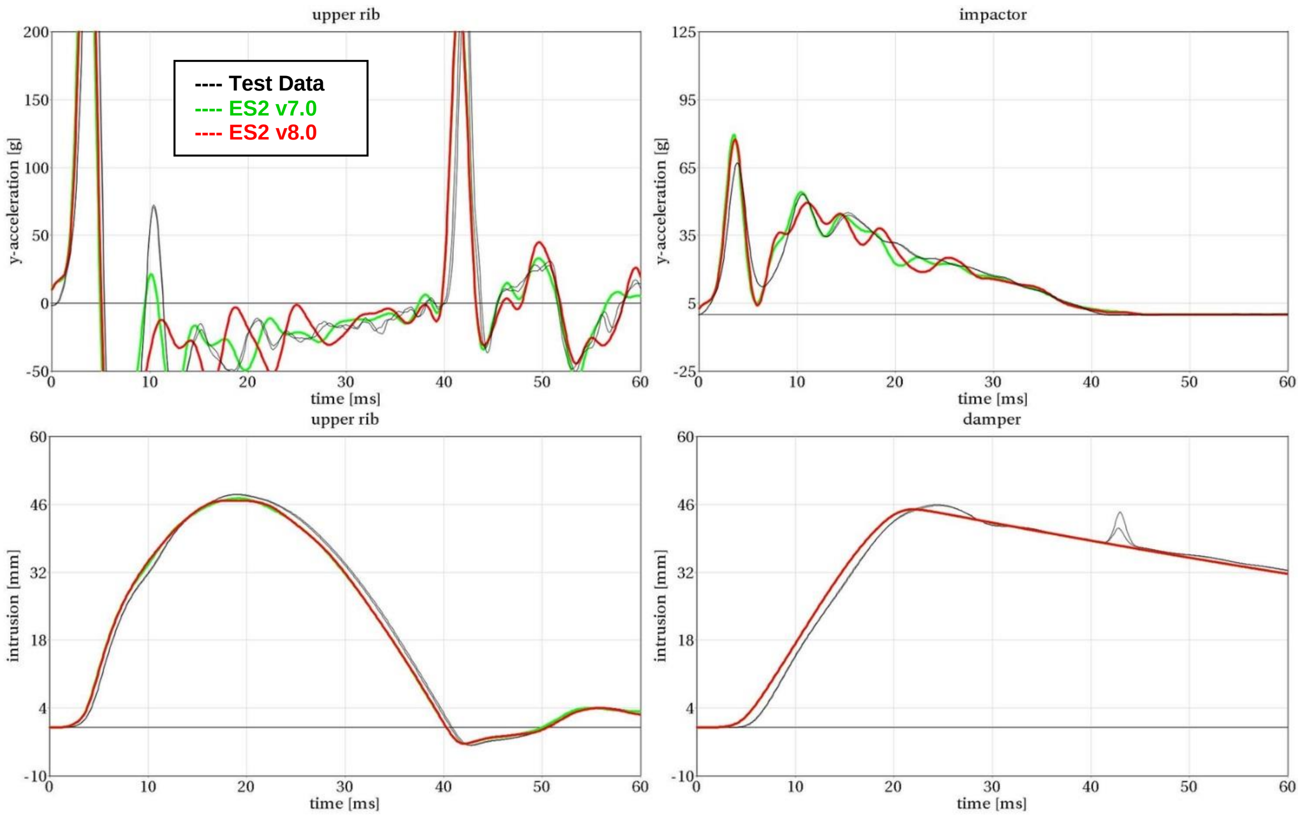
10.2.21 Test setup 3: velocity 3



10.2.22 Test setup 3: velocity 4



10.2.23 Test setup 3: velocity 5



10.2.24 Test setup 4

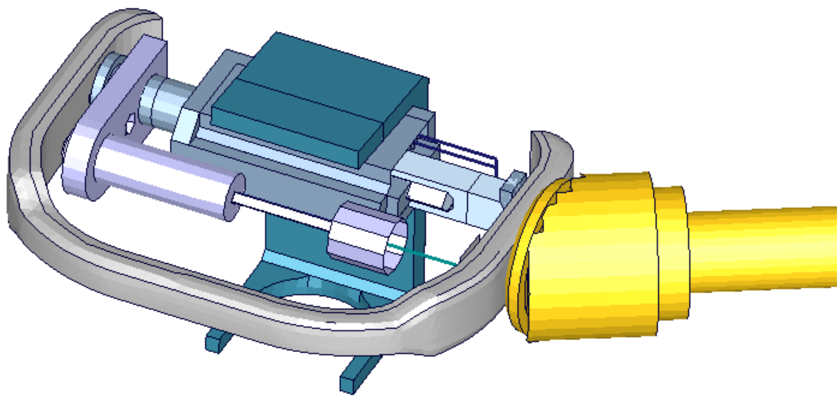
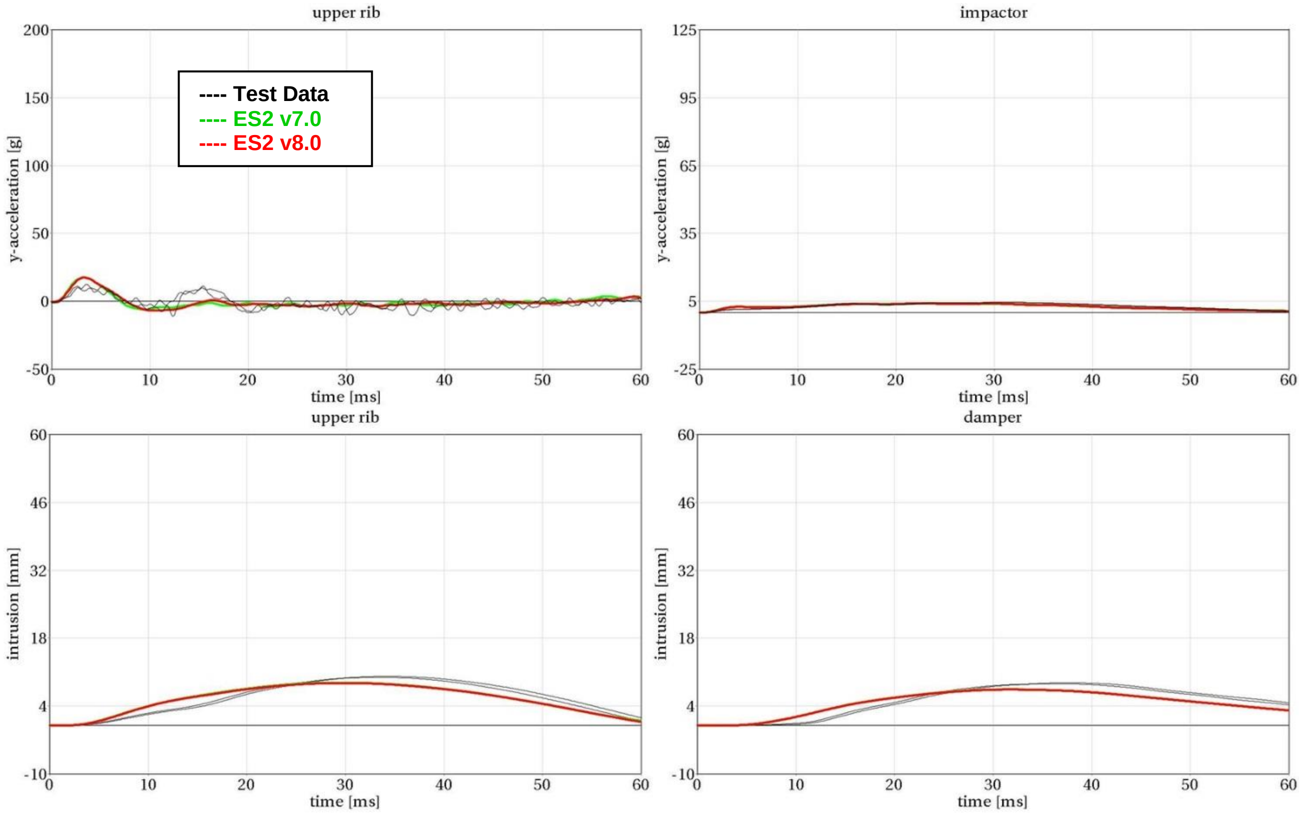


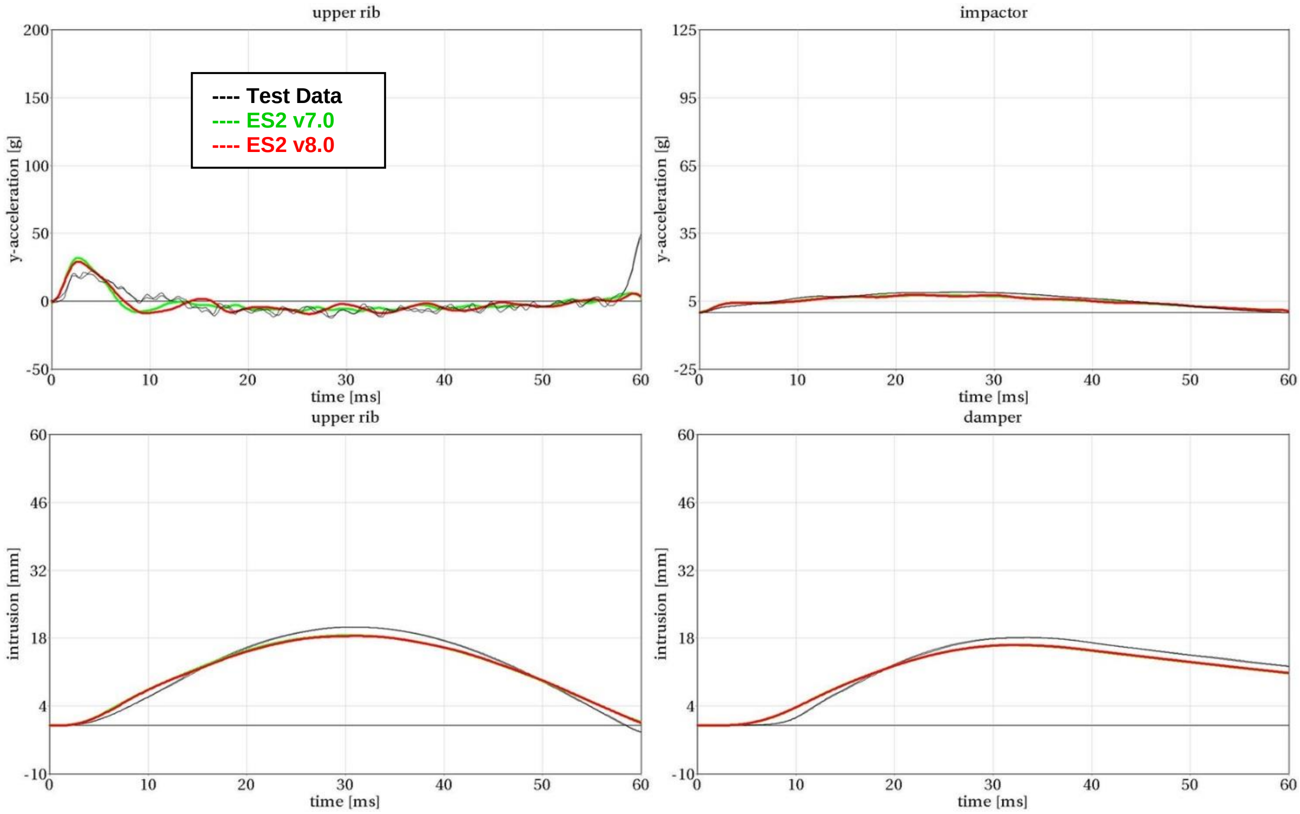
Figure 40: ES-2 rib module test setup 4

- Pendulum impacting the assembly at between damper and guidance
- five impact velocities
- Damper assembly is included
- The impact direction is oblique

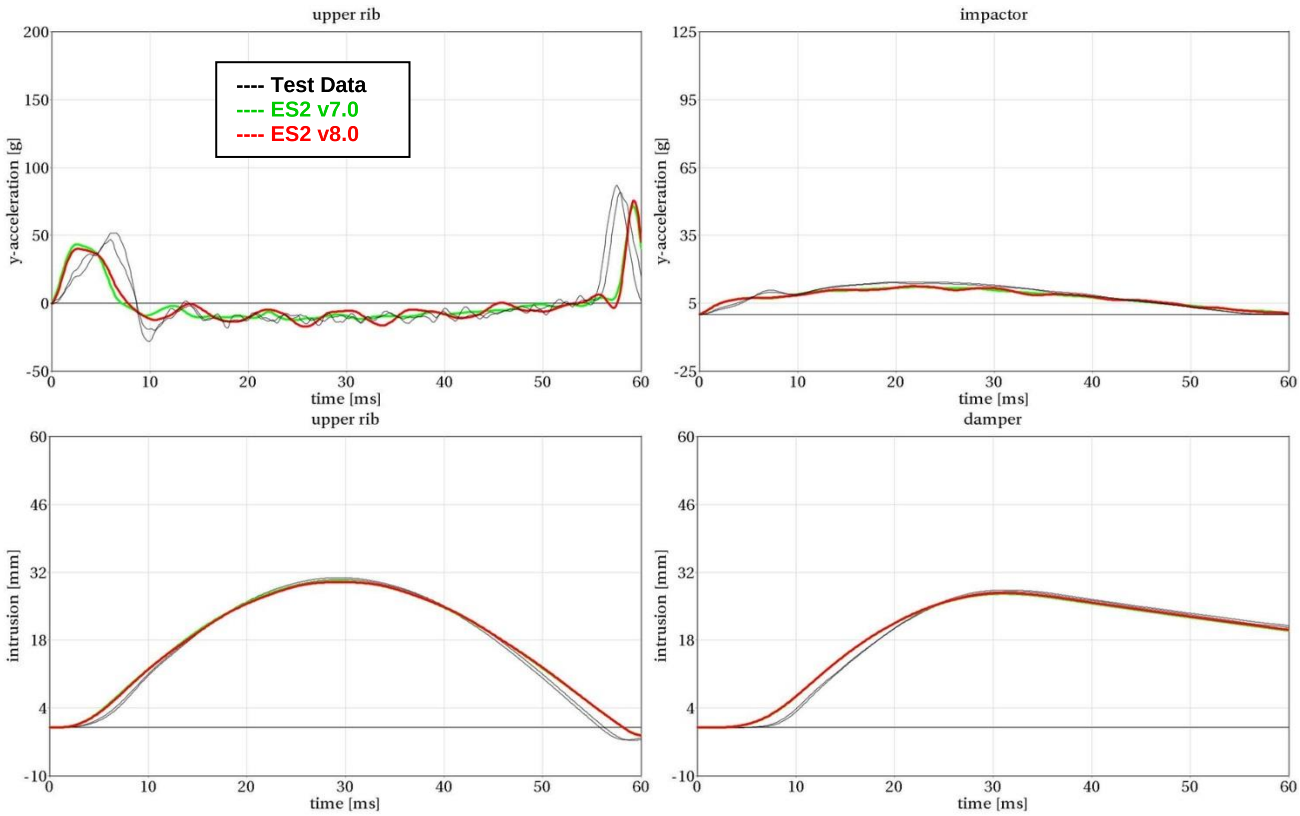
10.2.25 Test setup 4: velocity 1



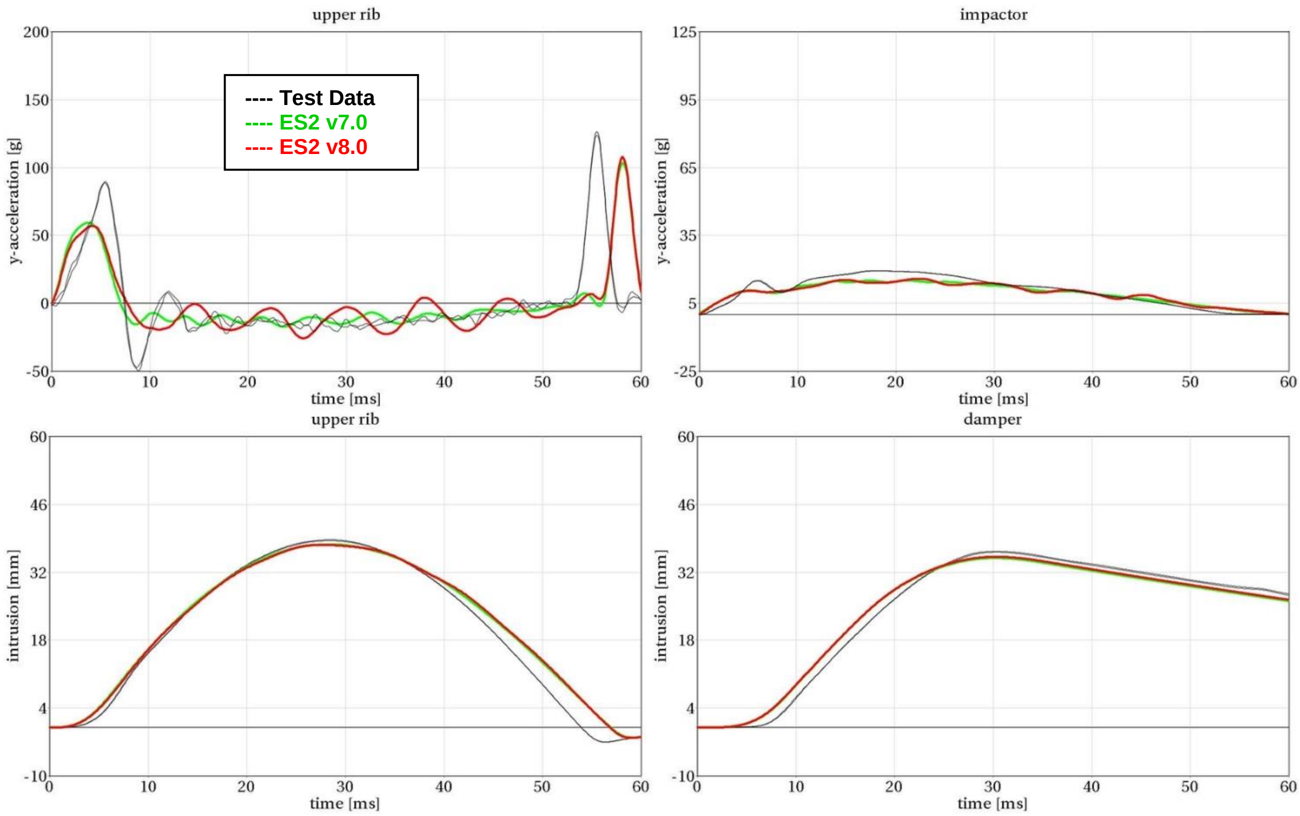
10.2.26 Test setup 4: velocity 2



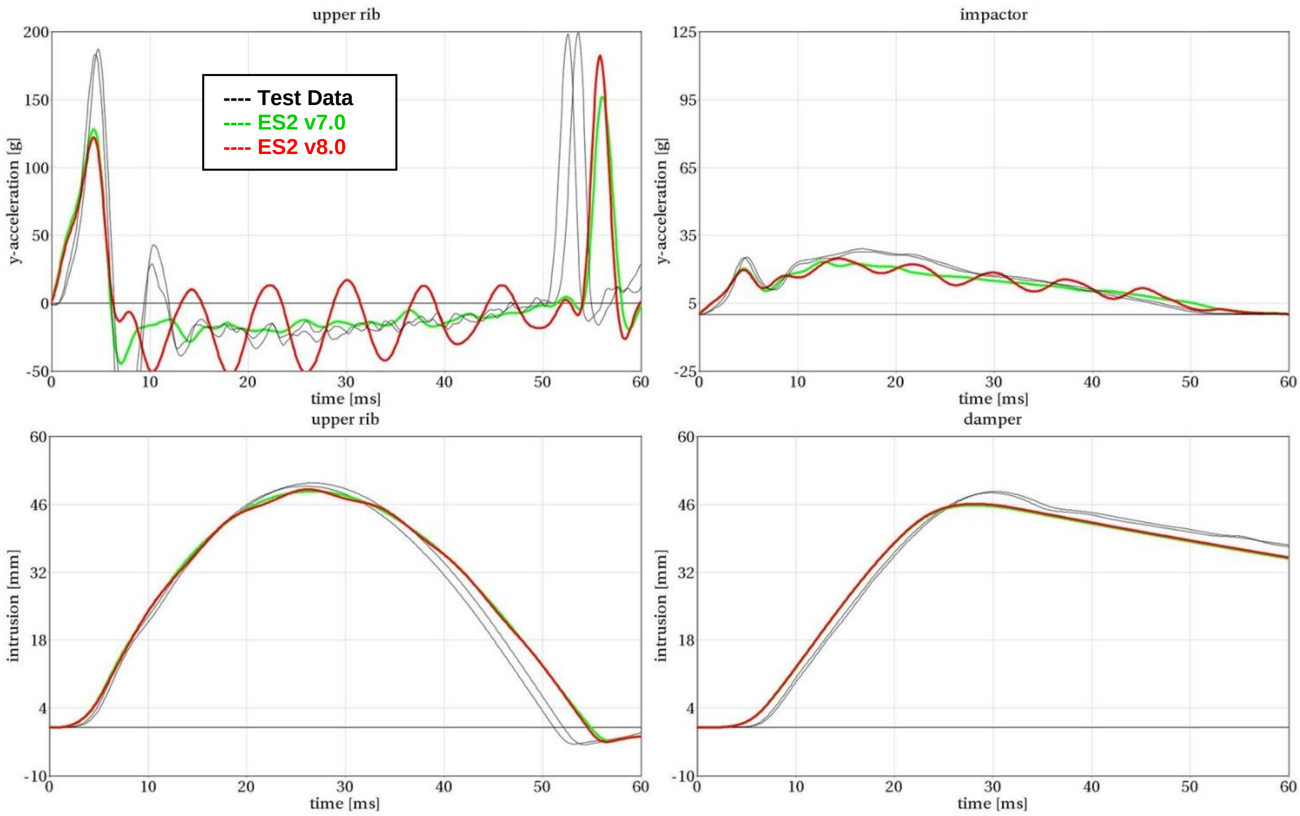
10.2.27 Test setup 4: velocity 3



10.2.28 Test setup 4: velocity 4



10.2.29 Test setup 4: velocity 5



11. Certification tests

11.1 Head drop test

- Head is mounted at an quick releases adapter.
- Head hits a flat Plate and the mid-sagittal plate of the Head has an Angle of 35° to the Horizontal
- Drop height is 200 mm.

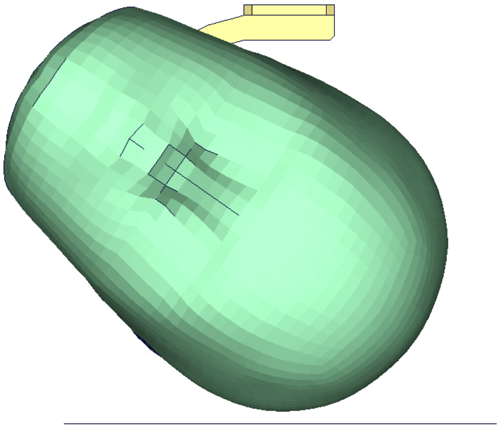
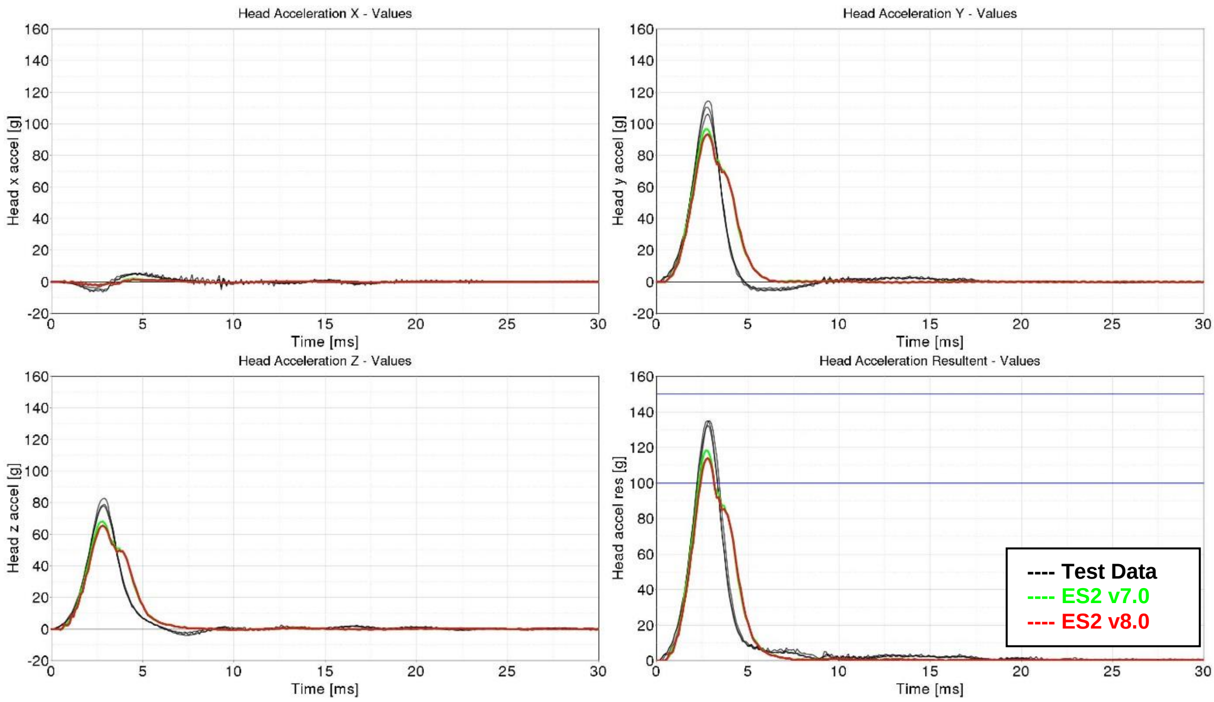


Figure 41: ES-2 head drop test setup

11.1.1 Results



11.2 Neck pendulum test

- Neck is mounted to a large pendulum.
- At the bottom of the neck a Head form is mounted
- The pendulum is decelerated by a honeycomb profile.

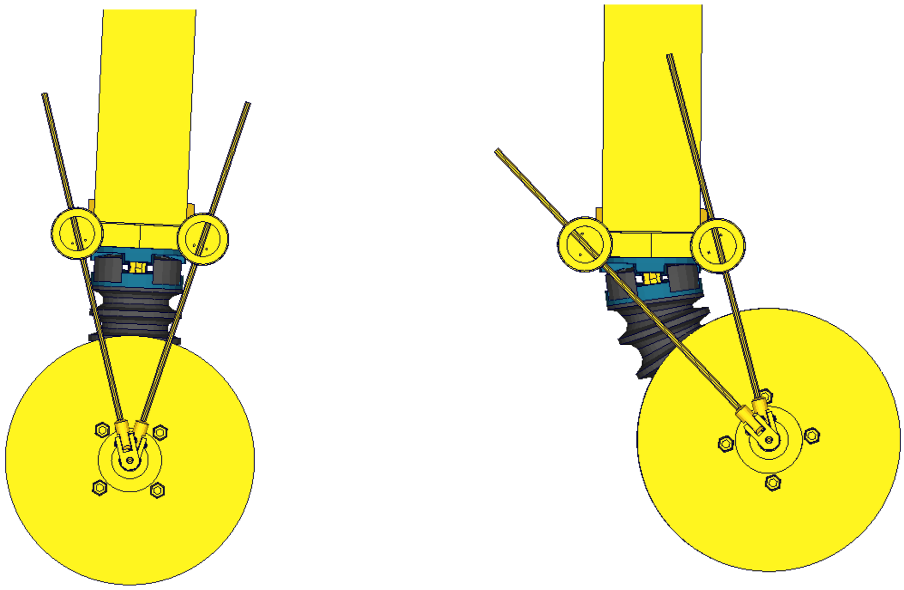
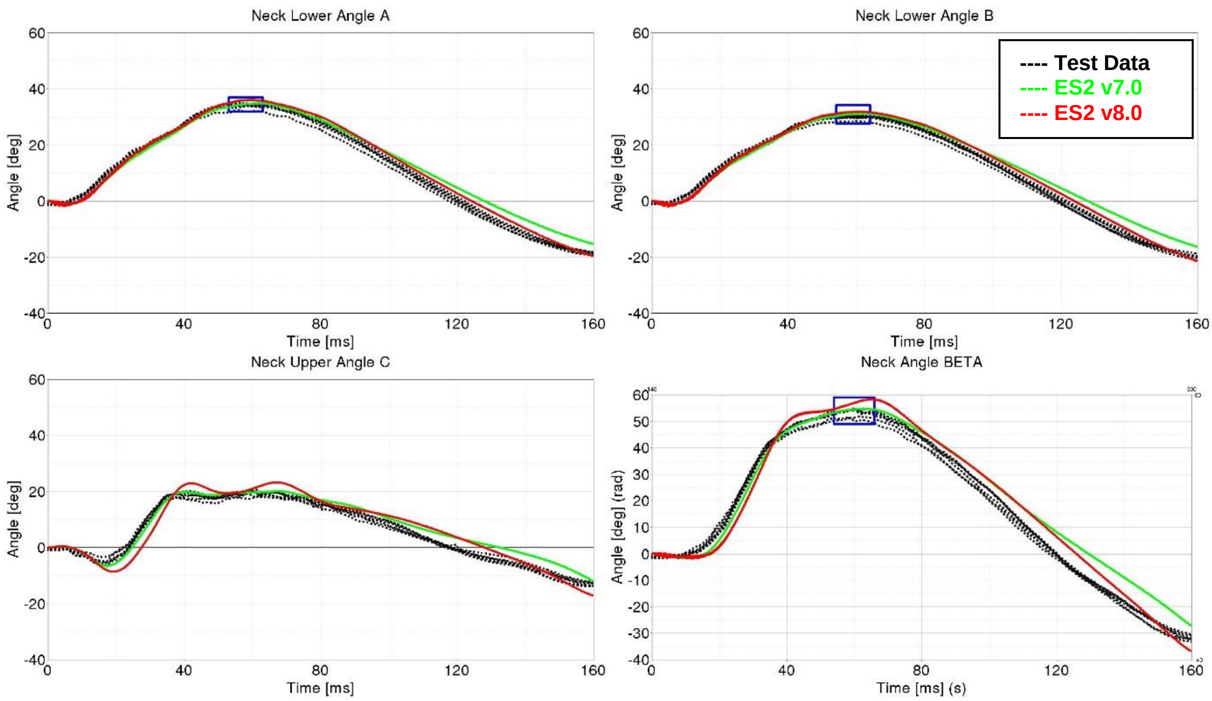


Figure 42: ES-2 neck calibration test setup

11.2.1 Results



11.3 Rib Certification

- The single rib is mounted in space.
- The rib is then loaded by a drop mass with three different drop heights.
- The rib deflection has to be in a defined corridor

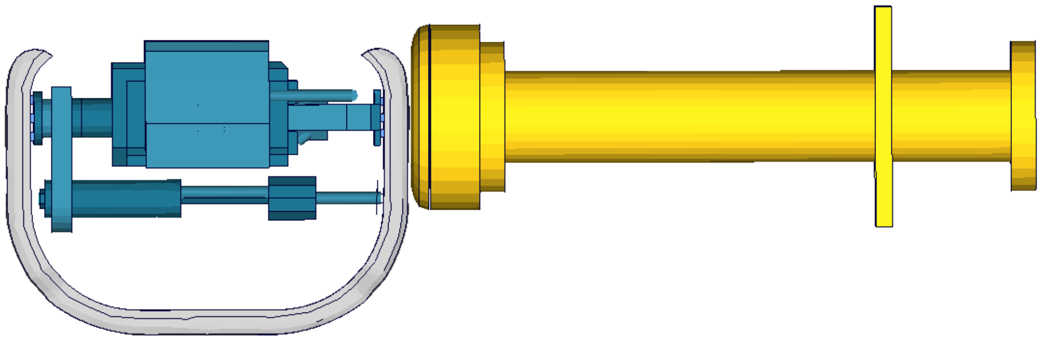
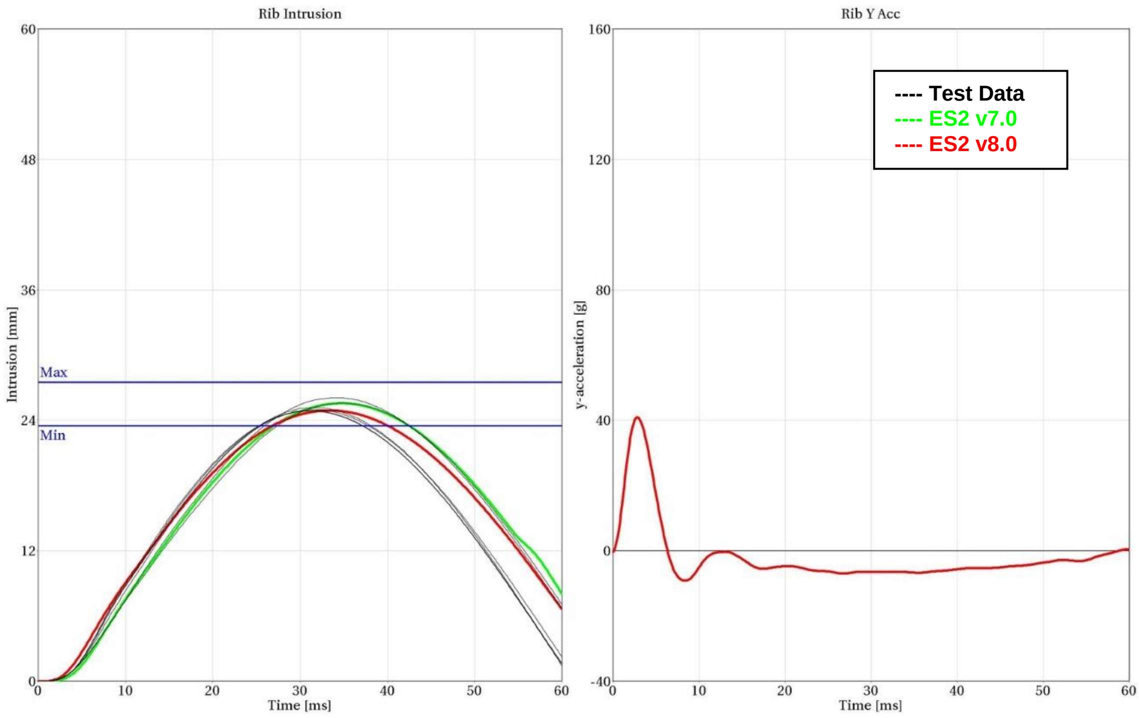
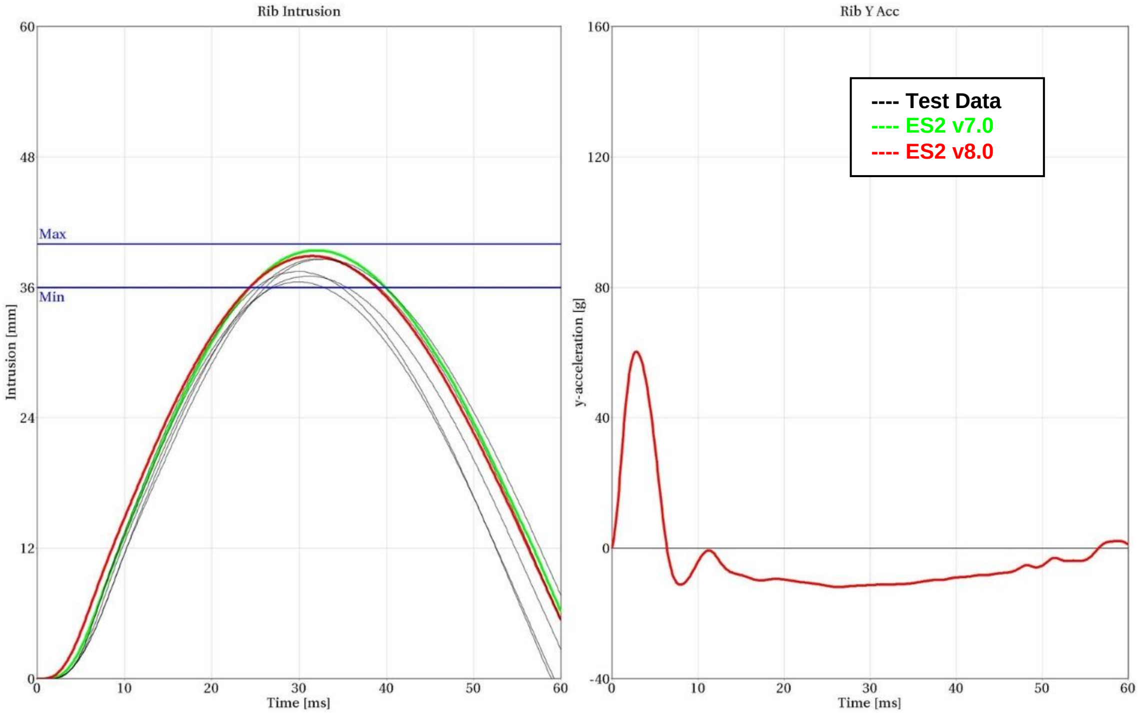


Figure 43: ES-2 rib calibration test setup

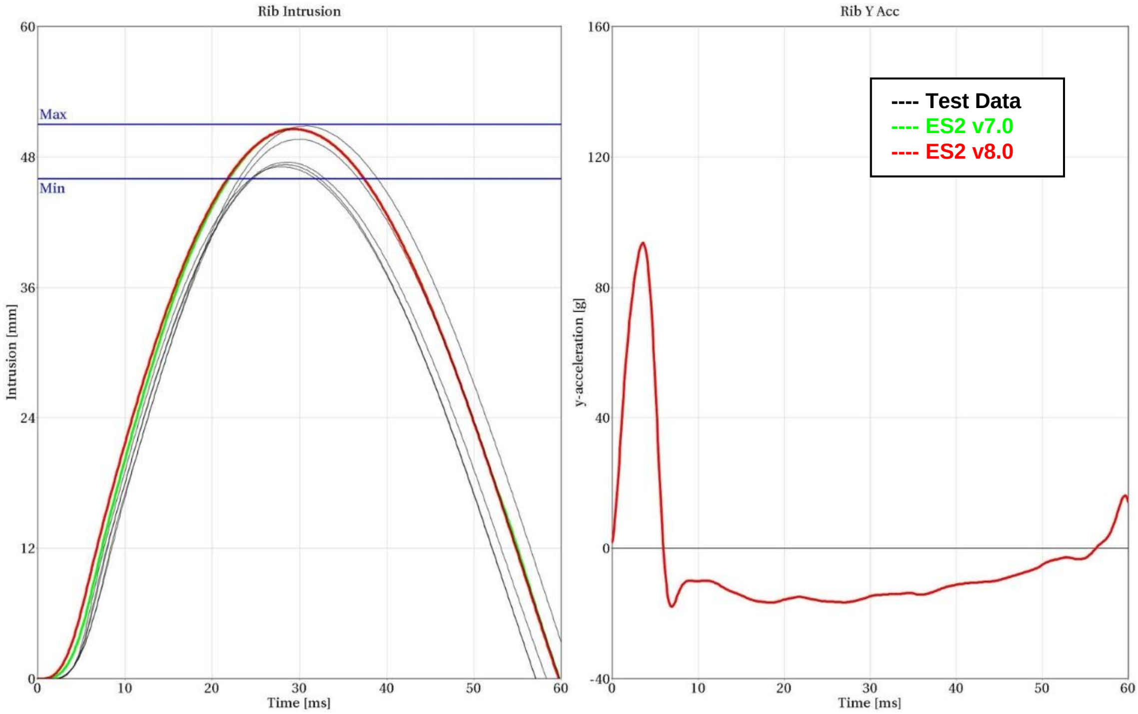
11.3.1 Results low velocity



11.3.2 Results medium velocity



11.3.3 Results high velocity



11.4 Lumbar spine pendulum test

- Lumbar Spine is mounted to a large pendulum.
- At the bottom of the Lumbar Spine a Head form is mounted
- The pendulum is decelerated by a honeycomb profile.

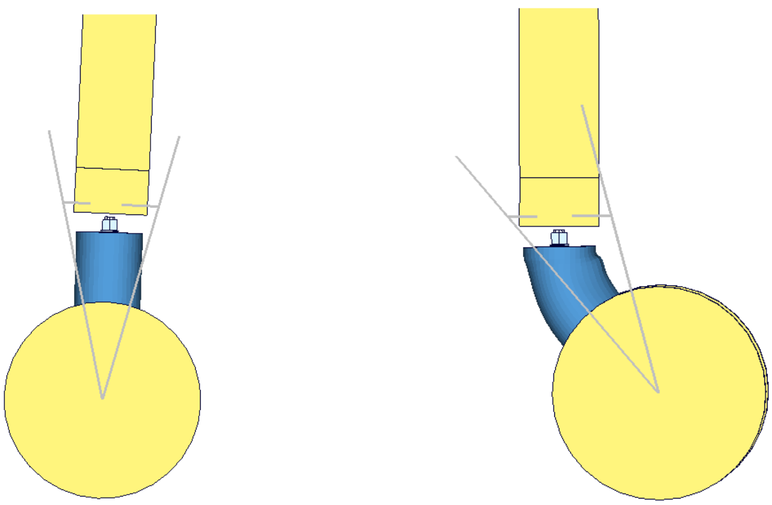
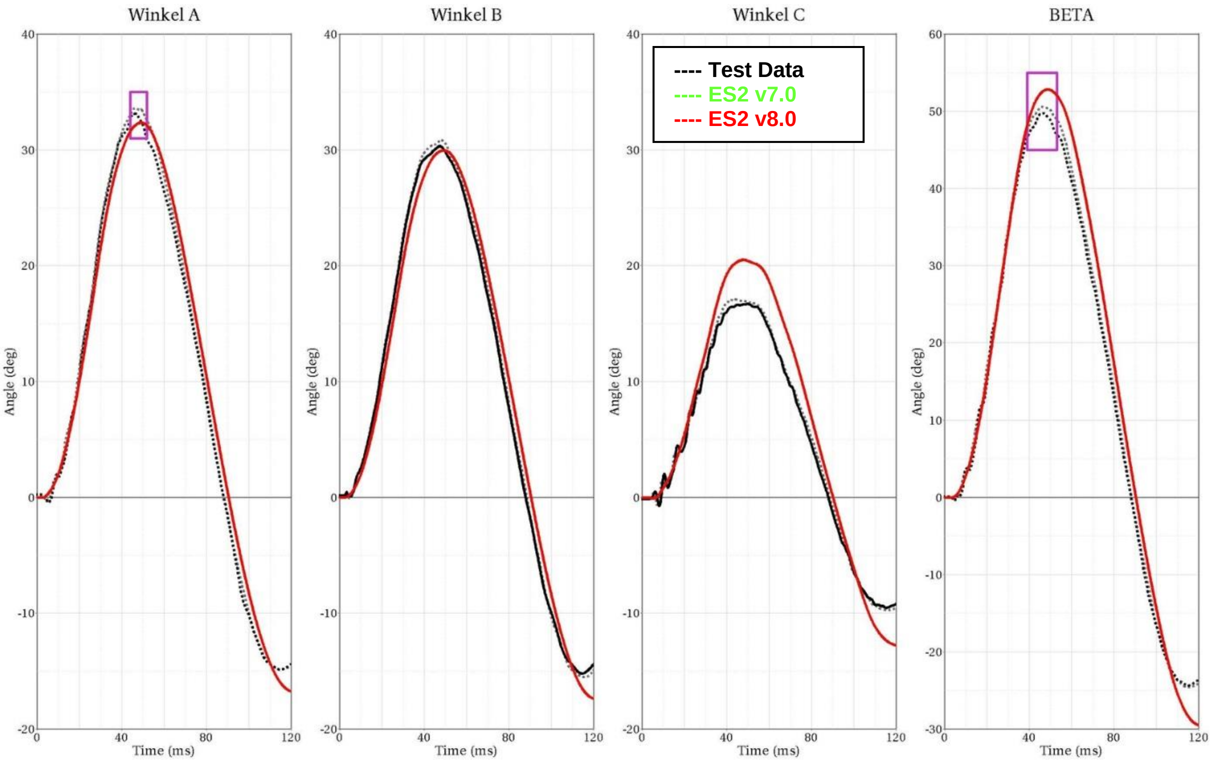


Figure 44: ES-2 lumbar spine calibration test setup

11.4.1 Results



11.5 Shoulder Certification test of ES-2

Boundaries:

- Pendulum impacting the shoulder
- Impact speed: 4.3 m/s
- Mass: 23.4 kg
- Arms in 40 degree position
- The pendulum hits the shoulder at the center pivot axis of the arm

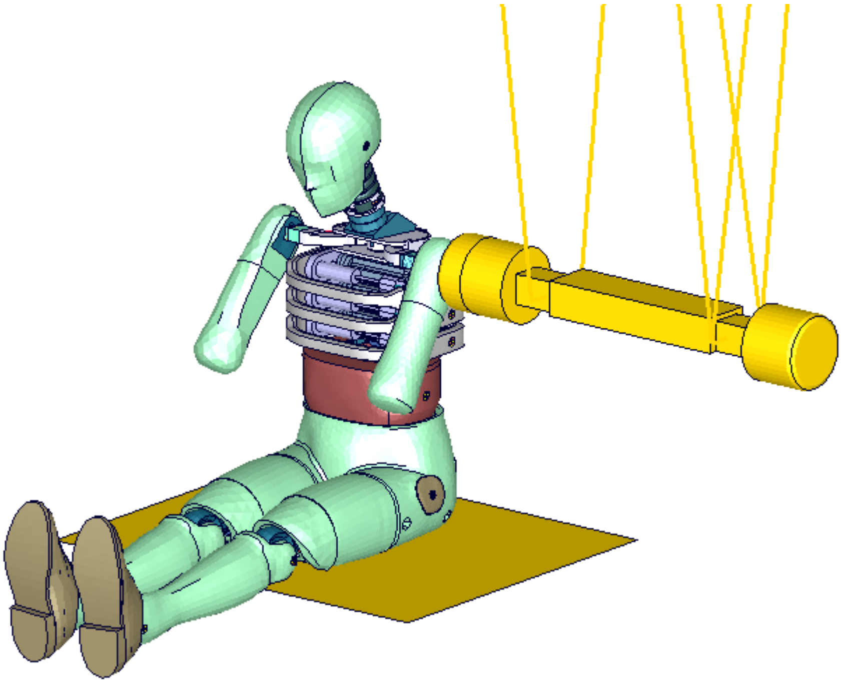
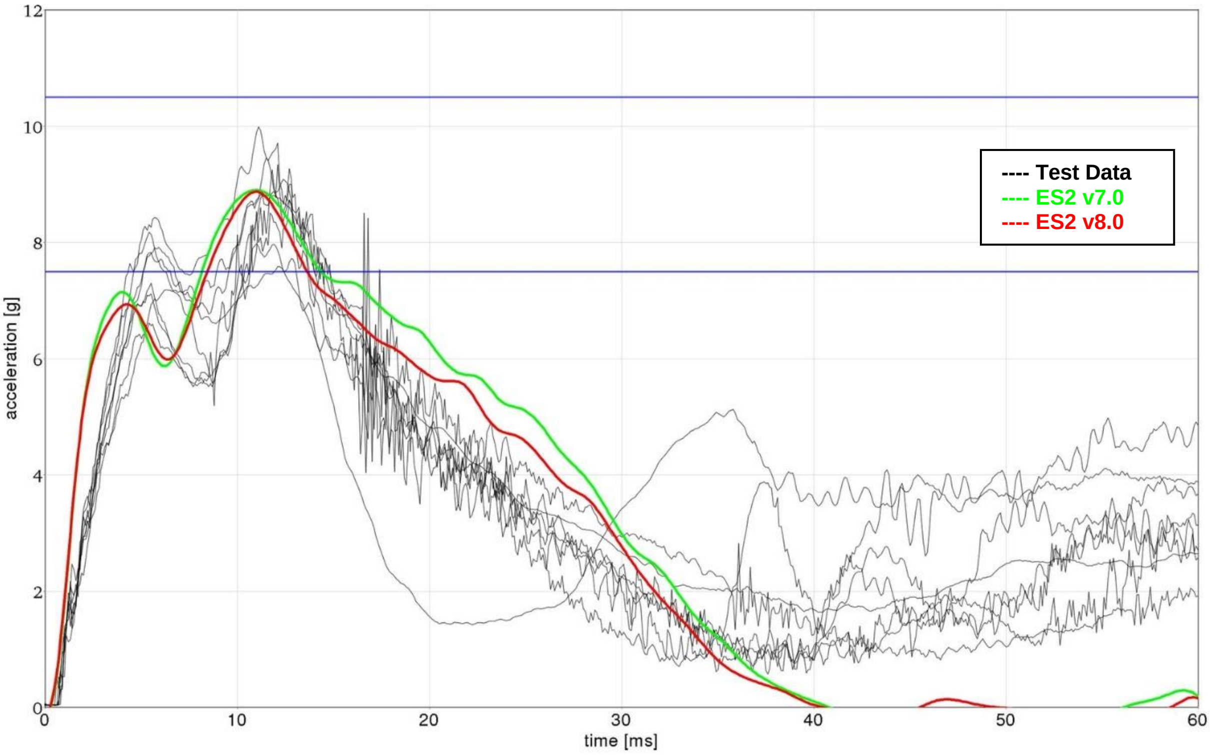


Figure 45: ES-2 shoulder certification test setup

11.5.1 Results



11.6 Thorax Certification test of ES2

- ES2 is sitting on a flat Plate.
- The Jacket, Arm and Shoulder foam is removed.
- The pendulum target point is the bearing system of the middle rib.

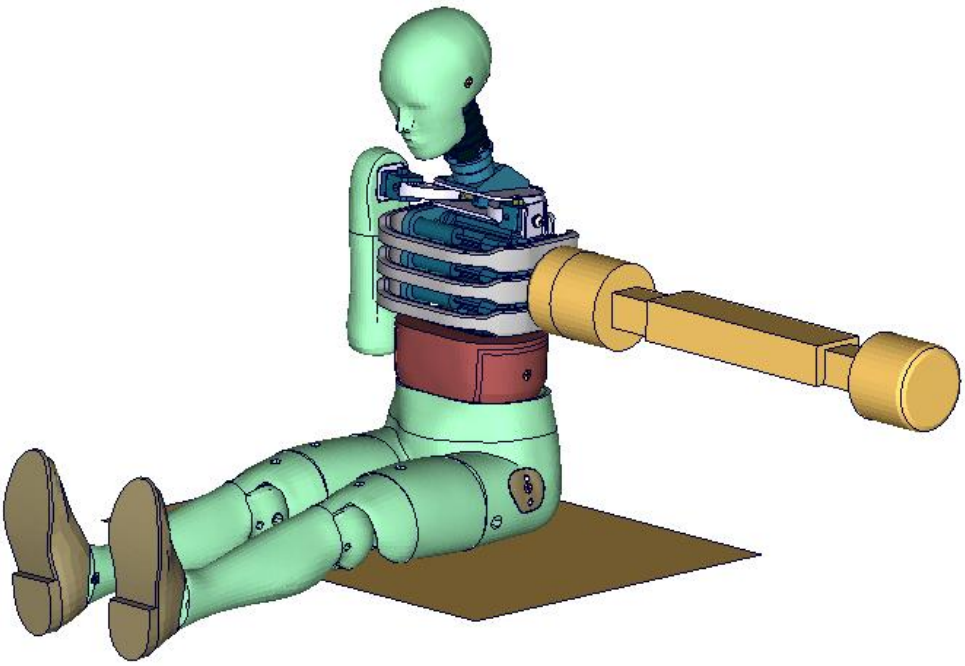
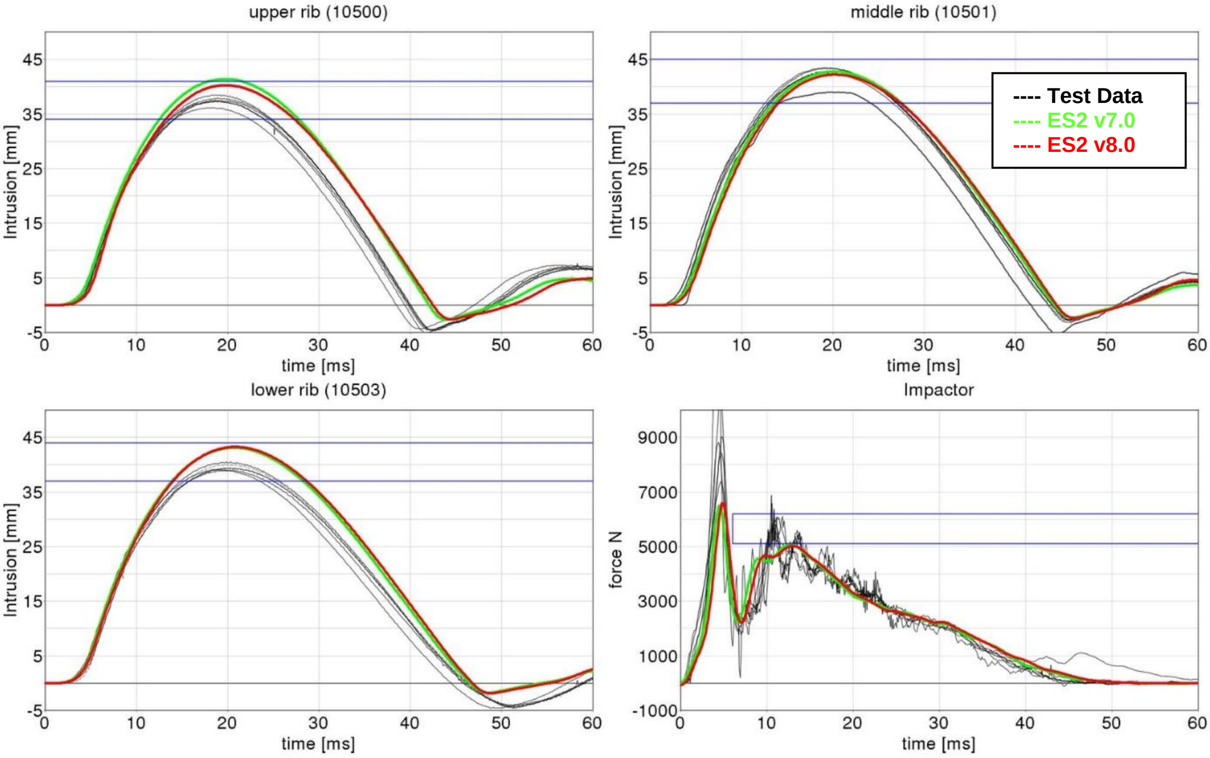


Figure 46: ES-2 thorax certification test setup

11.6.1 Results



11.7 Abdomen Certification test of ES-2

Boundaries:

- Pendulum impacting the abdomen
- Impact speed: 4.0 m/s
- Mass: 24.4 kg
- Arms in 90 degree position
- A wooden block is mounted in front of the pendulum

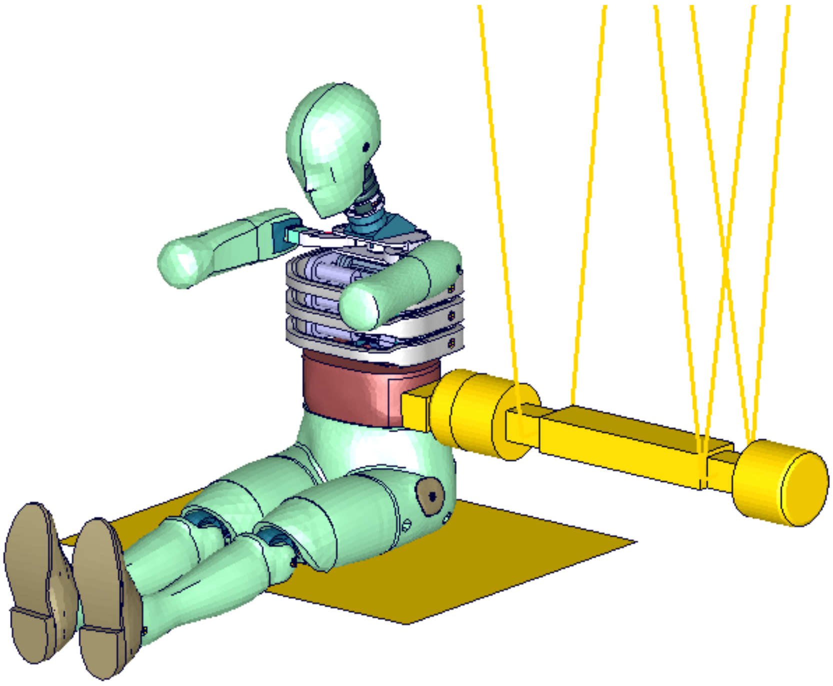
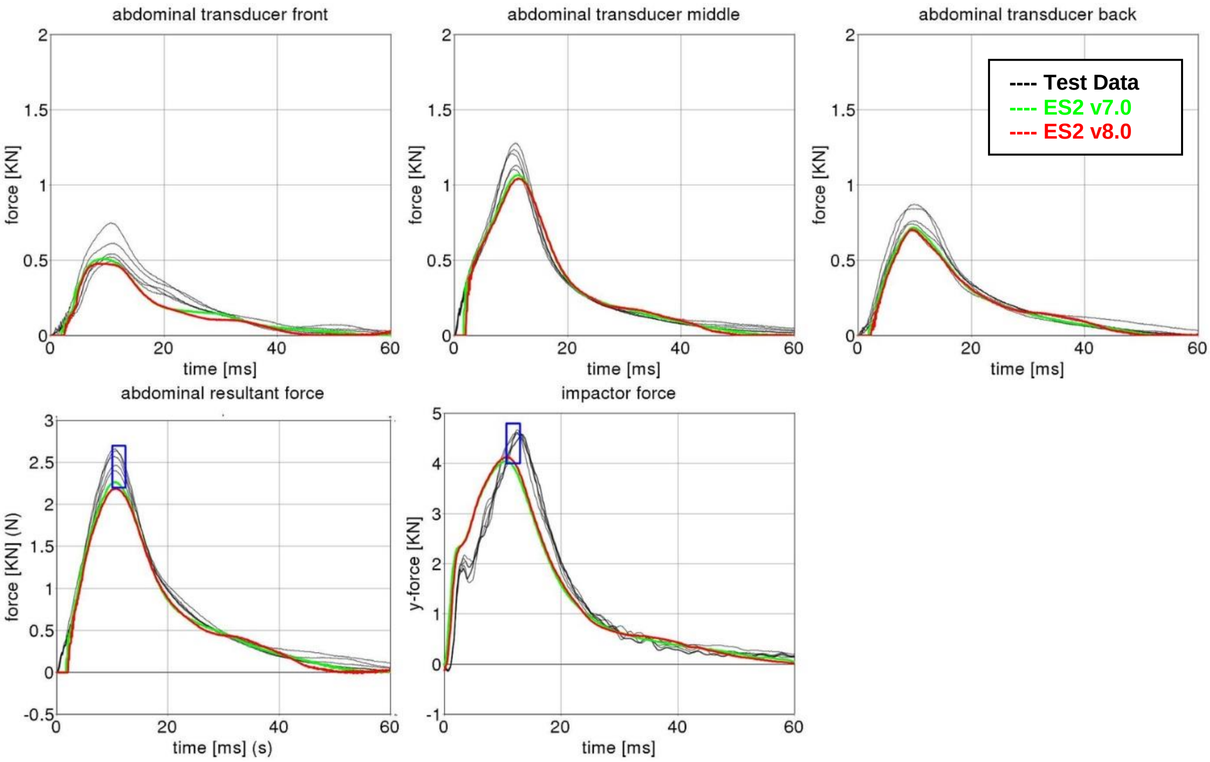


Figure 47: ES-2 abdomen certification test setup

11.7.1 Results



11.8 Pelvis Certification test of ES-2

Boundaries:

- Pendulum impacting the pelvis
- Impact speed: 4.3 m/s
- Mass: 23.4 kg
- Arms in 90 degree position
- The pendulum impact is aligned to the H-point

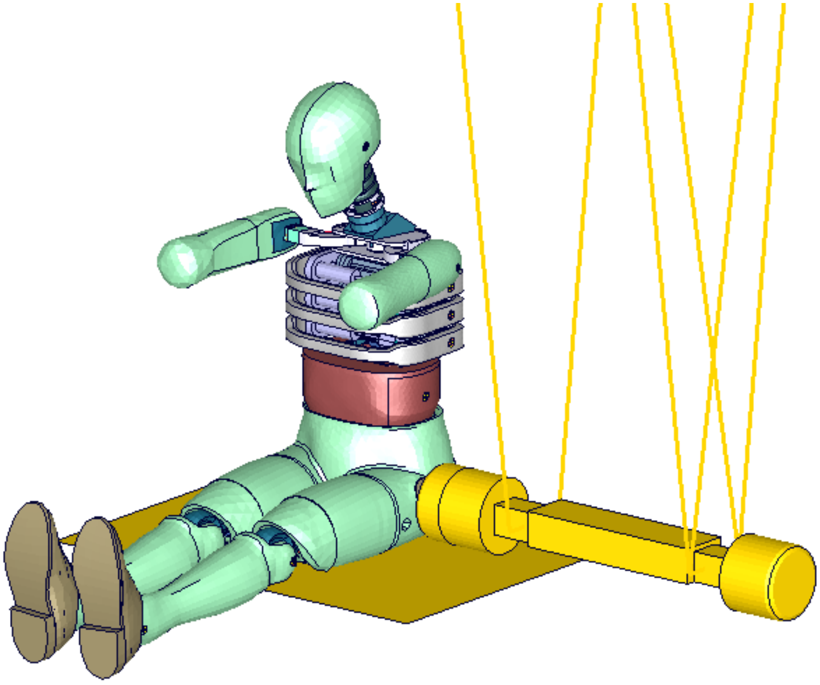
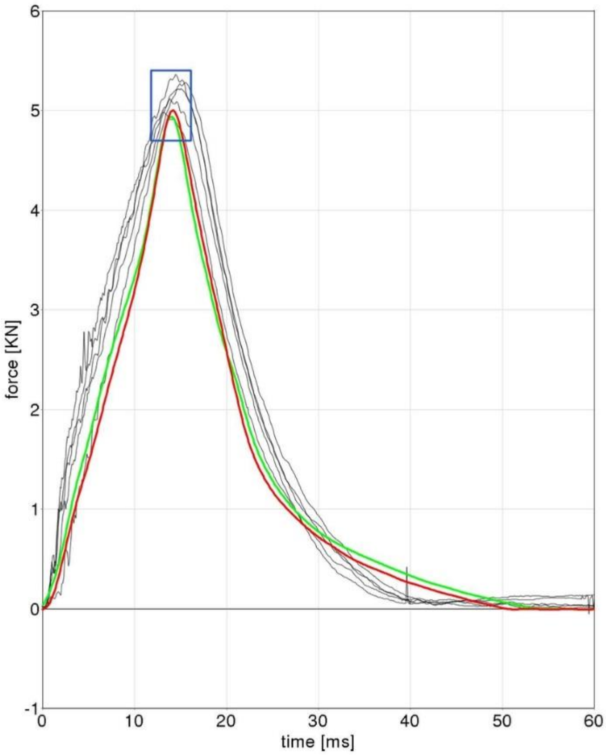
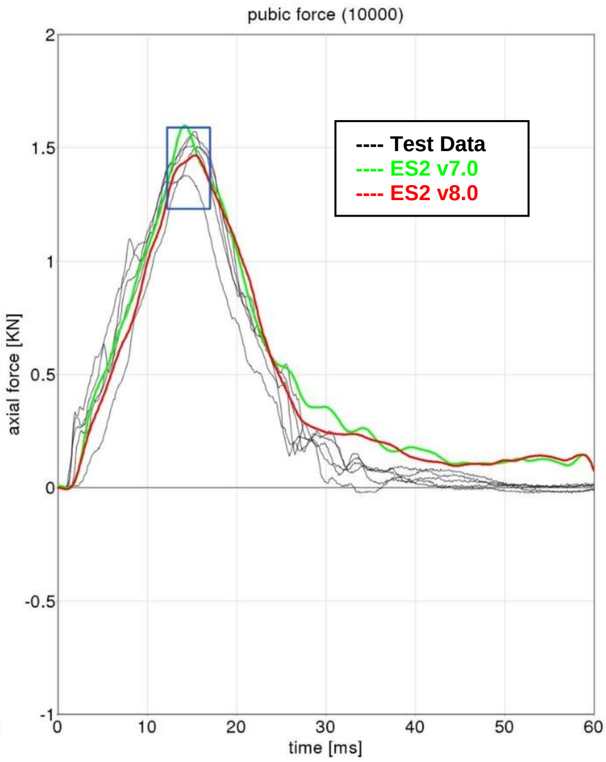


Figure 48: ES-2 pelvis certification test setup

11.8.1 Results





12. Performance

12.1 Configuration D1: Plane Barrier

Boundaries:

- Rigid barrier
- Impact speed: Low velocity
- Arms in 40 degree position
- Orthogonal impact

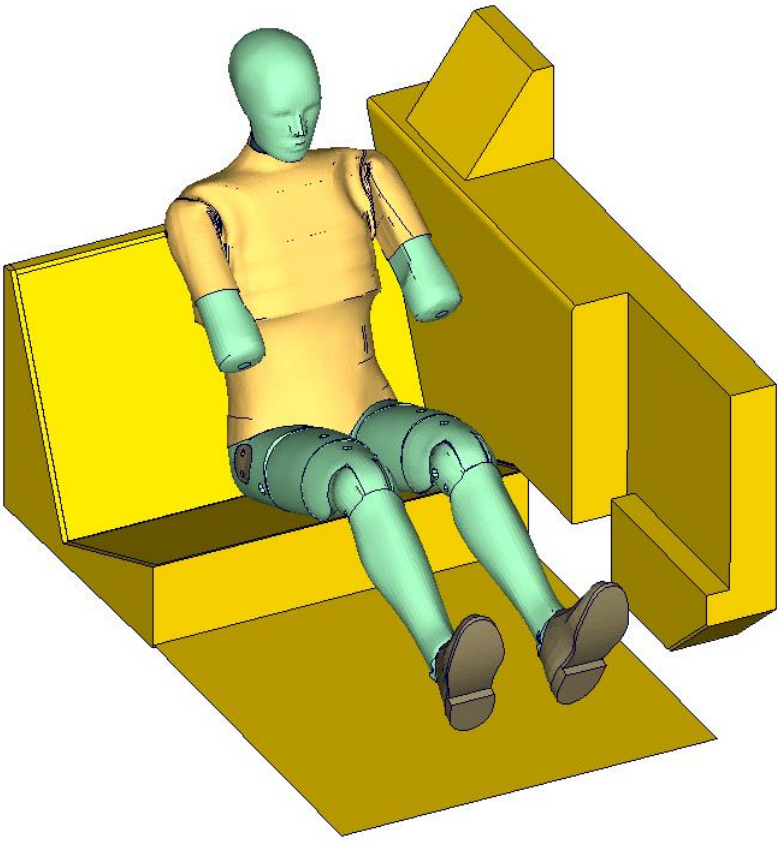
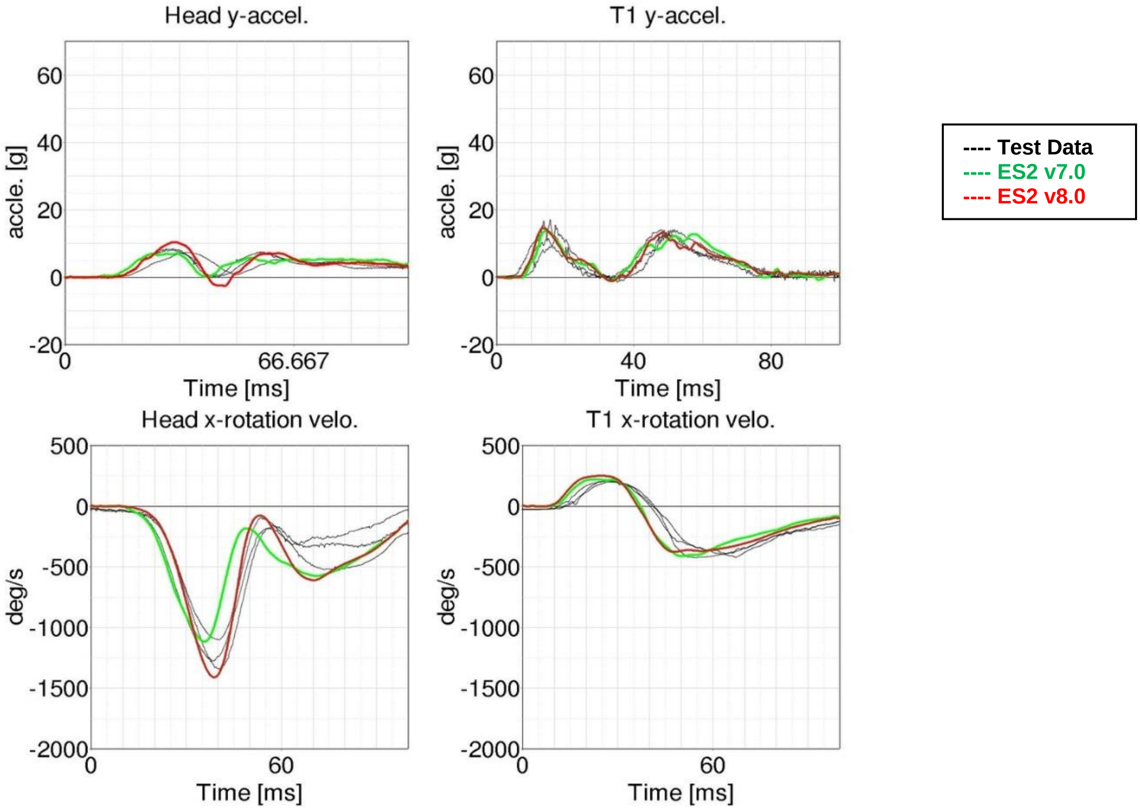
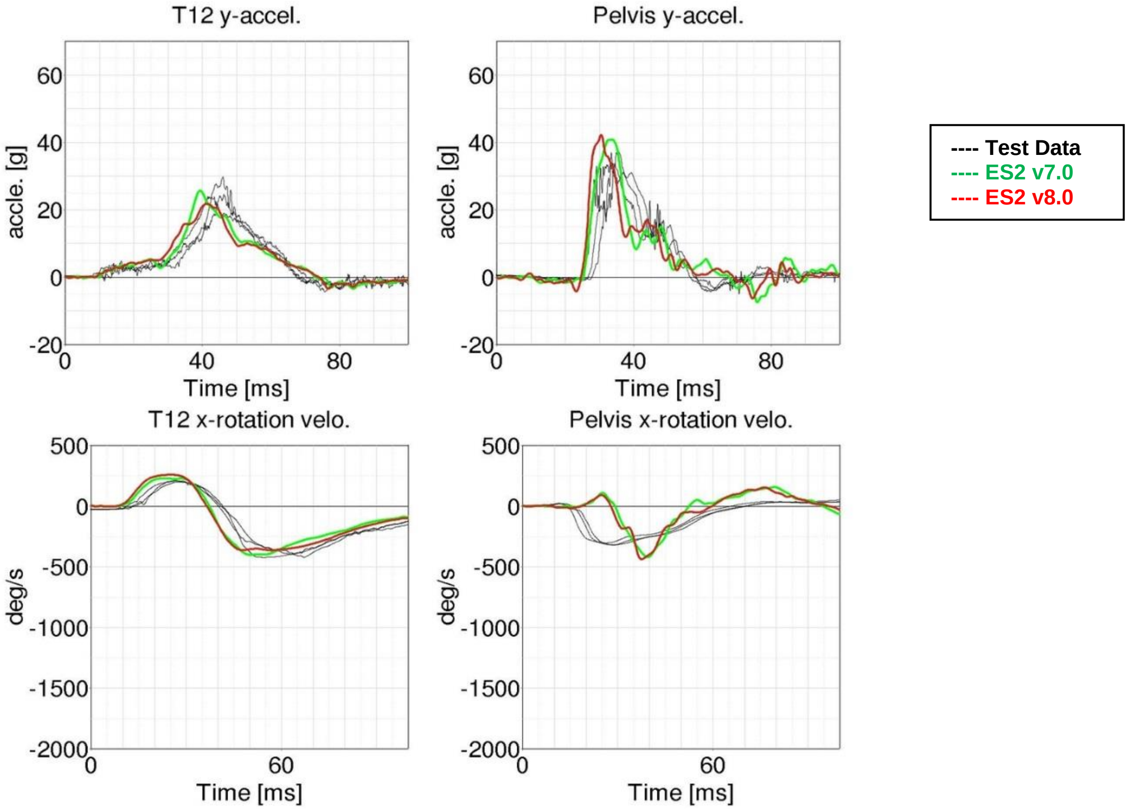
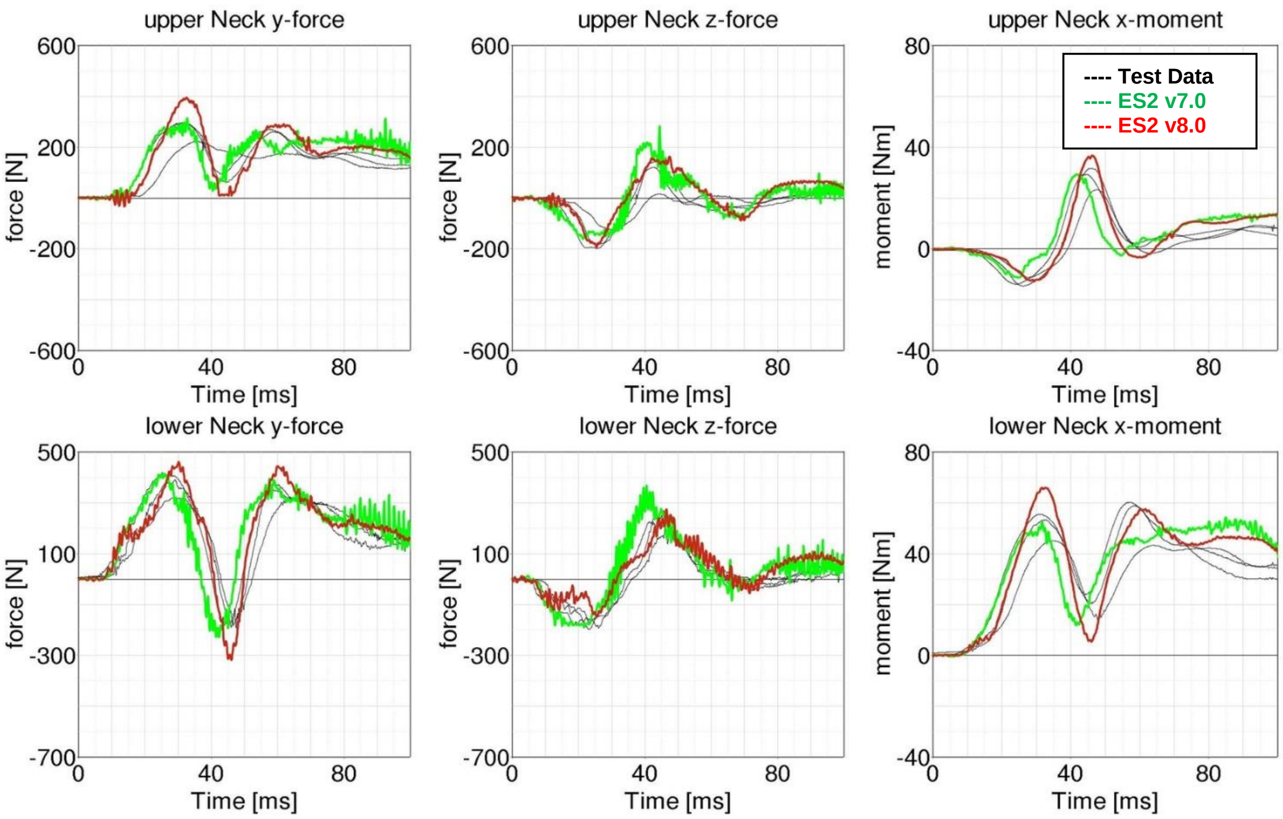


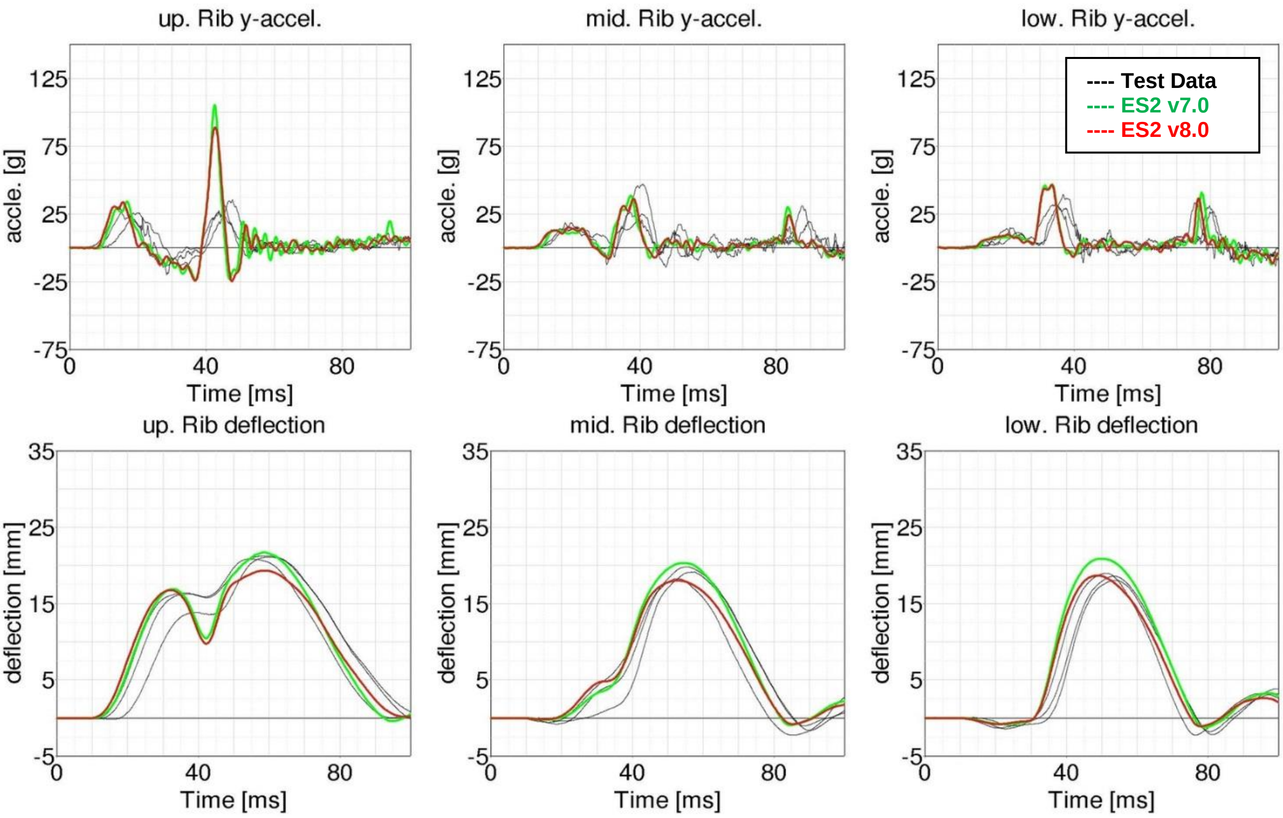
Figure 49: D1 plane barrier test setup

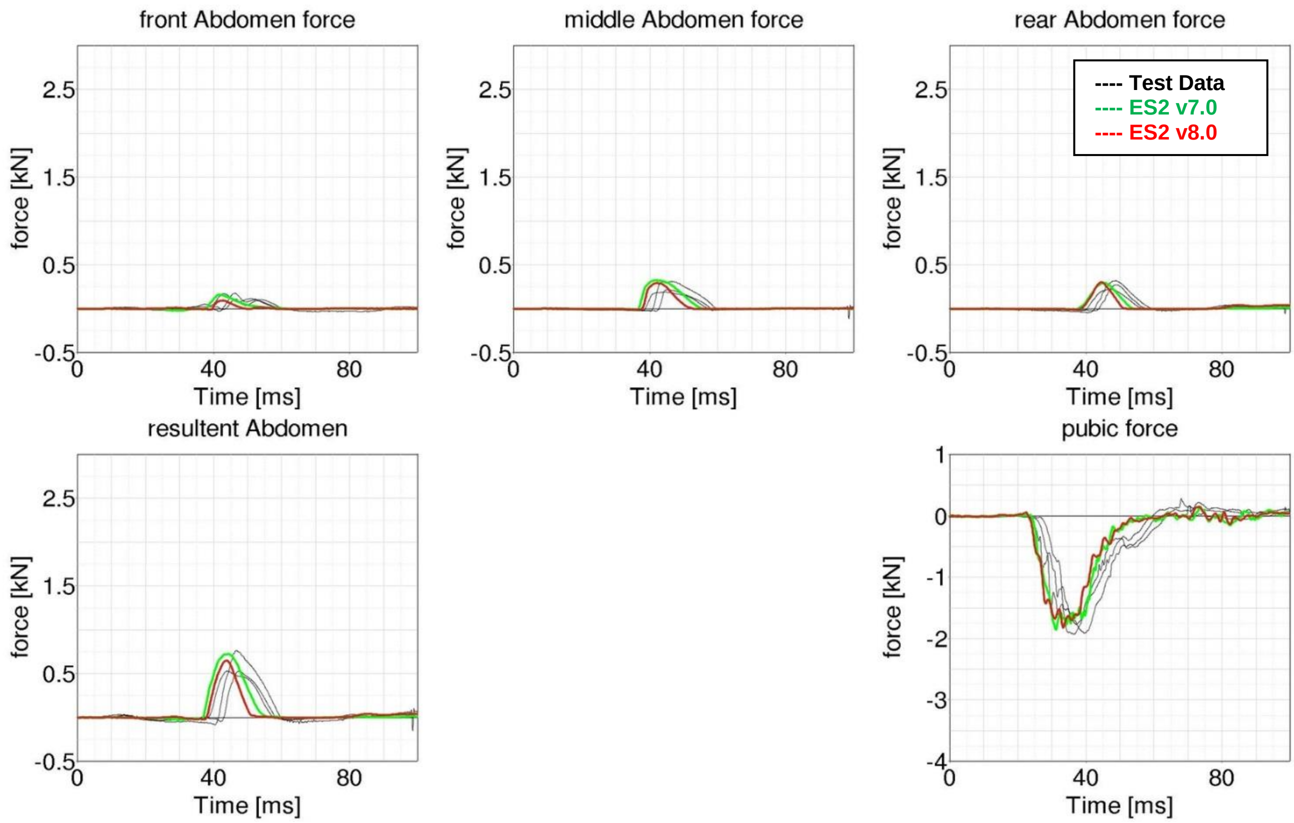
12.1.1 Results at low velocity impact

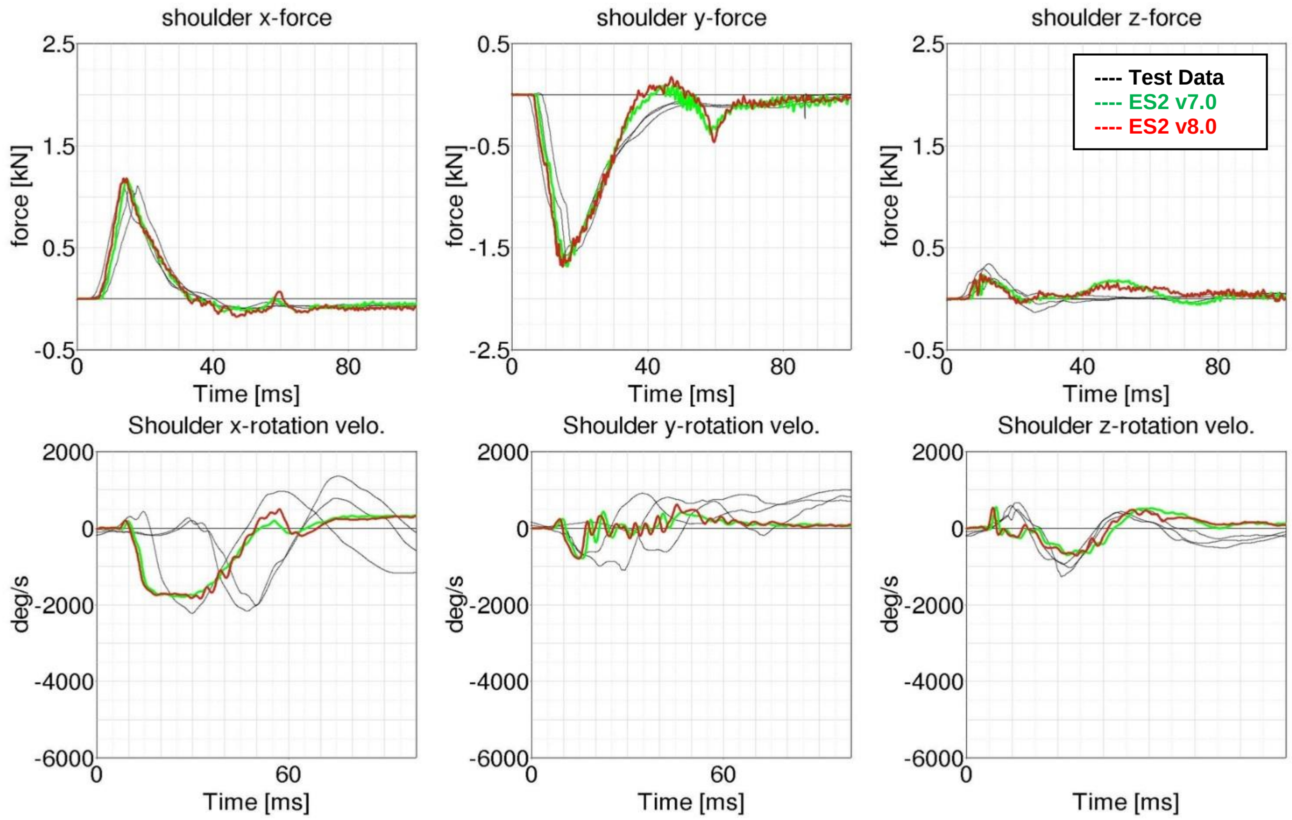


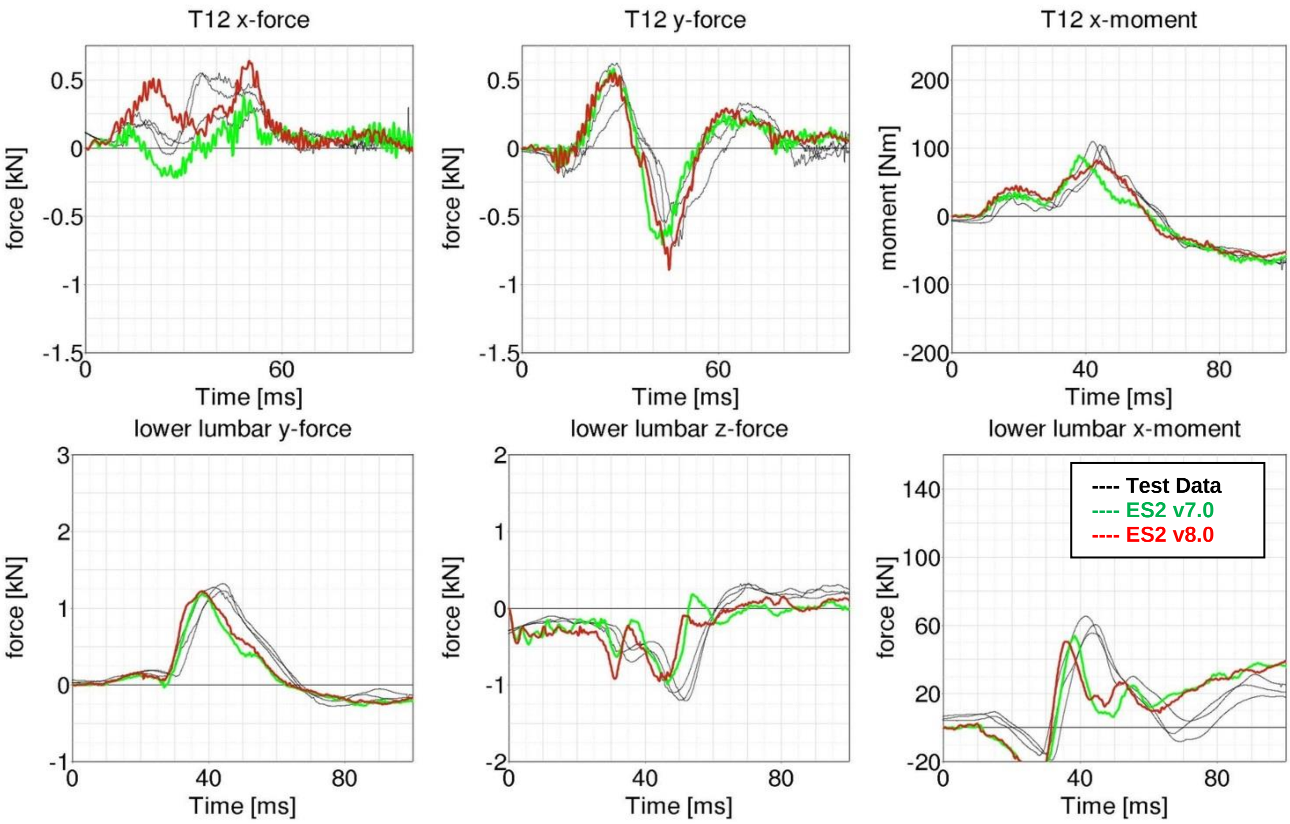



upper Neck y-force
upper Neck z-force
upper Neck x-moment
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
lower Neck y-force
lower Neck z-force
lower Neck x-moment
force [N]
moment [Nm]
Time [ms]


up. Rib y-accel.
mid. Rib y-accel.
low. Rib y-accel.
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
up. Rib deflection
mid. Rib deflection
low. Rib deflection
accle. [g]
deflection [mm]
Time [ms]


front Abdomen force
middle Abdomen force
rear Abdomen force
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
force [kN]
Time [ms]
resultent Abdomen
pubic force


shoulder x-force
shoulder y-force
shoulder z-force
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
force [kN]
Time [ms]
Shoulder x-rotation velo.
Shoulder y-rotation velo.
Shoulder z-rotation velo.
deg/s


T12 x-force
force [kN]
Time [ms]
T12 y-force
force [kN]
Time [ms]
T12 x-moment
moment [Nm]
Time [ms]
lower lumbar y-force
force [kN]
Time [ms]
lower lumbar z-force
force [kN]
Time [ms]
lower lumbar x-moment
force [kN]
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0

12.2 Configuration D3: Barrier with pelvis bumper

Boundaries:

- Rigid barrier
- Impact speed: High velocity
- Arms in 40 degree position
- Pelvis pusher
- Oblique impact

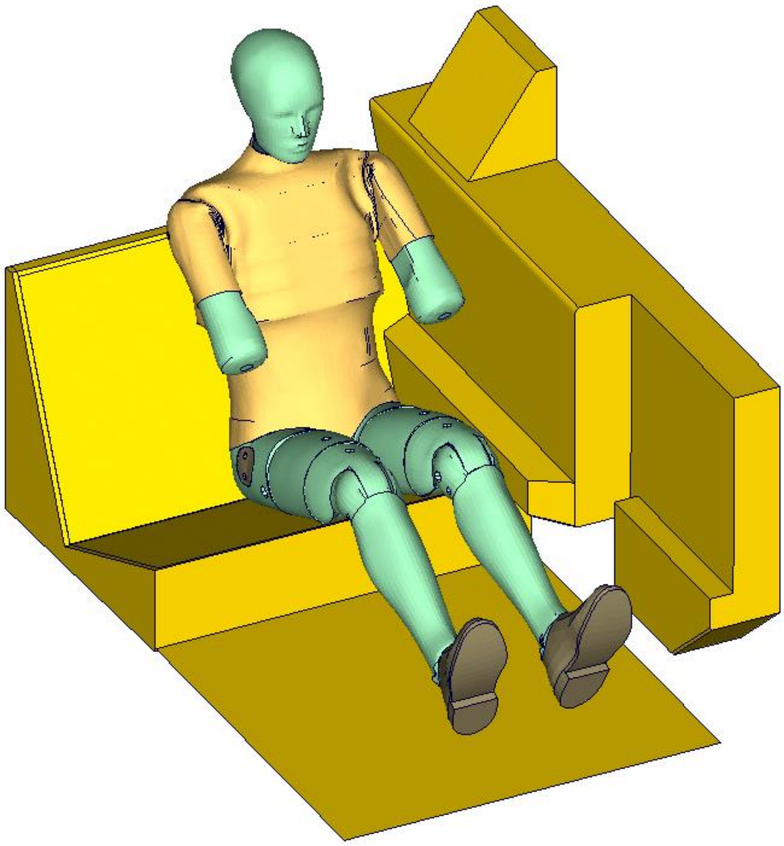
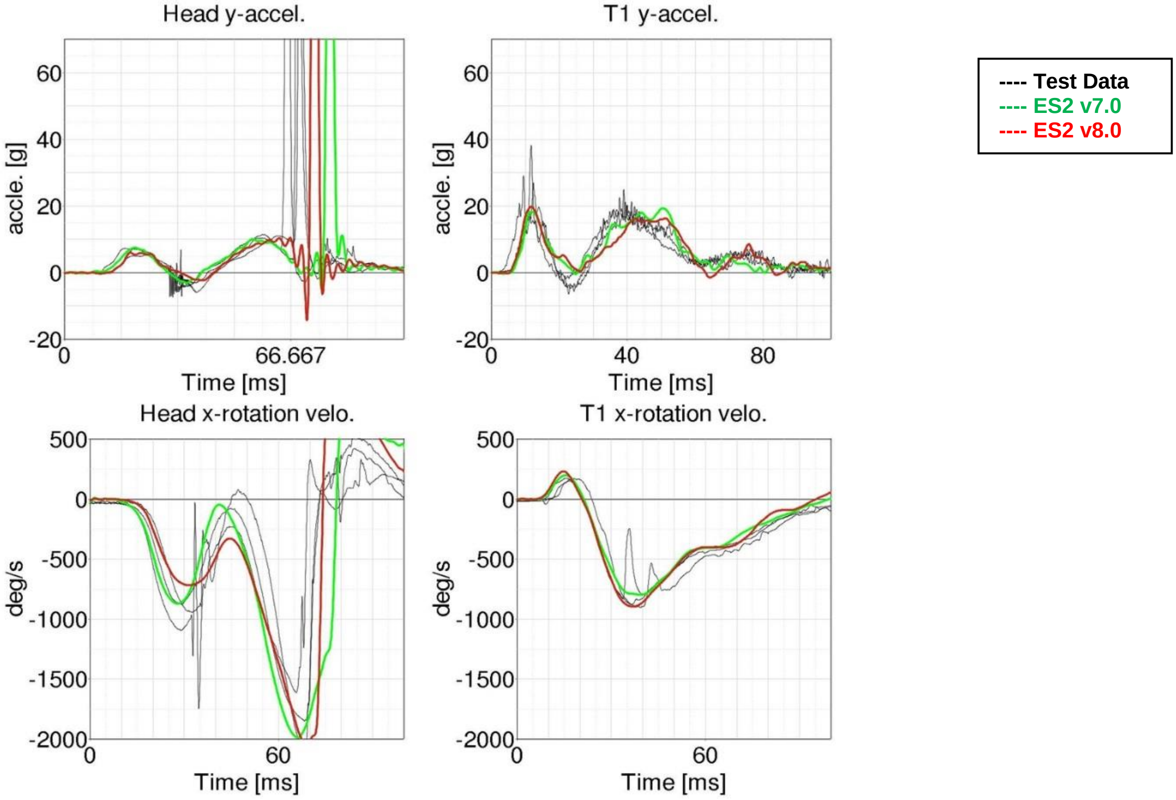
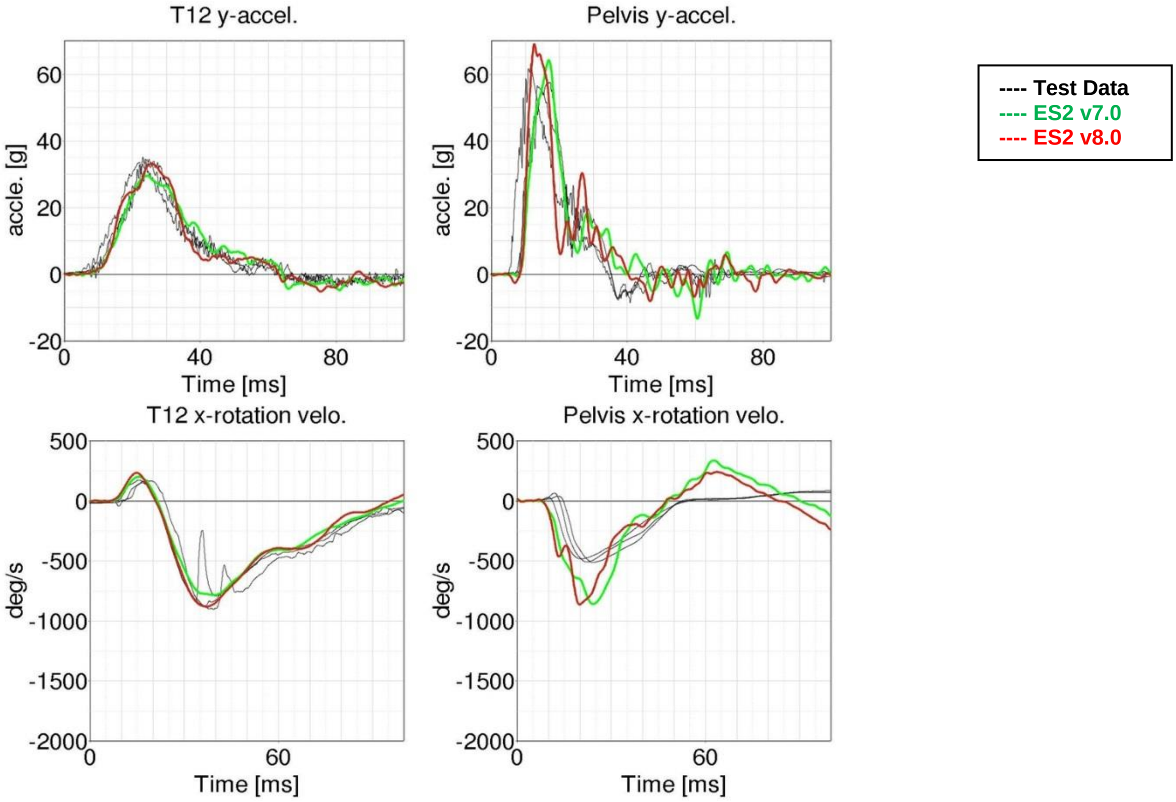
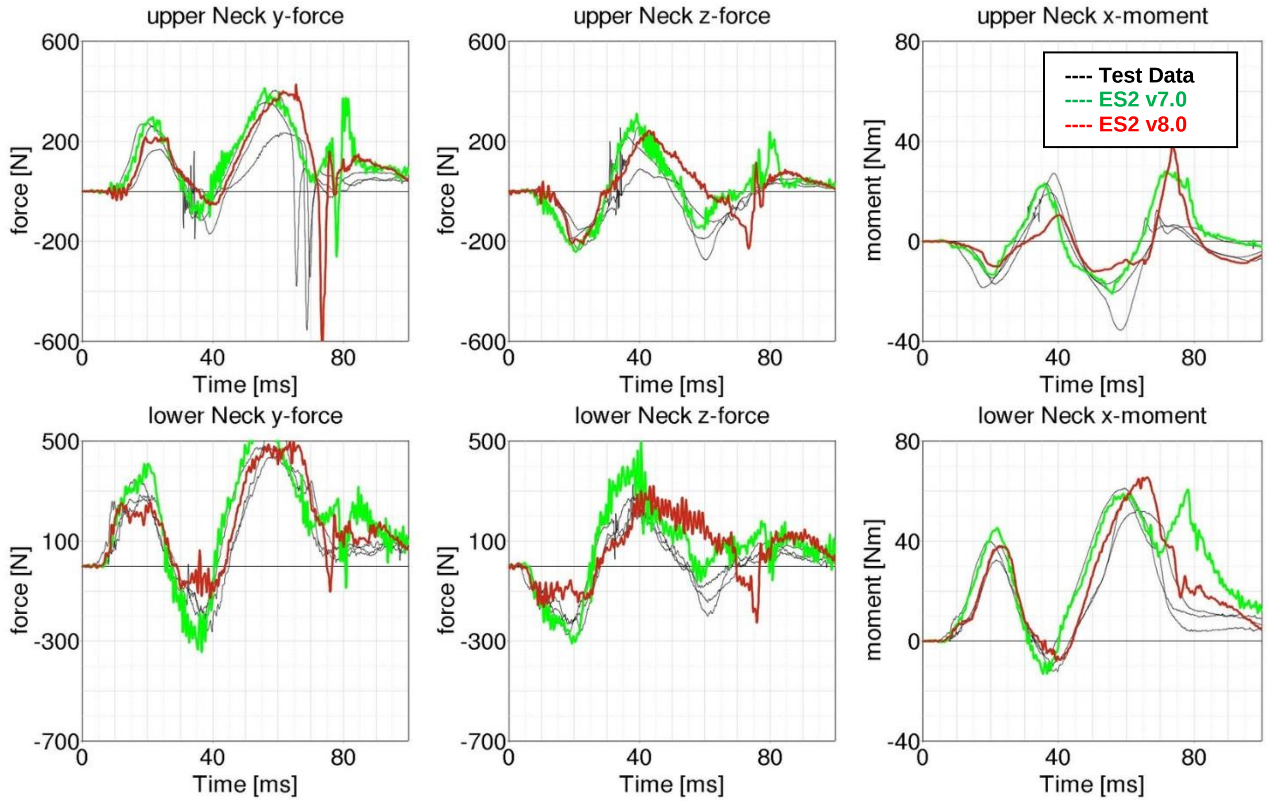


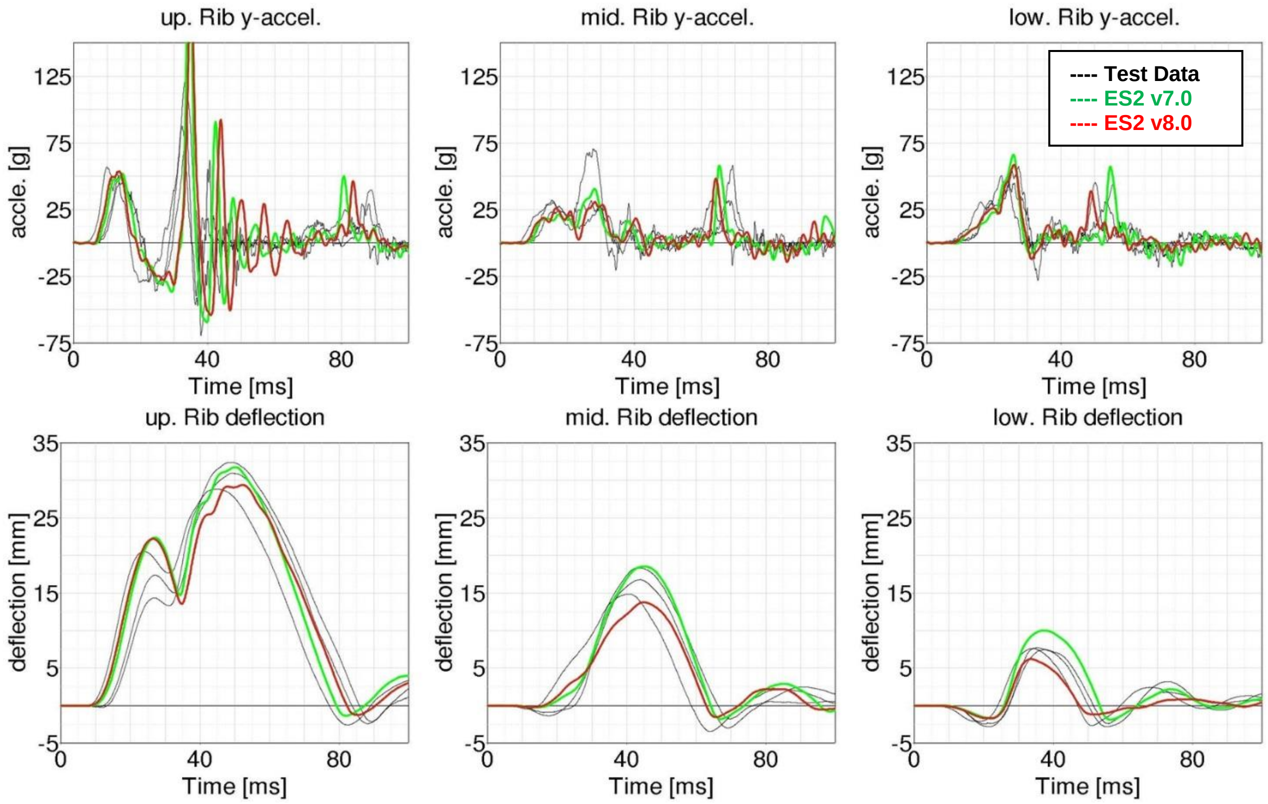
Figure 50: D3 barrier test setup

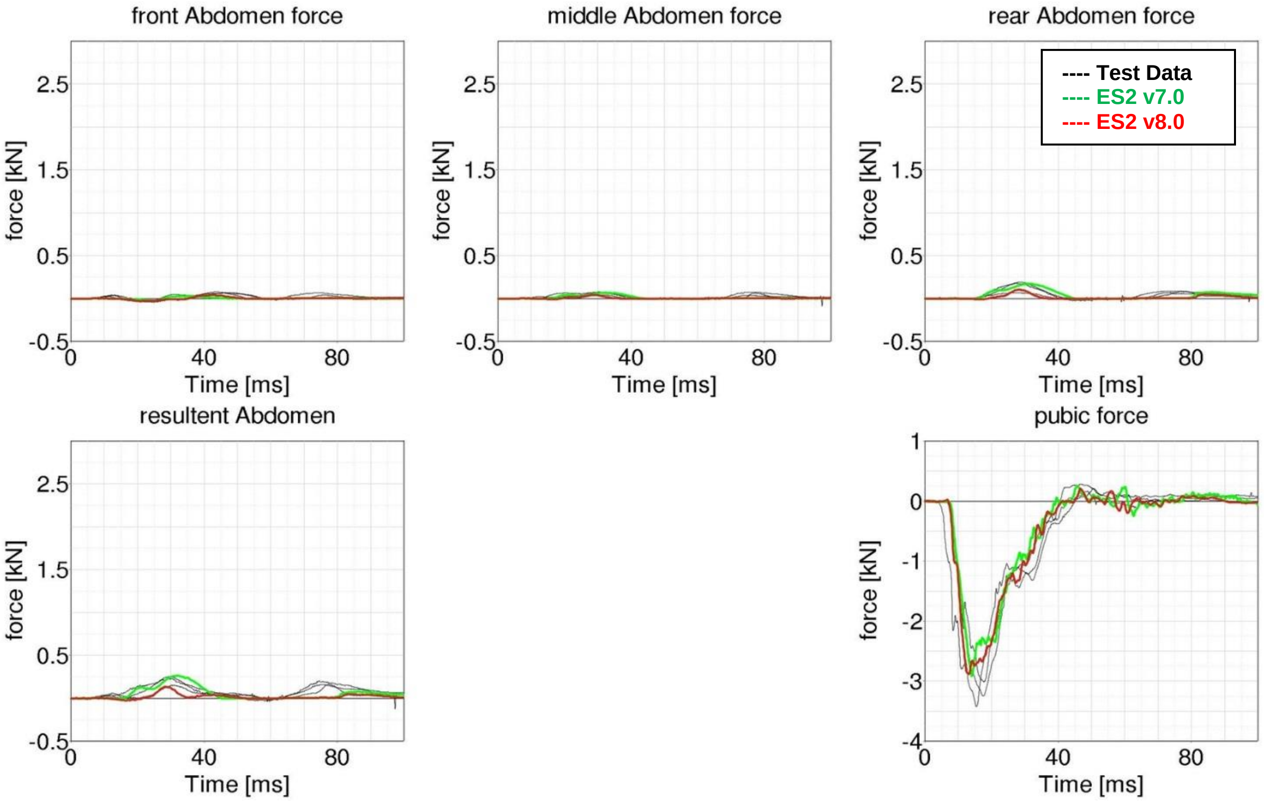
12.2.1 Results at high velocity impact

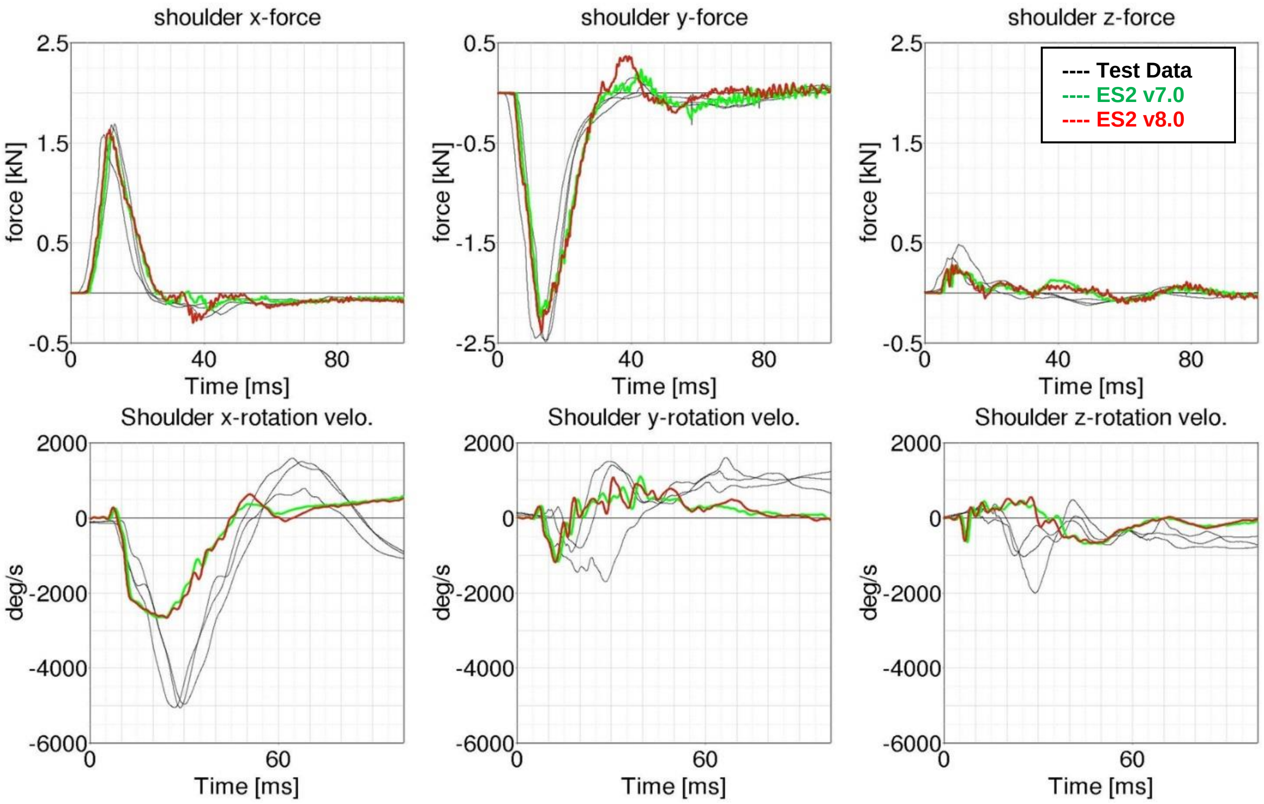


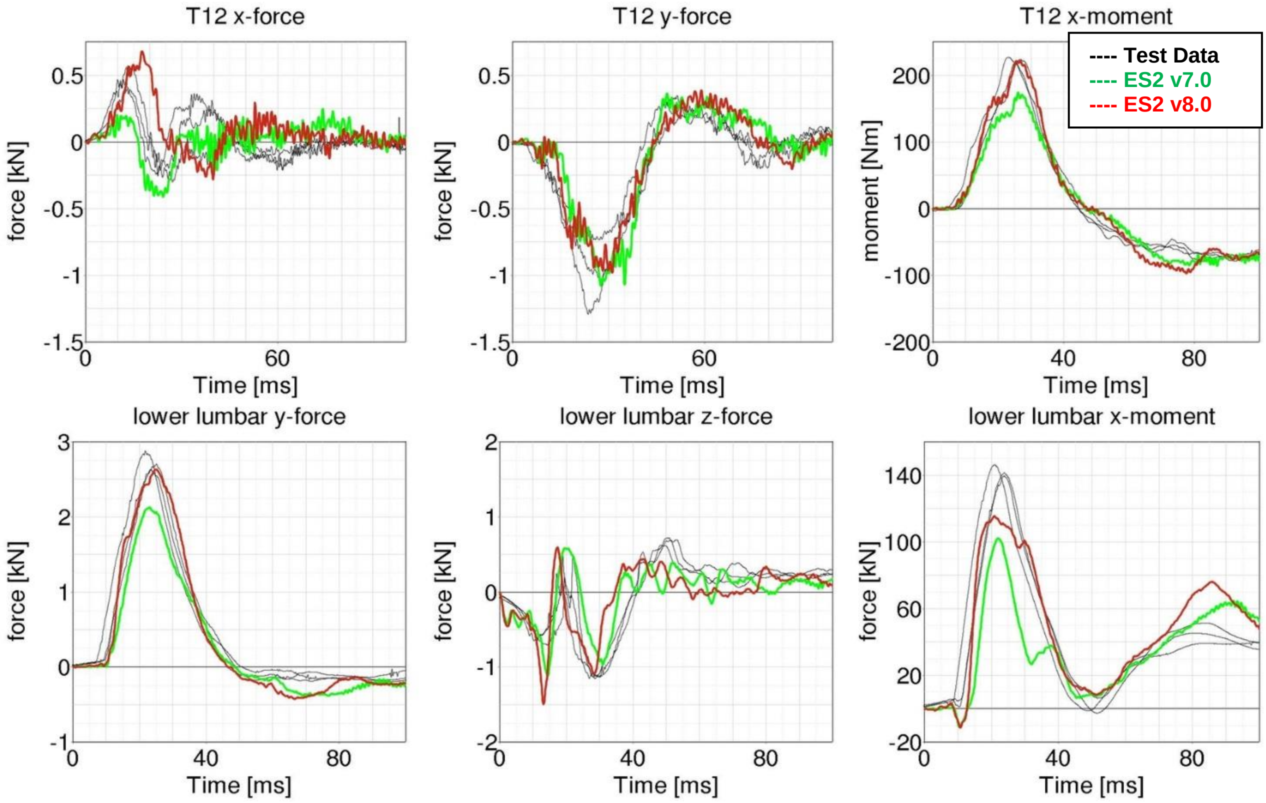



upper Neck y-force
upper Neck z-force
upper Neck x-moment
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
lower Neck y-force
lower Neck z-force
lower Neck x-moment
force [N]
moment [Nm]
Time [ms]


up. Rib y-accel.
mid. Rib y-accel.
low. Rib y-accel.
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
up. Rib deflection
mid. Rib deflection
low. Rib deflection
accle. [g]
deflection [mm]
Time [ms]


front Abdomen force
middle Abdomen force
rear Abdomen force
resultent Abdomen
pubic force
force [kN]
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
2.5
1.5
0.5
-0.5
1
0
-1
-2
-3
-4
0
40
80


shoulder x-force
shoulder y-force
shoulder z-force
Shoulder x-rotation velo.
Shoulder y-rotation velo.
Shoulder z-rotation velo.
force [kN]
deg/s
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
2.5
1.5
0.5
-0.5
-1.5
-2.5
2000
0
-2000
-4000
-6000
40
80
60


T12 x-force
T12 y-force
T12 x-moment
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
force [kN]
moment [Nm]
Time [ms]
lower lumbar y-force
lower lumbar z-force
lower lumbar x-moment

12.3 Configuration D4: Door barrier

Boundaries:

- Rigid barrier (Figure 51)
- Impact speed: High velocity
- Arms in 40 degree position
- Curb edge
- Orthogonal impact

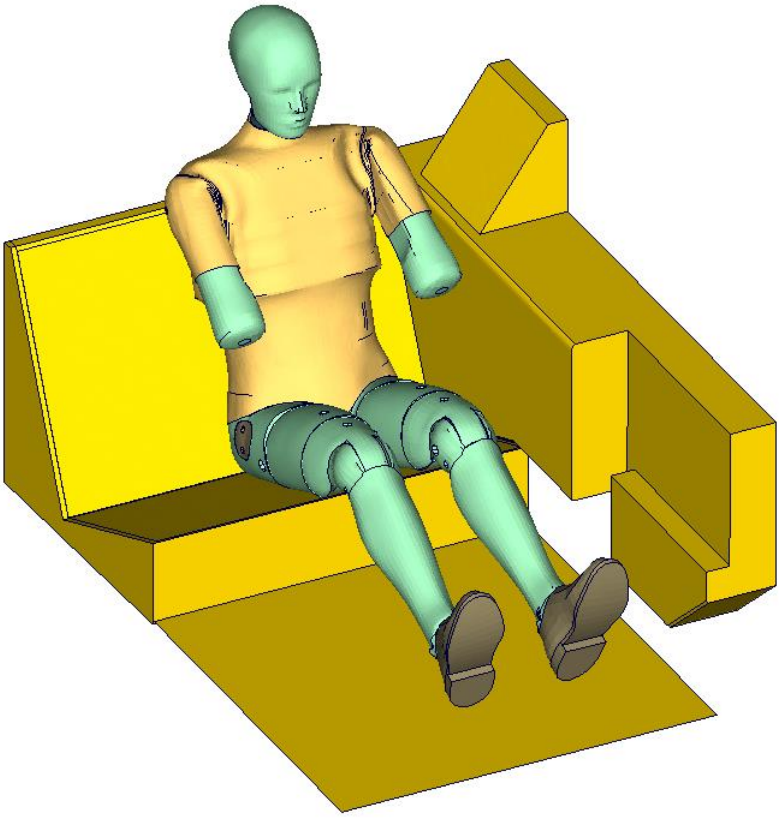
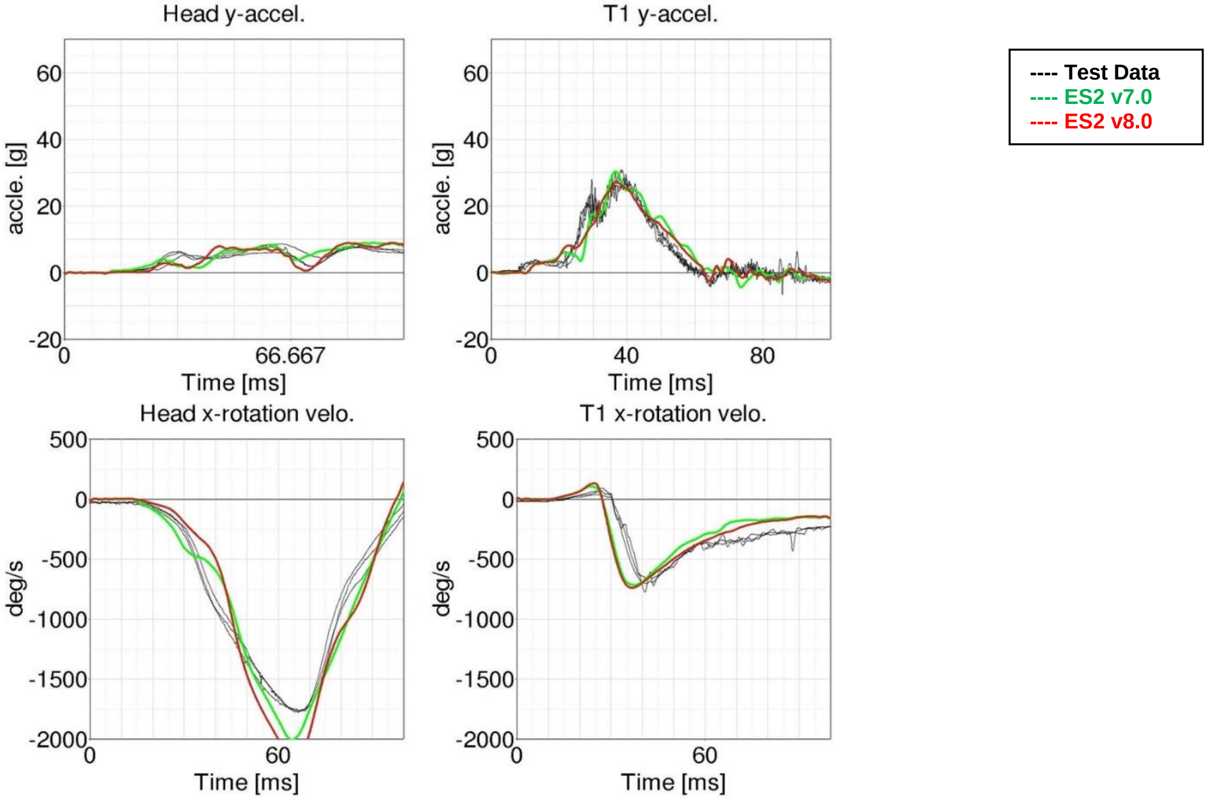
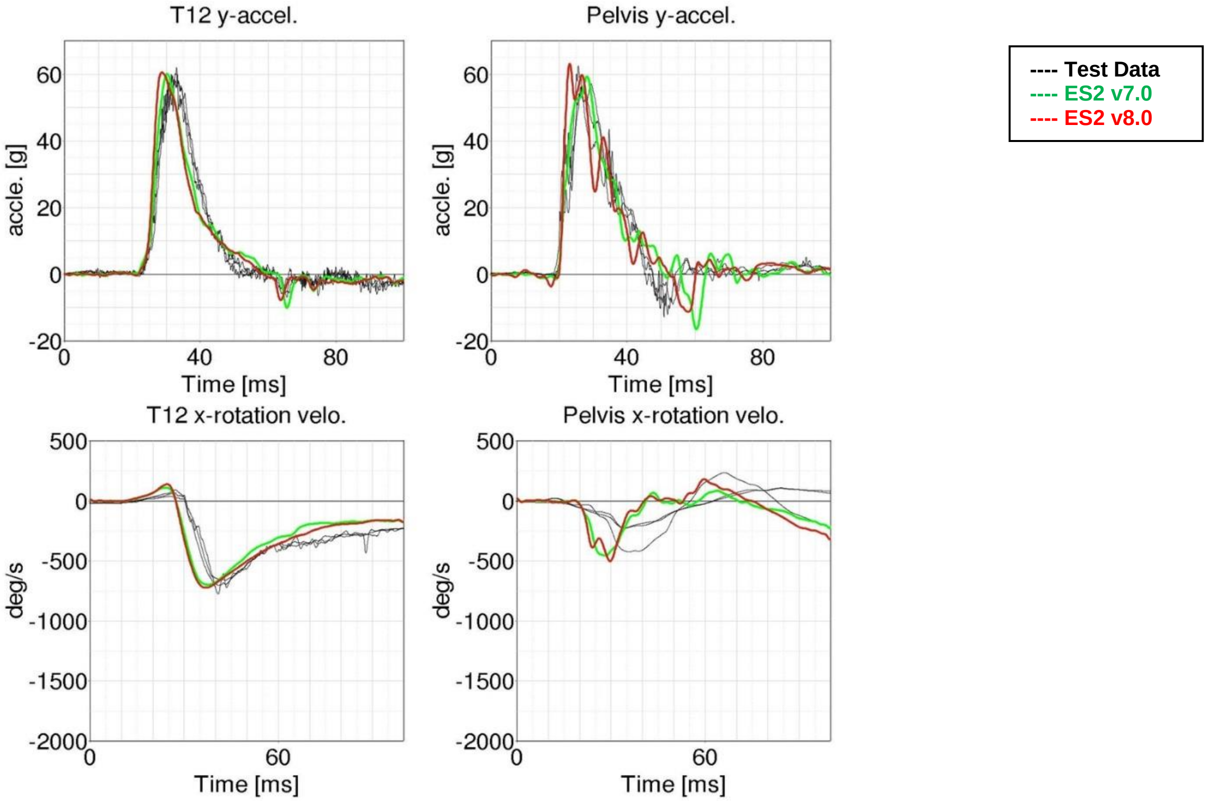
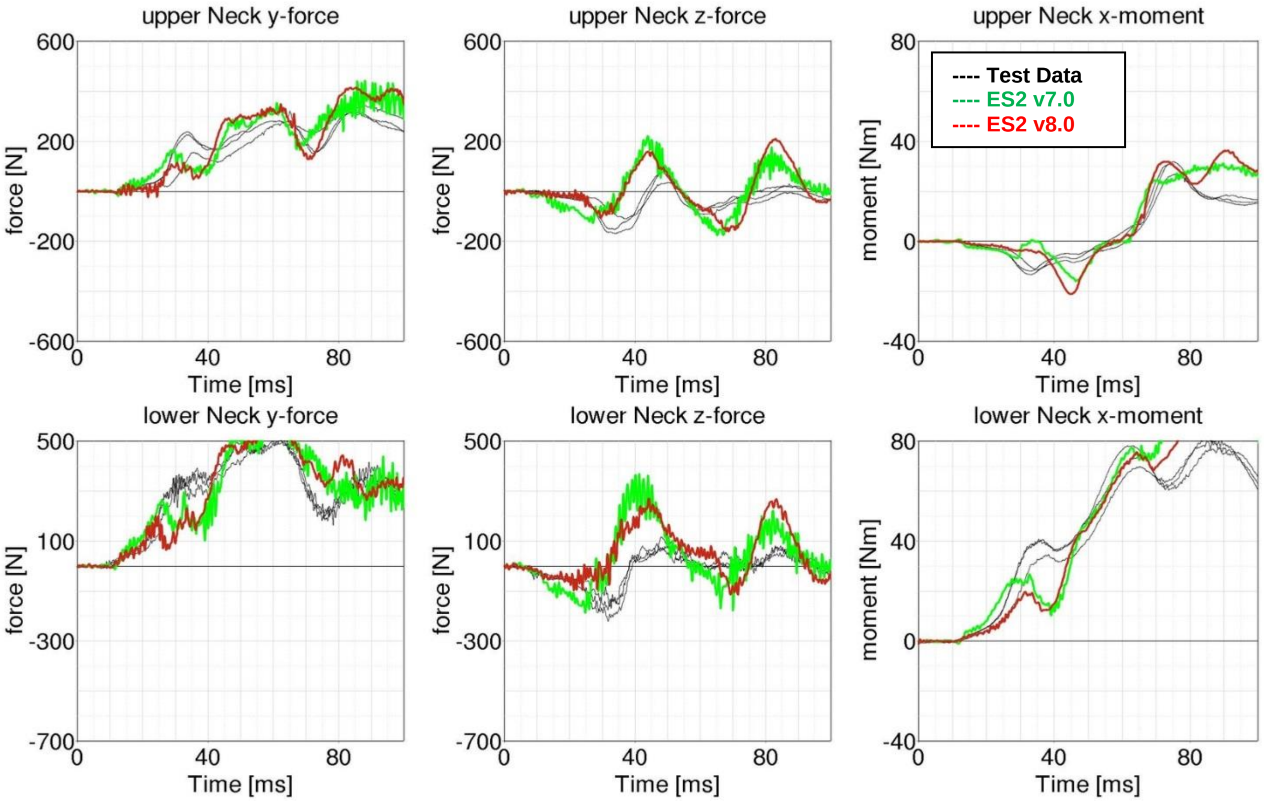


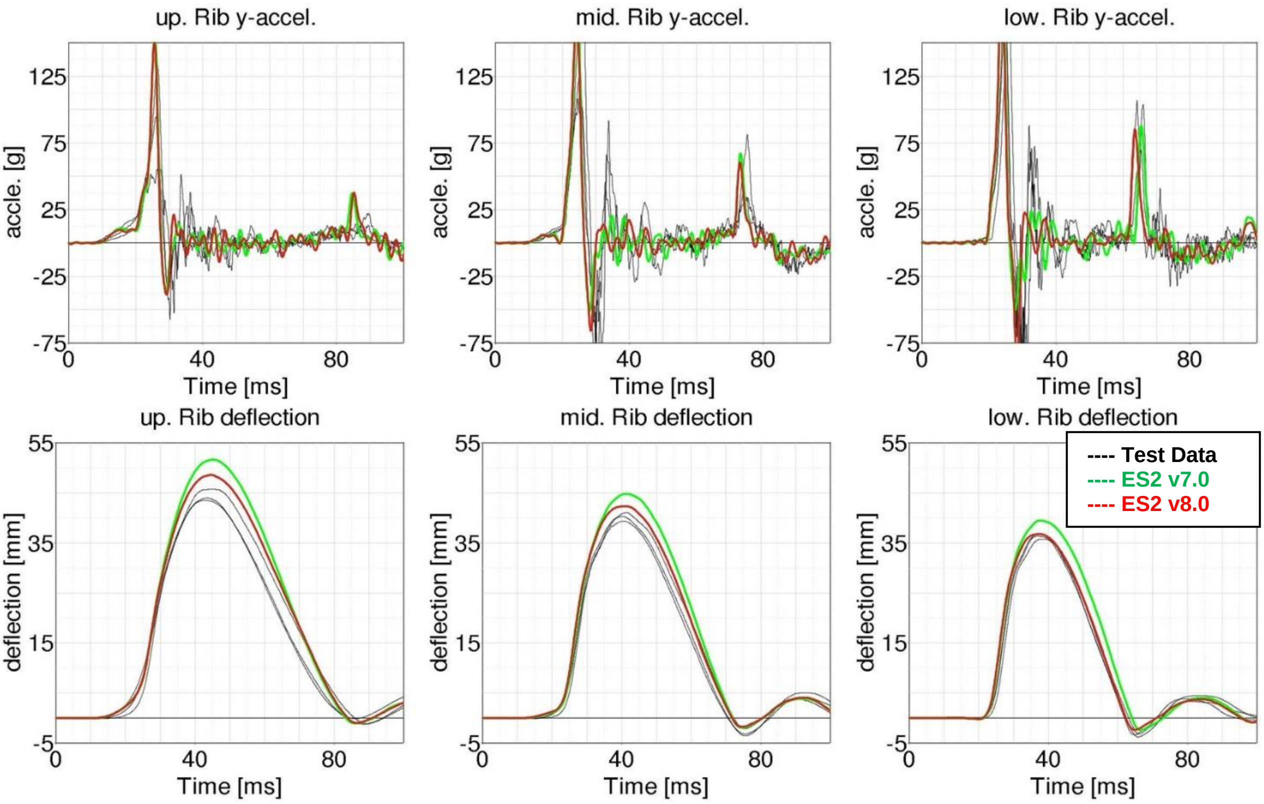
Figure 51: D4 door barrier test setup

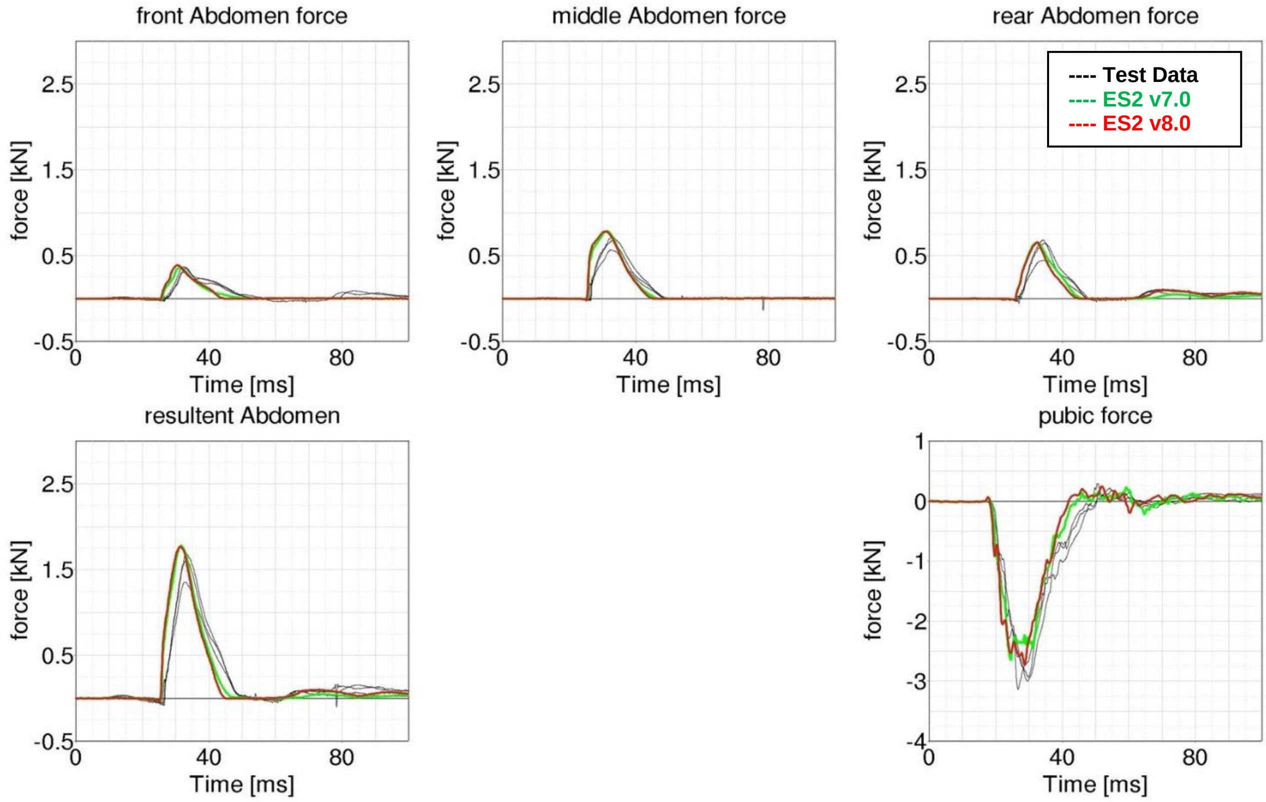
12.3.1 Results at high velocity impact

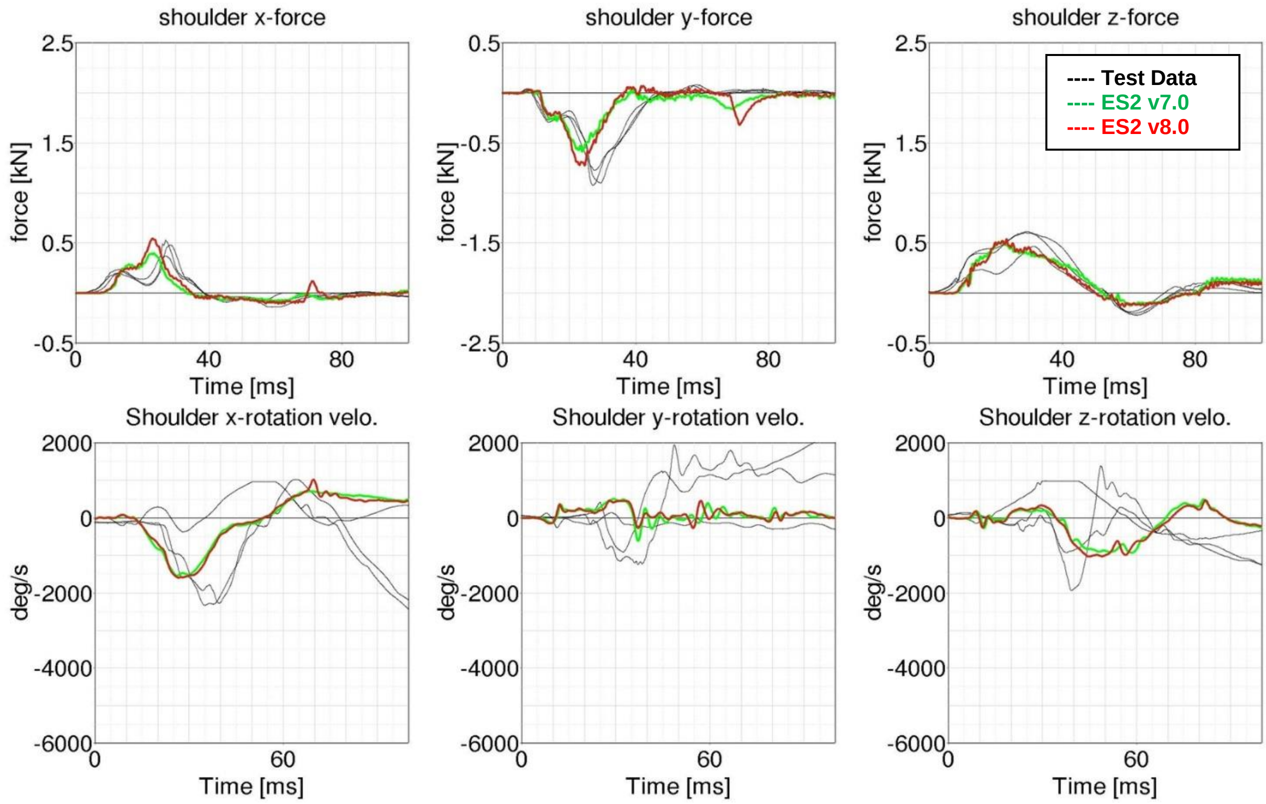


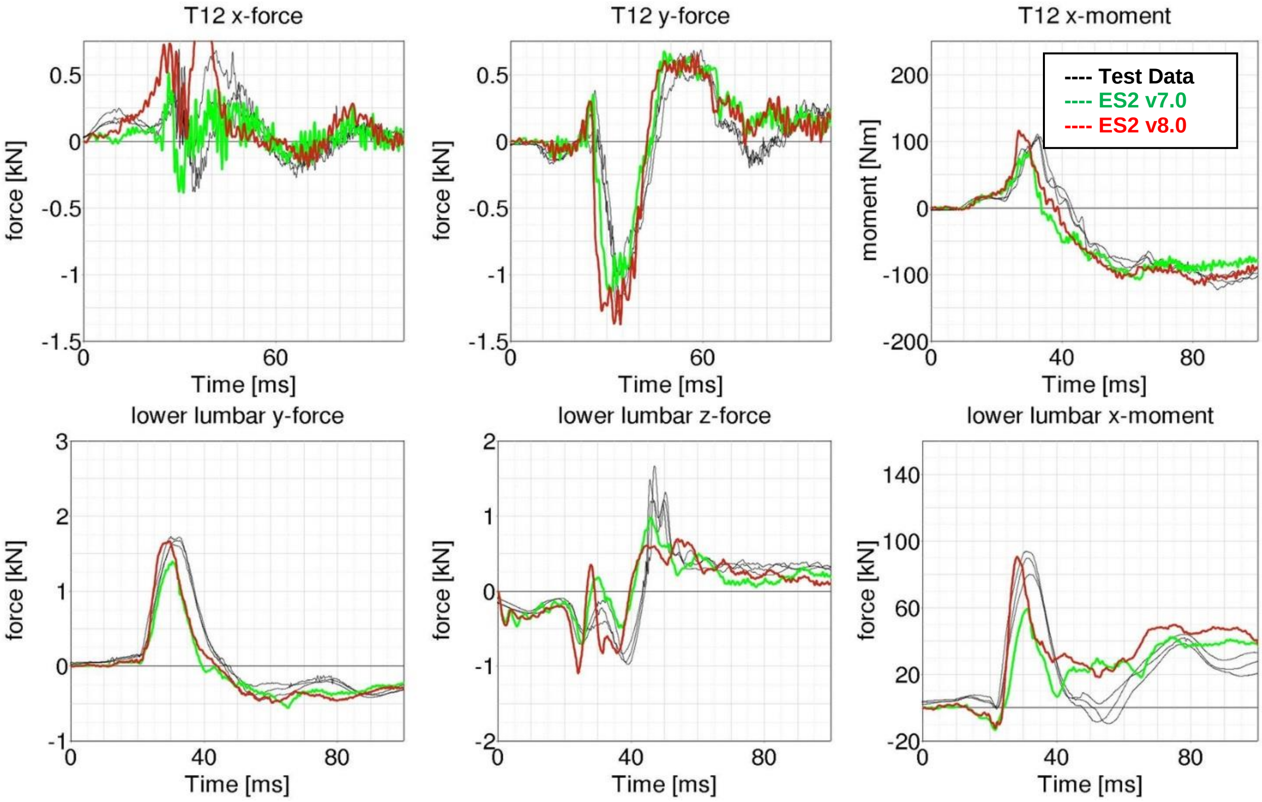



upper Neck y-force
upper Neck z-force
upper Neck x-moment
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
lower Neck y-force
lower Neck z-force
lower Neck x-moment
force [N]
moment [Nm]
Time [ms]


up. Rib y-accel.
mid. Rib y-accel.
low. Rib y-accel.
accle. [g]
up. Rib deflection
mid. Rib deflection
low. Rib deflection
deflection [mm]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Time [ms]


front Abdomen force
middle Abdomen force
rear Abdomen force
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
resultent Abdomen
pubic force
force [kN]
Time [ms]
2.5
1.5
0.5
-0.5
1
0
-1
-2
-3
-4
0
40
80


shoulder x-force
shoulder y-force
shoulder z-force
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
Shoulder x-rotation velo.
Shoulder y-rotation velo.
Shoulder z-rotation velo.
force [kN]
deg/s
Time [ms]
2.5
1.5
0.5
-0.5
-1.5
-2.5
2000
0
-2000
-4000
-6000
0
40
60
80



T12 x-force
force [kN]
Time [ms]
T12 y-force
force [kN]
Time [ms]
T12 x-moment
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0
lower lumbar y-force
force [kN]
Time [ms]
lower lumbar z-force
force [kN]
Time [ms]
lower lumbar x-moment
force [kN]
Time [ms]

12.4 Additional tests of ES-2re

12.4.1 Pendulum at 90 degree without jacket and arm

Boundaries:

- Pendulum at 90 degrees
- Speed: low and high velocity
- Pendulum mass: 24.1 kg
- No jacket and left arm is not attached

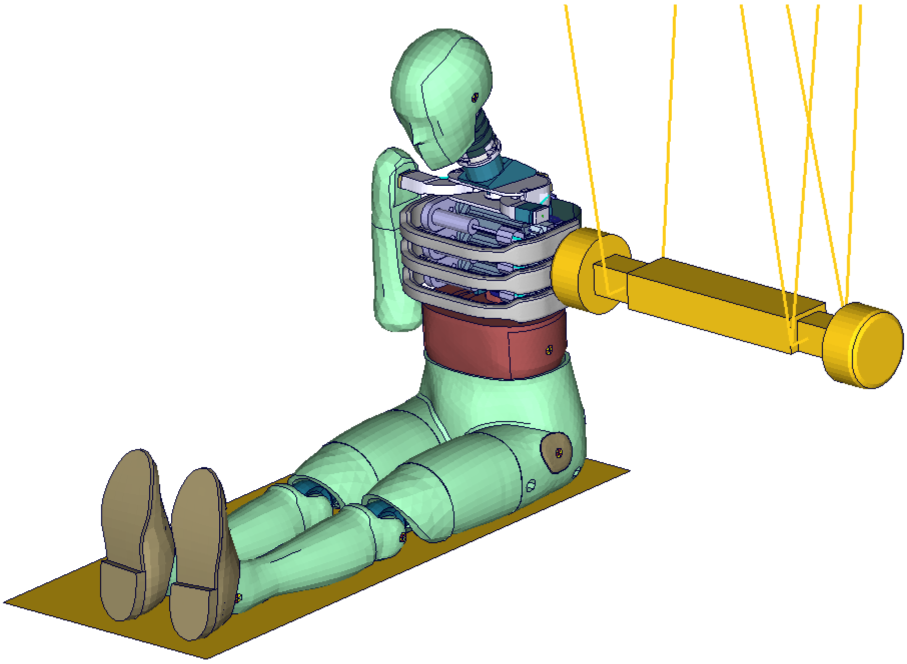
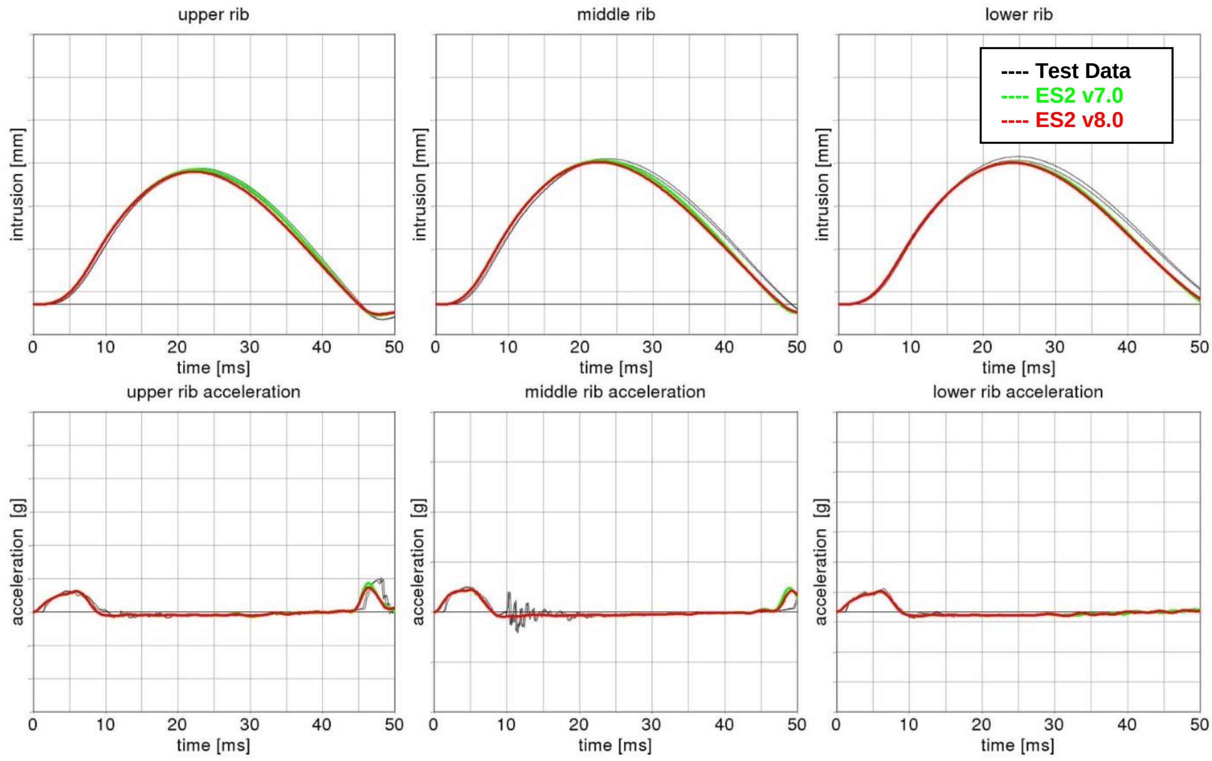
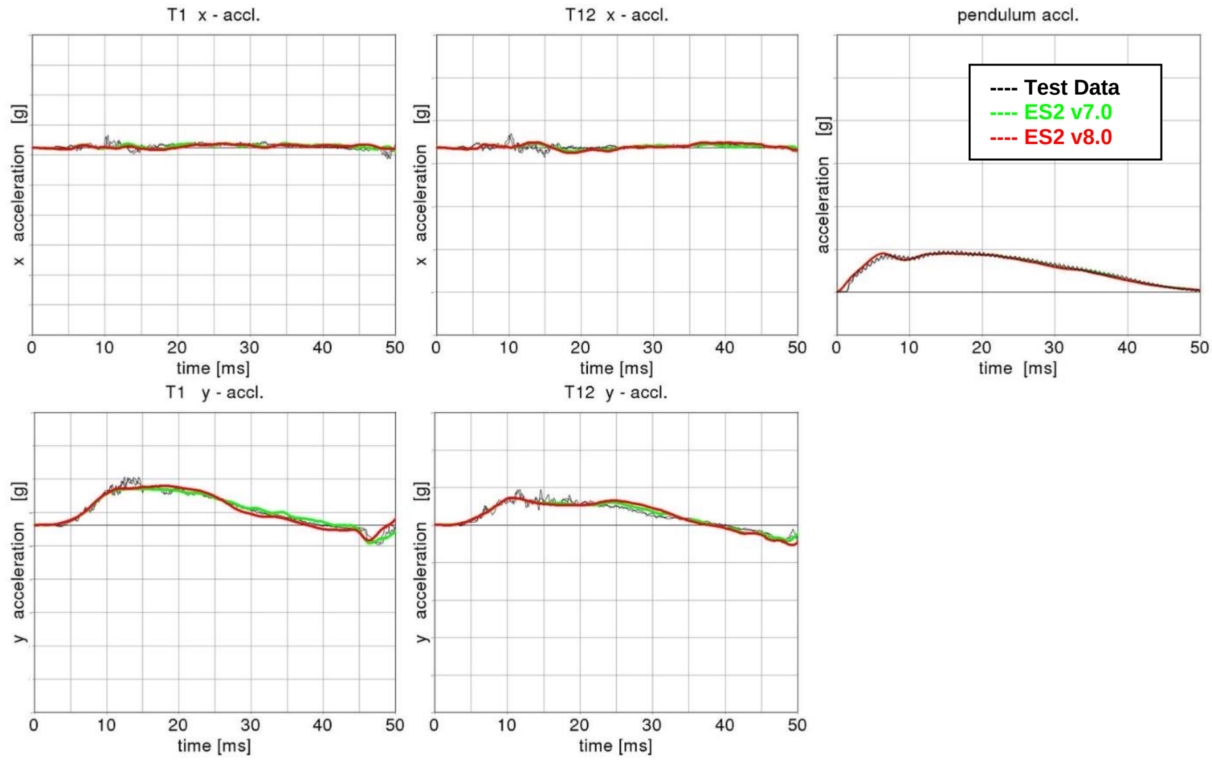


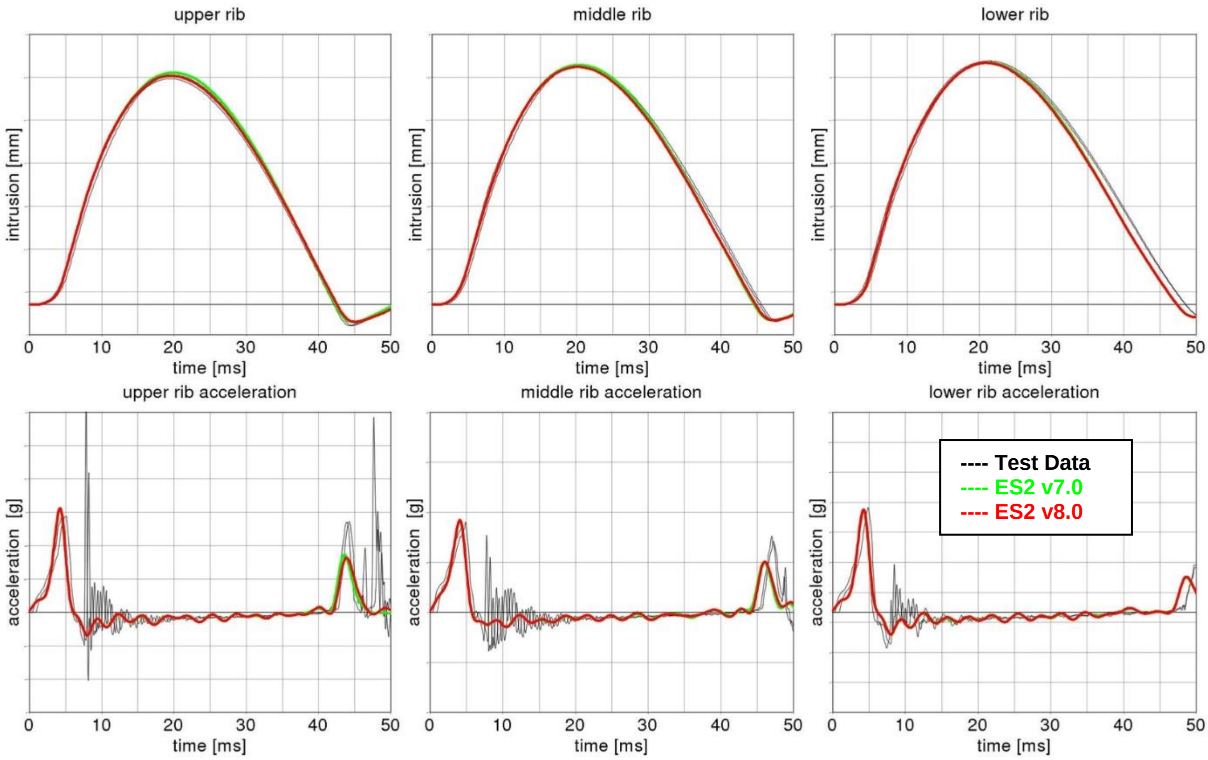
Figure 52: Pendulum impacting the ribs at 90 degrees; without arm and jacket

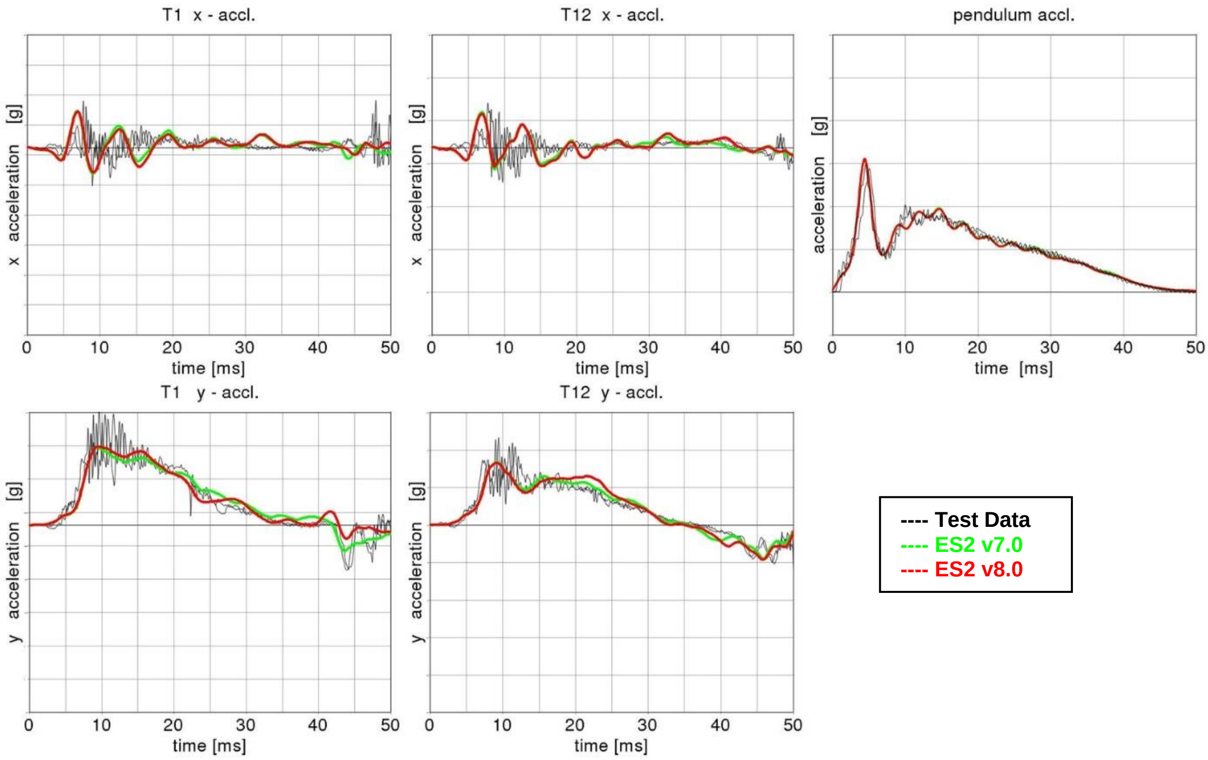
Results at low velocity





Results at high velocity





12.4.2 Pendulum at 45 degree without jacket and arm

Boundaries:

- Pendulum at 45 degrees
- Speed: low and high velocity
- Pendulum mass: 24.1 kg
- No jacket and left arm is not attached
- An ensolite foam is mounted in front of the pendulum

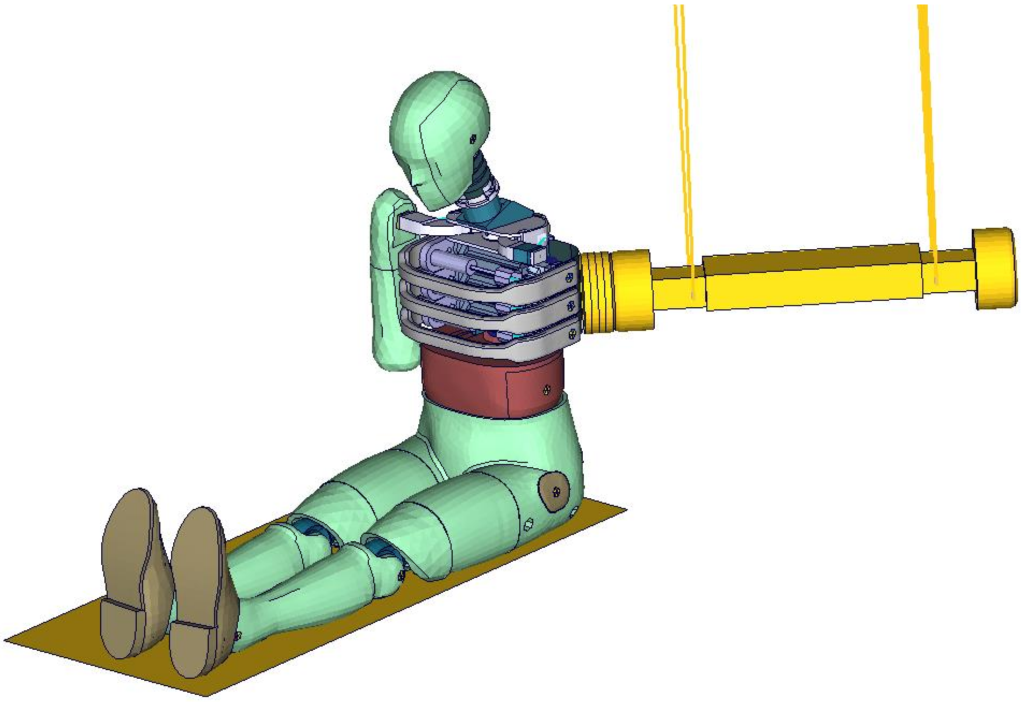
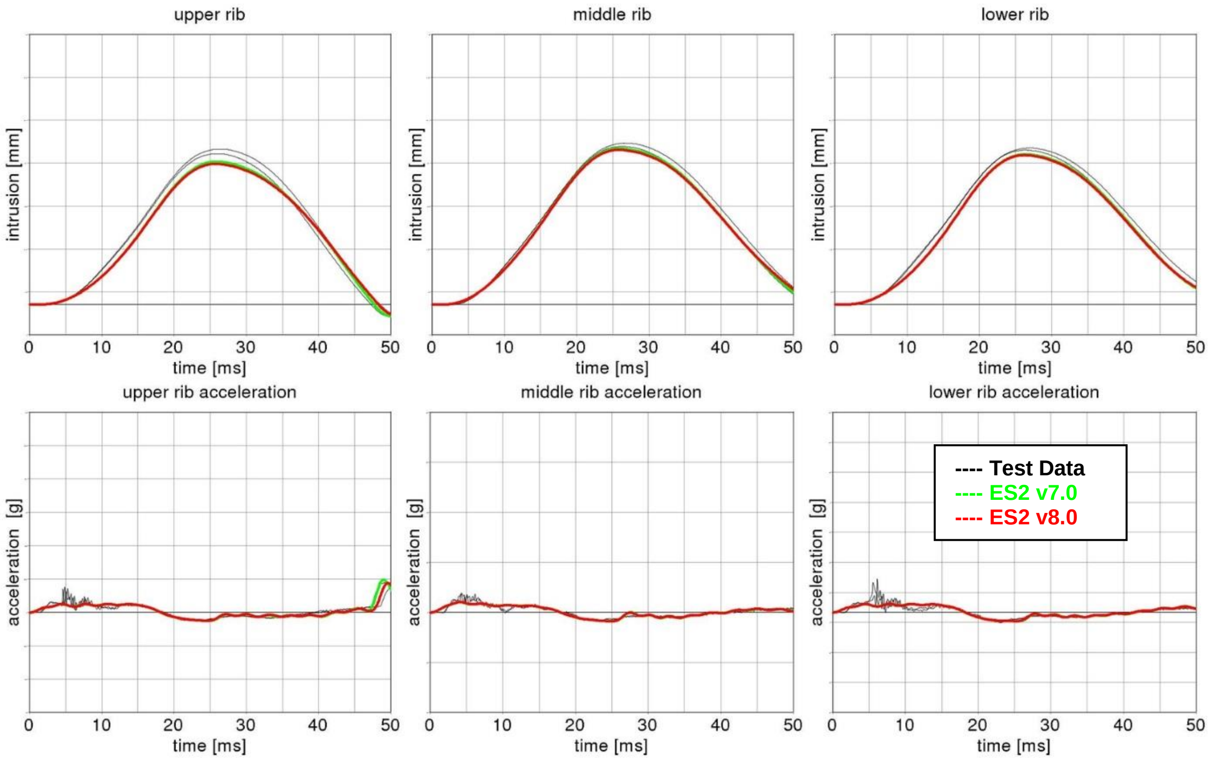
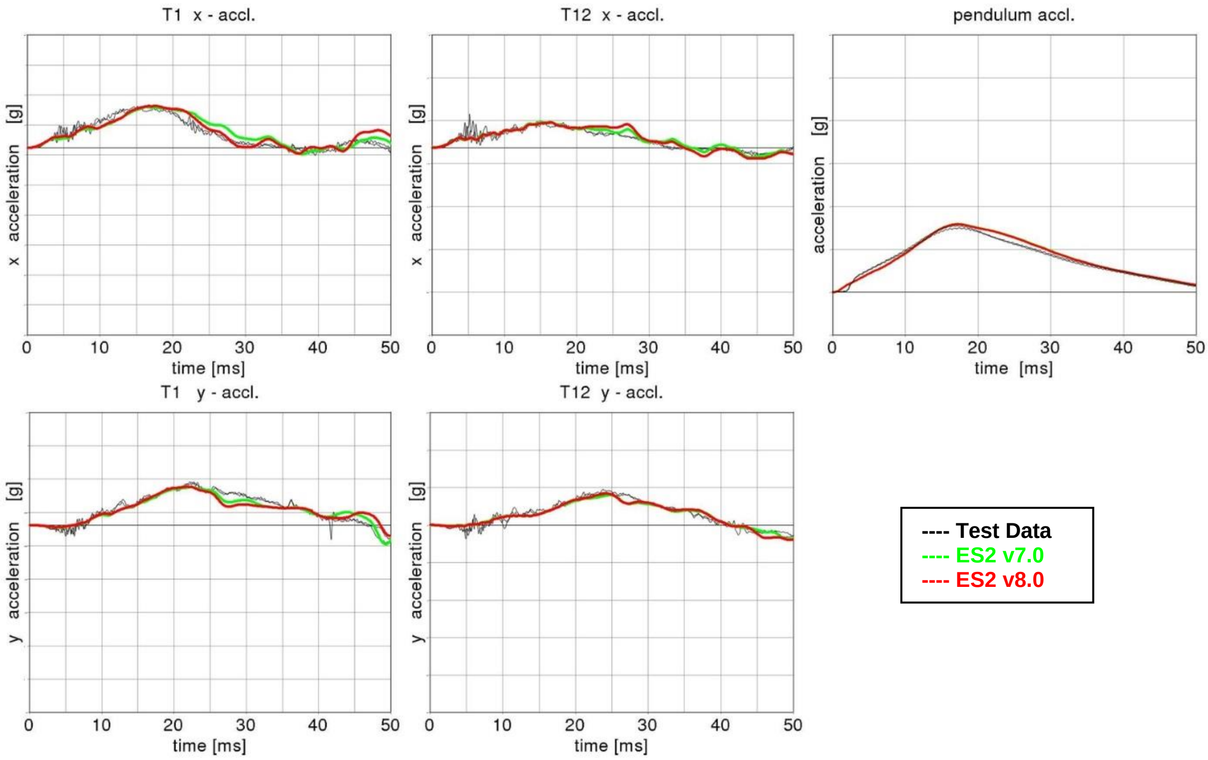


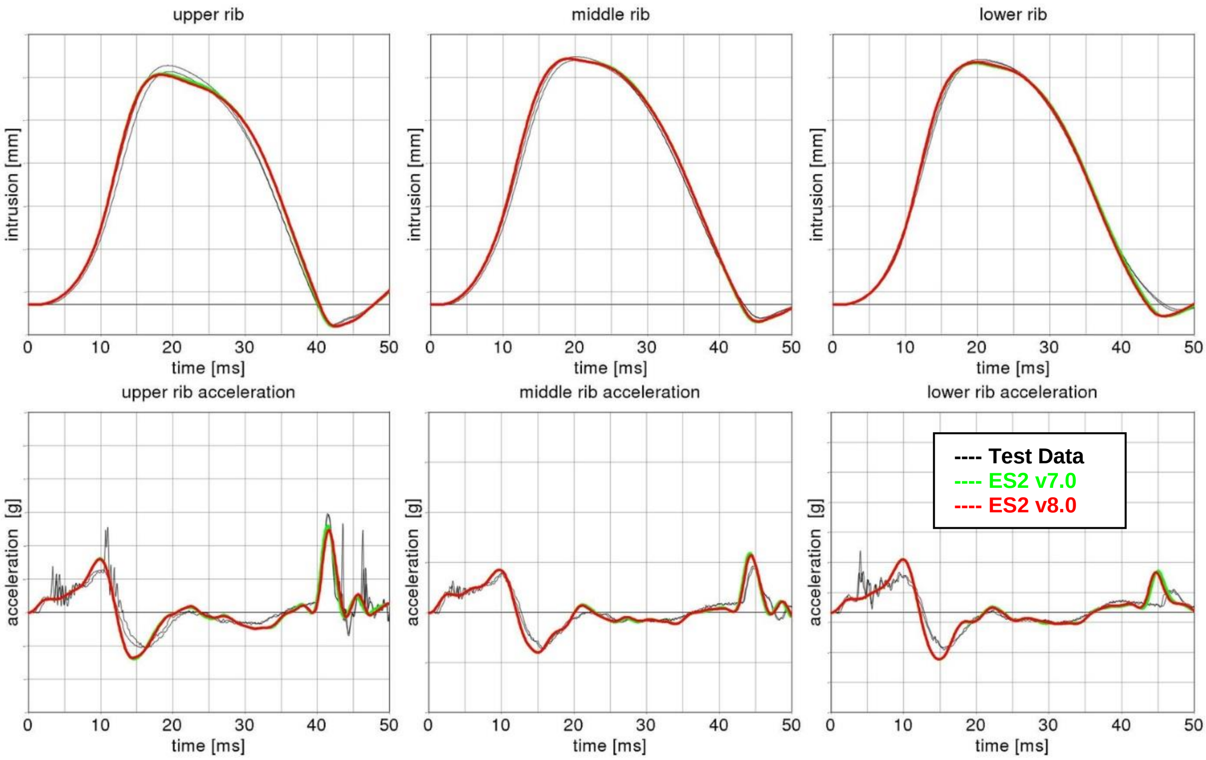
Figure 53: Pendulum impacting the ribs at 45 degrees; without arm and jacket

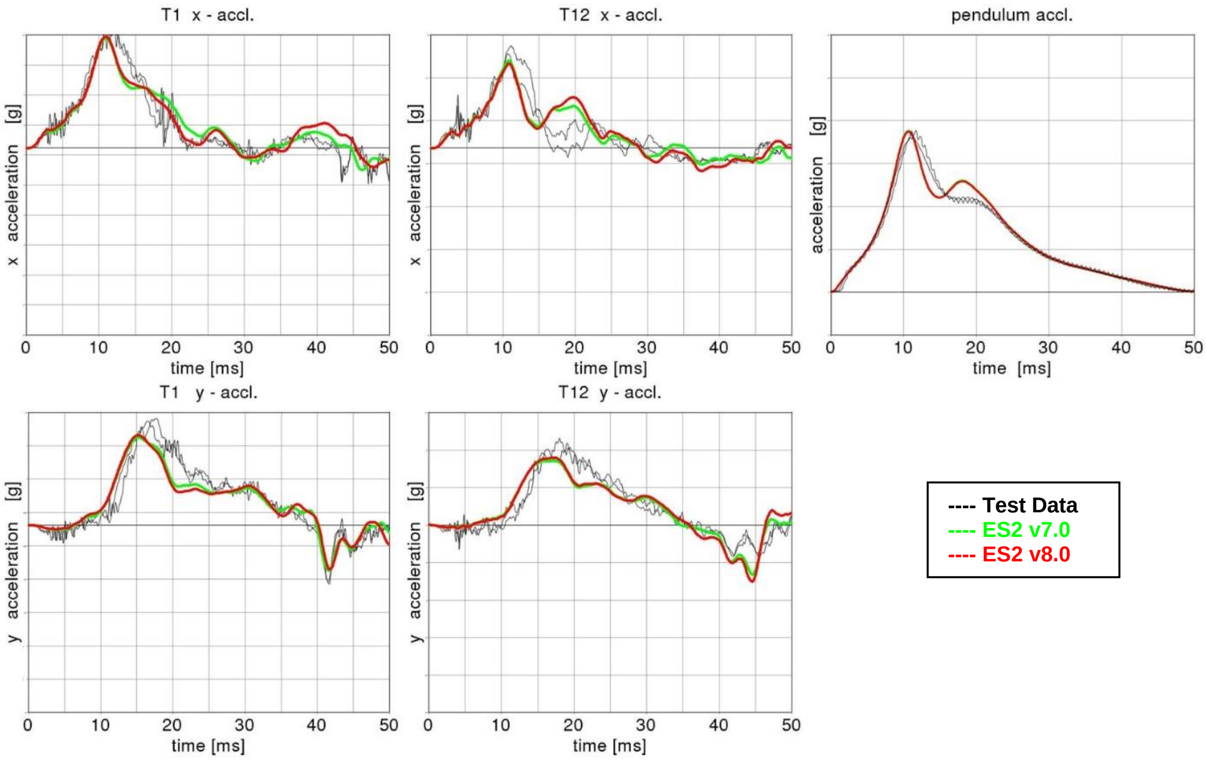
Results at low velocity





Results at high velocity





12.4.3 Pendulum at 45 degree on full Dummy

Boundaries:

- Pendulum at 45 degrees
- Speed: high velocity
- Pendulum mass: 24.1 kg
- Arms in 90 degree position
- The pendulum hits the rib extension at an angle of 45 degrees
- ES-2 is equipped with arms and jacket

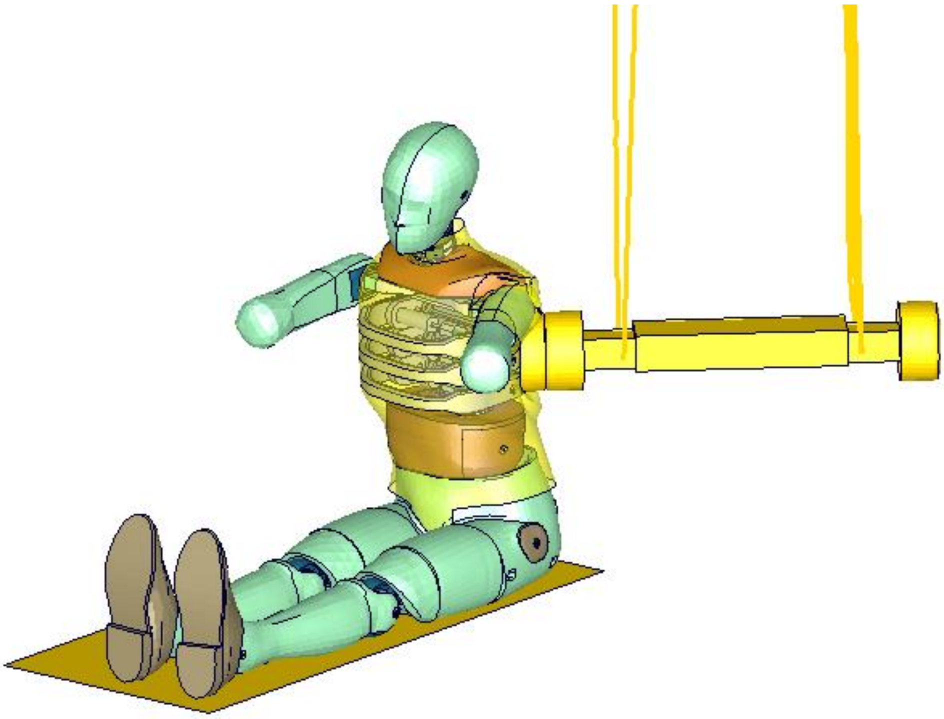
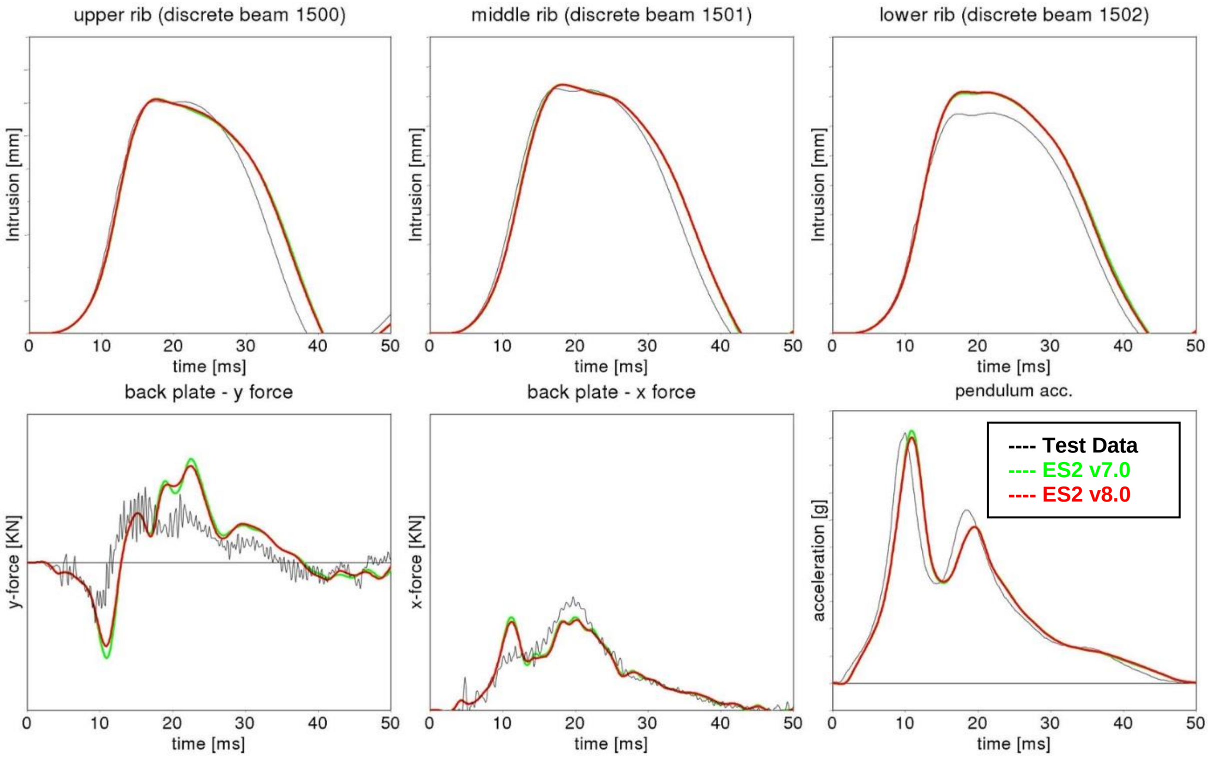


Figure 54: Pendulum impacting the ribs at 45 degrees; with arm and jacket

Results


upper rib (discrete beam 1500)
middle rib (discrete beam 1501)
lower rib (discrete beam 1502)
Intrusion [mm]
time [ms]
0 10 20 30 40 50
back plate - y force
back plate - x force
pendulum acc.
y-force [KN]
x-force [KN]
acceleration [g]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0

12.5 ARP-sled-tests with ES-2re

12.5.1 ARP-sled-test with armrest

Boundaries:

- Three-point-belt-system
- Sled with armrest
- Sled accelerated to high velocity
- The Test data come from FAA-CAMI (Federal Aviation Administration)

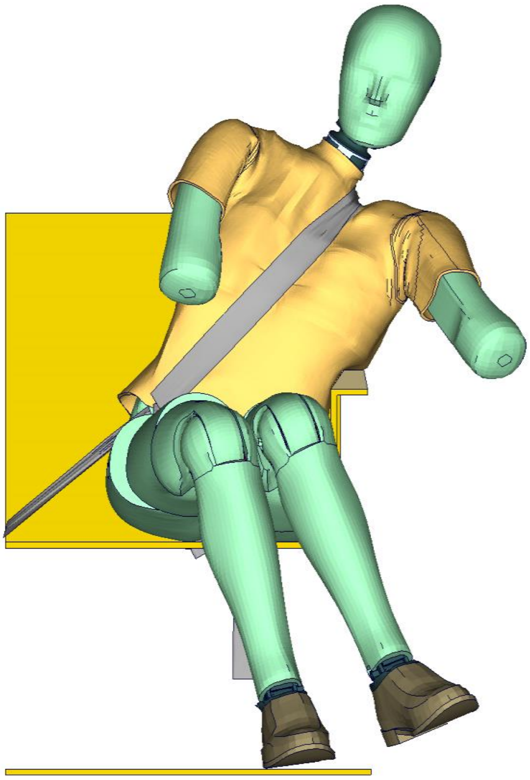
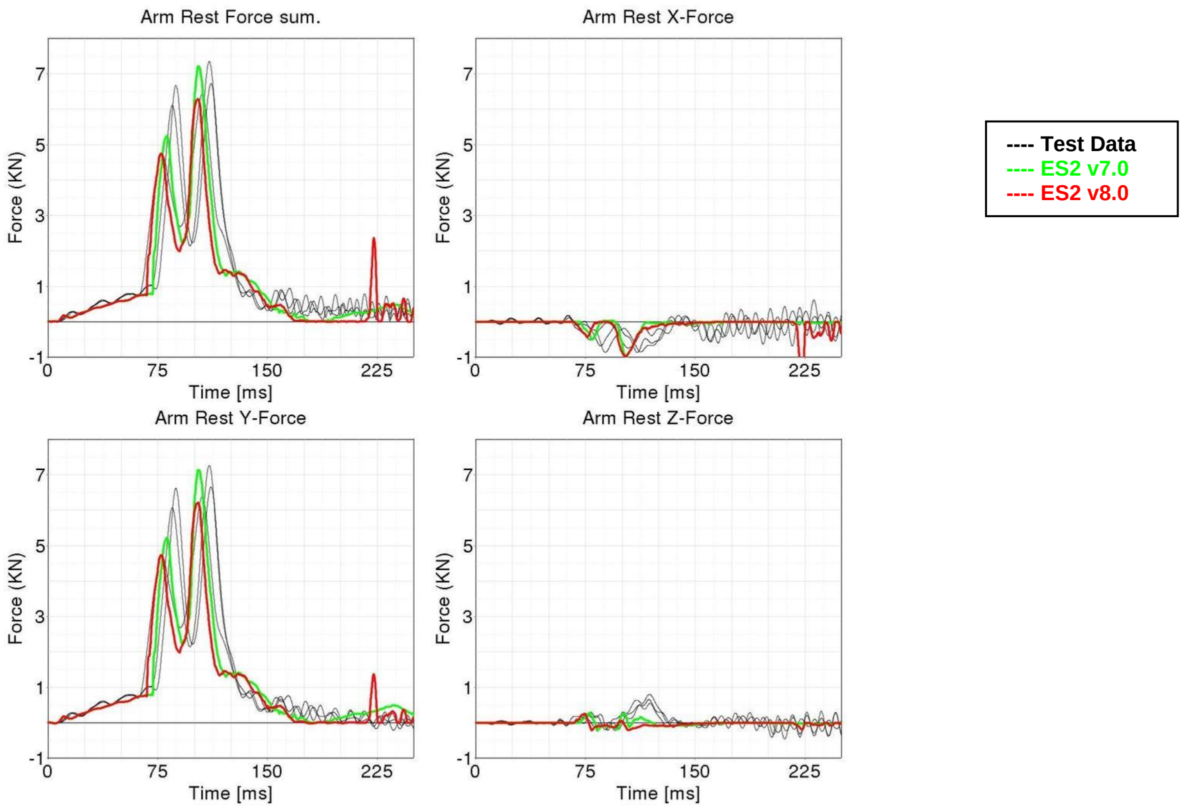
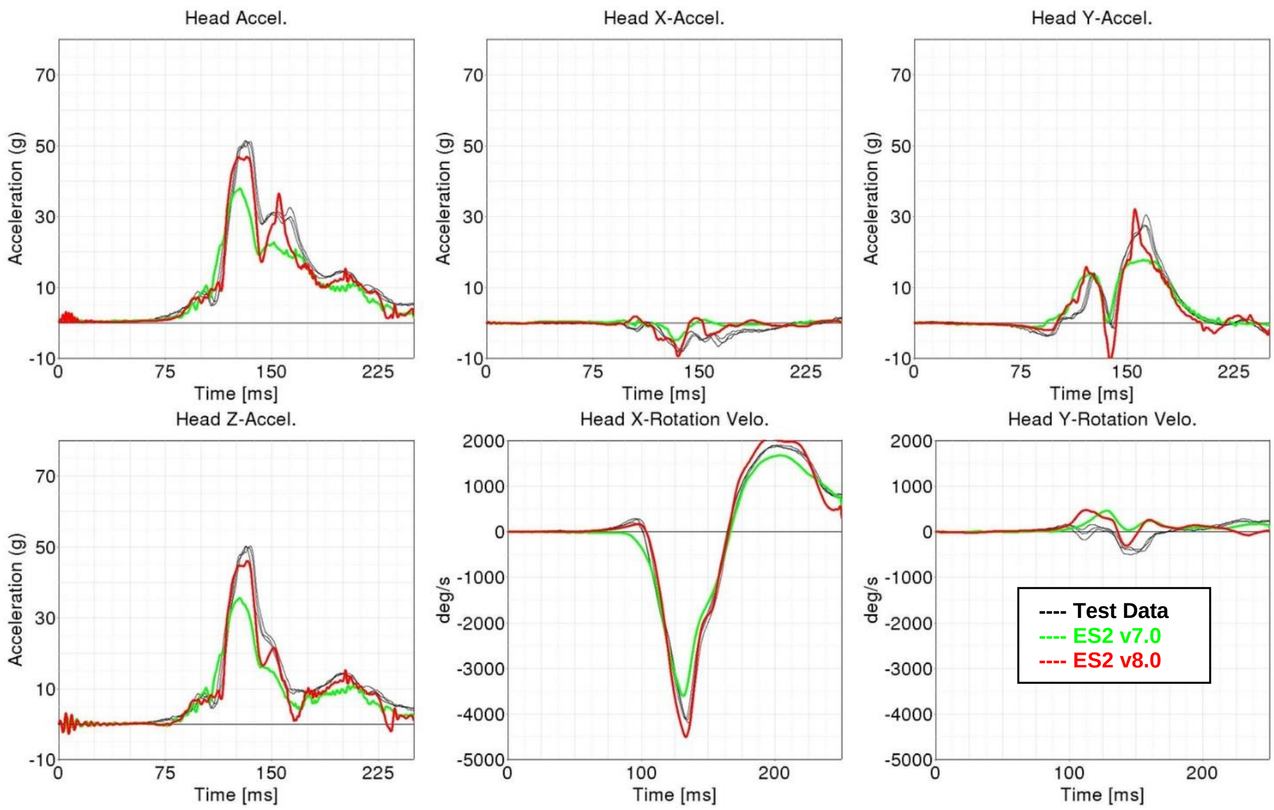
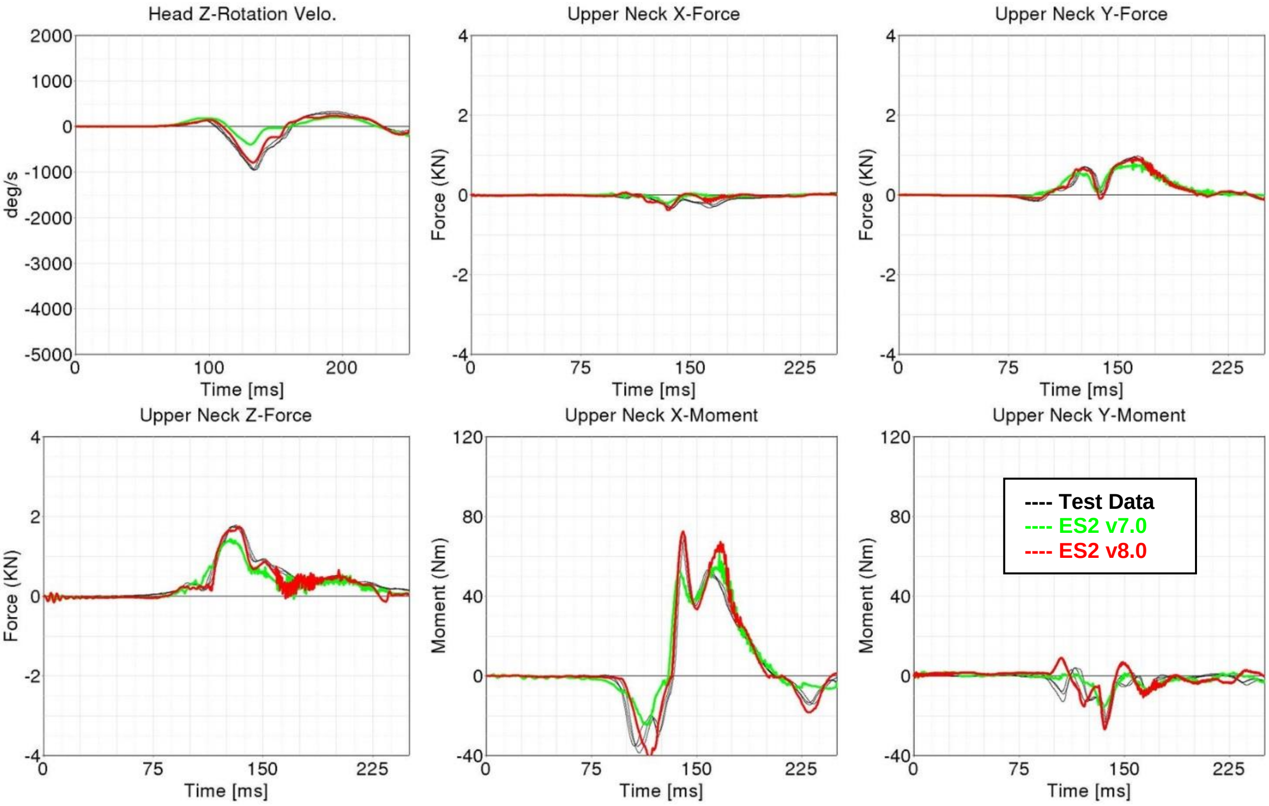


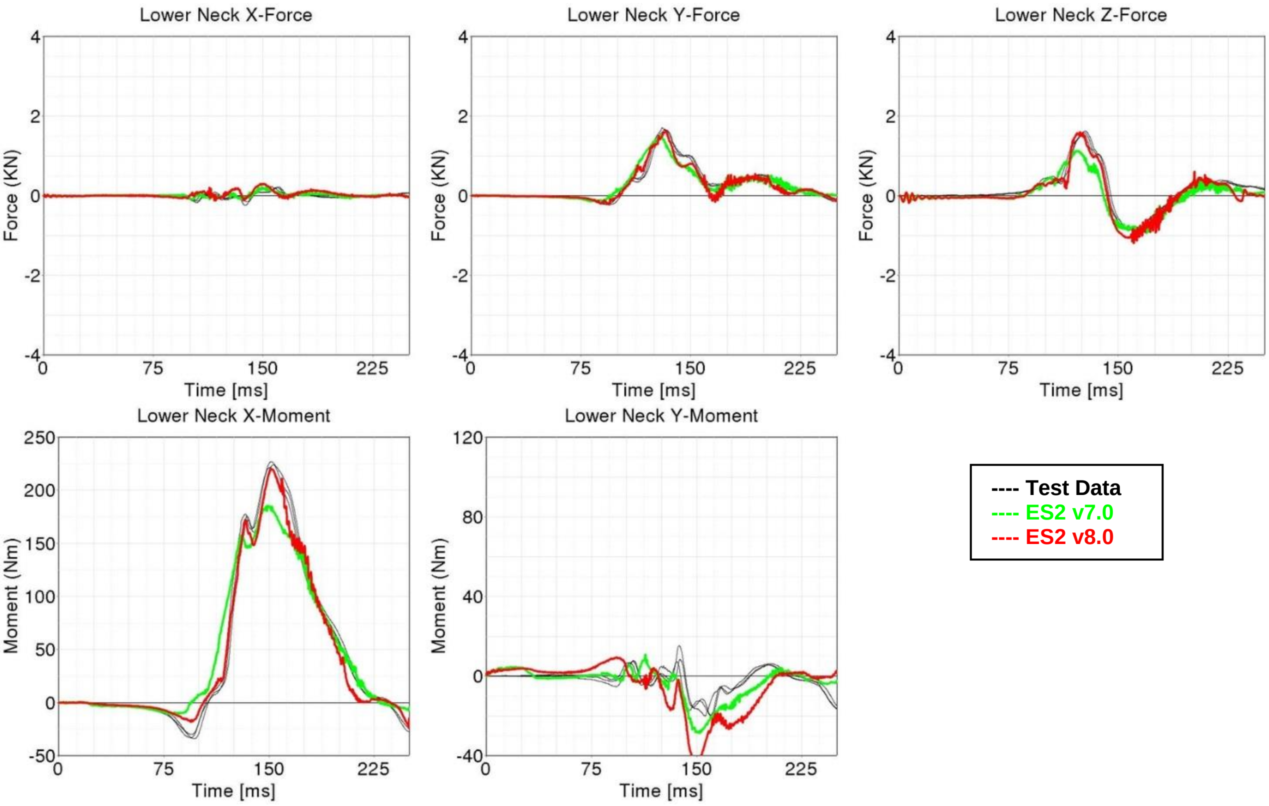
Figure 55: ARP-sled-test with armrest

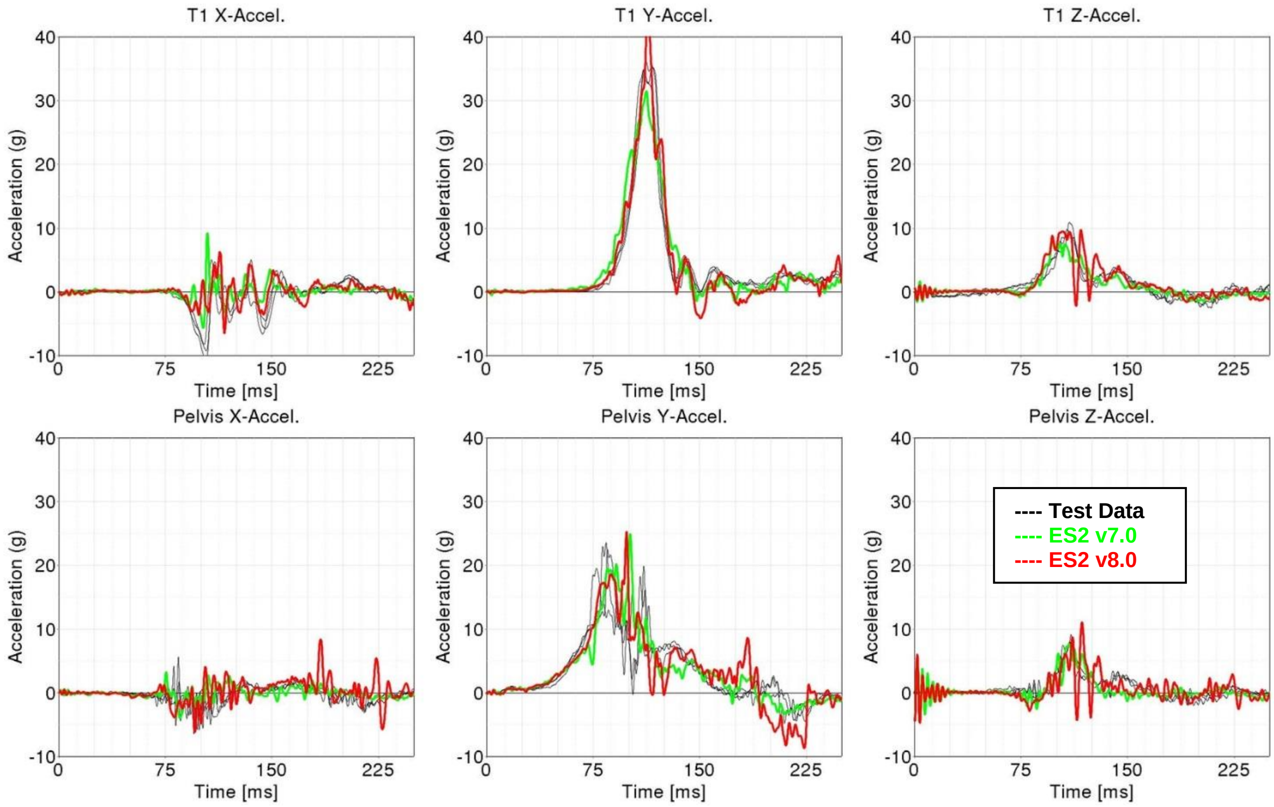
Results with armrest

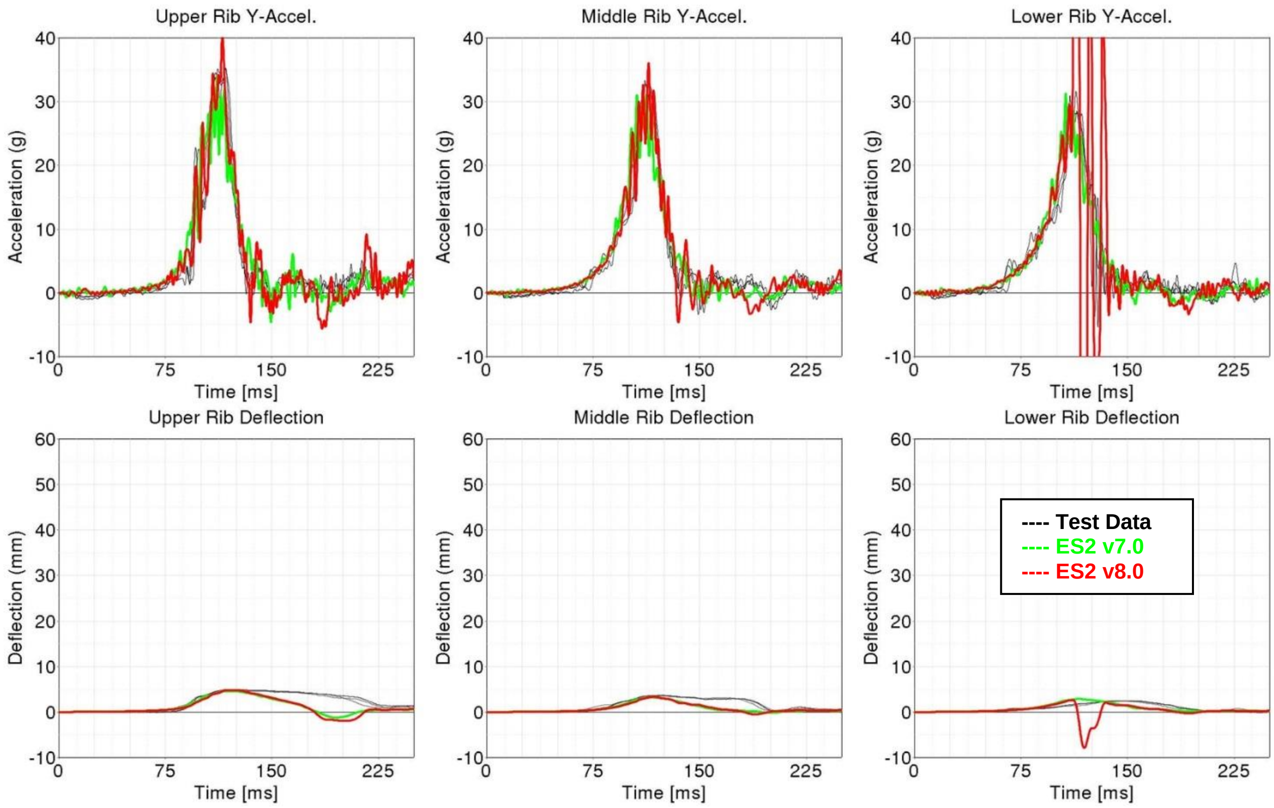


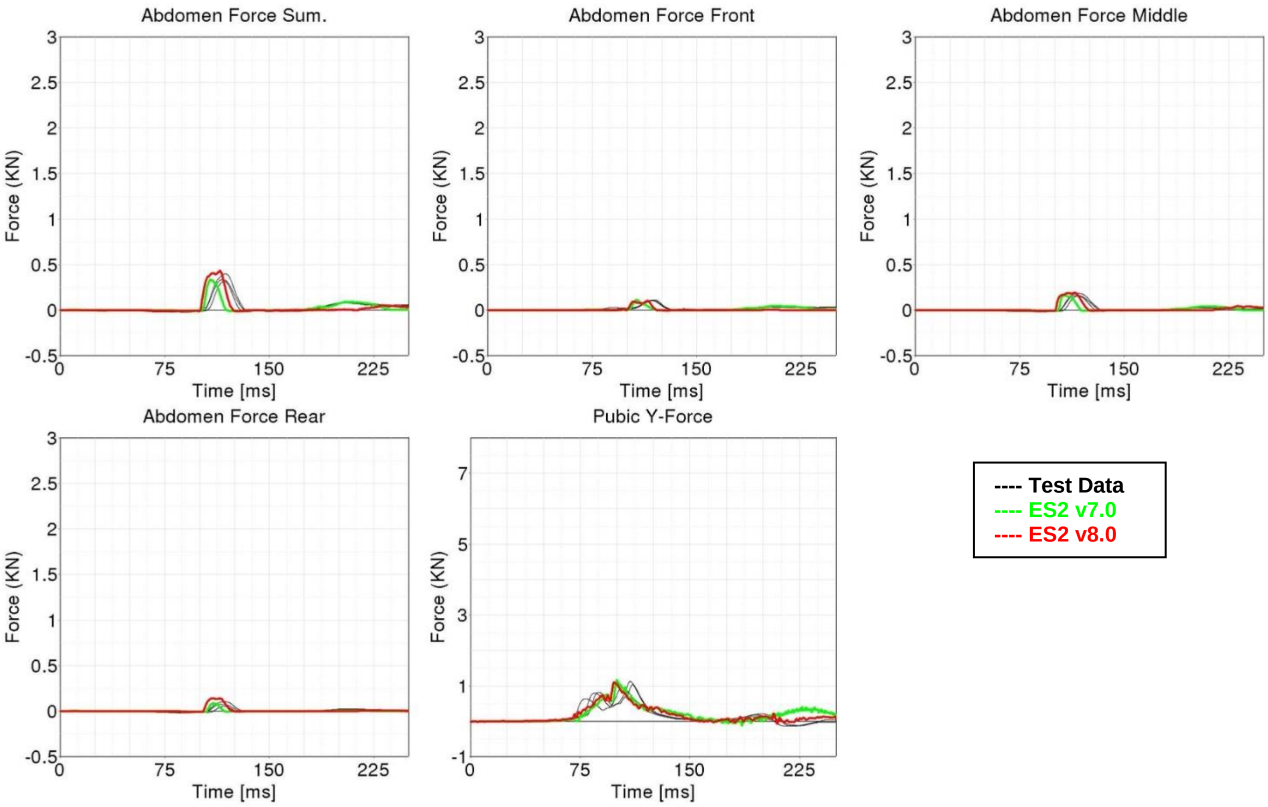



Head Z-Rotation Velo.
deg/s
Time [ms]
Upper Neck X-Force
Force (KN)
Time [ms]
Upper Neck Y-Force
Force (KN)
Time [ms]
Upper Neck Z-Force
Force (KN)
Time [ms]
Upper Neck X-Moment
Moment (Nm)
Time [ms]
Upper Neck Y-Moment
Moment (Nm)
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


Lower Neck X-Force
Force (KN)
Time [ms]
Lower Neck Y-Force
Force (KN)
Time [ms]
Lower Neck Z-Force
Force (KN)
Time [ms]
Lower Neck X-Moment
Moment (Nm)
Time [ms]
Lower Neck Y-Moment
Moment (Nm)
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


T1 X-Accel.
T1 Y-Accel.
T1 Z-Accel.
Pelvis X-Accel.
Pelvis Y-Accel.
Pelvis Z-Accel.
Acceleration (g)
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


Upper Rib Y-Accel.
Middle Rib Y-Accel.
Lower Rib Y-Accel.
Upper Rib Deflection
Middle Rib Deflection
Lower Rib Deflection
Acceleration (g)
Deflection (mm)
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


Abdomen Force Sum.
Abdomen Force Front
Abdomen Force Middle
Abdomen Force Rear
Pubic Y-Force
Force (KN)
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0

12.5.2 ARP-sled-test without armrest

Boundaries:

- Three-point-belt-system
- Sled without armrest
- Sled accelerated to high velocity
- The Test data come from FAA-CAMI (Federal Aviation Administration)

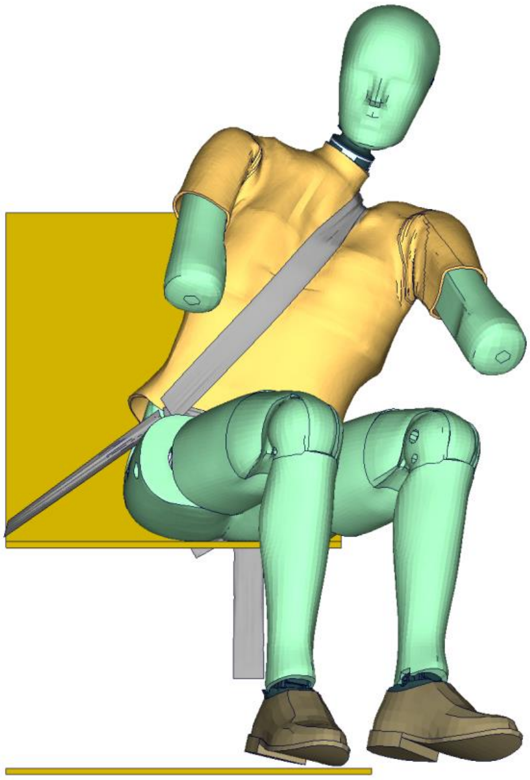
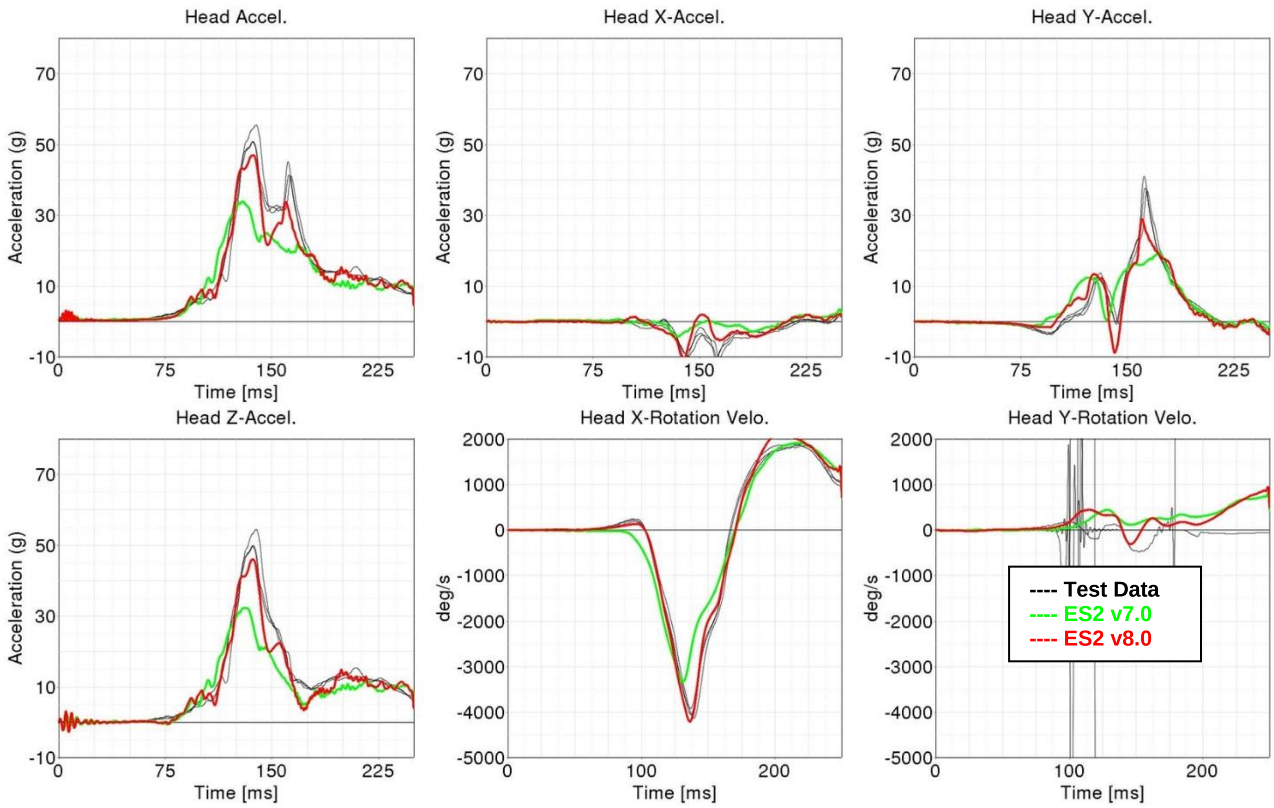
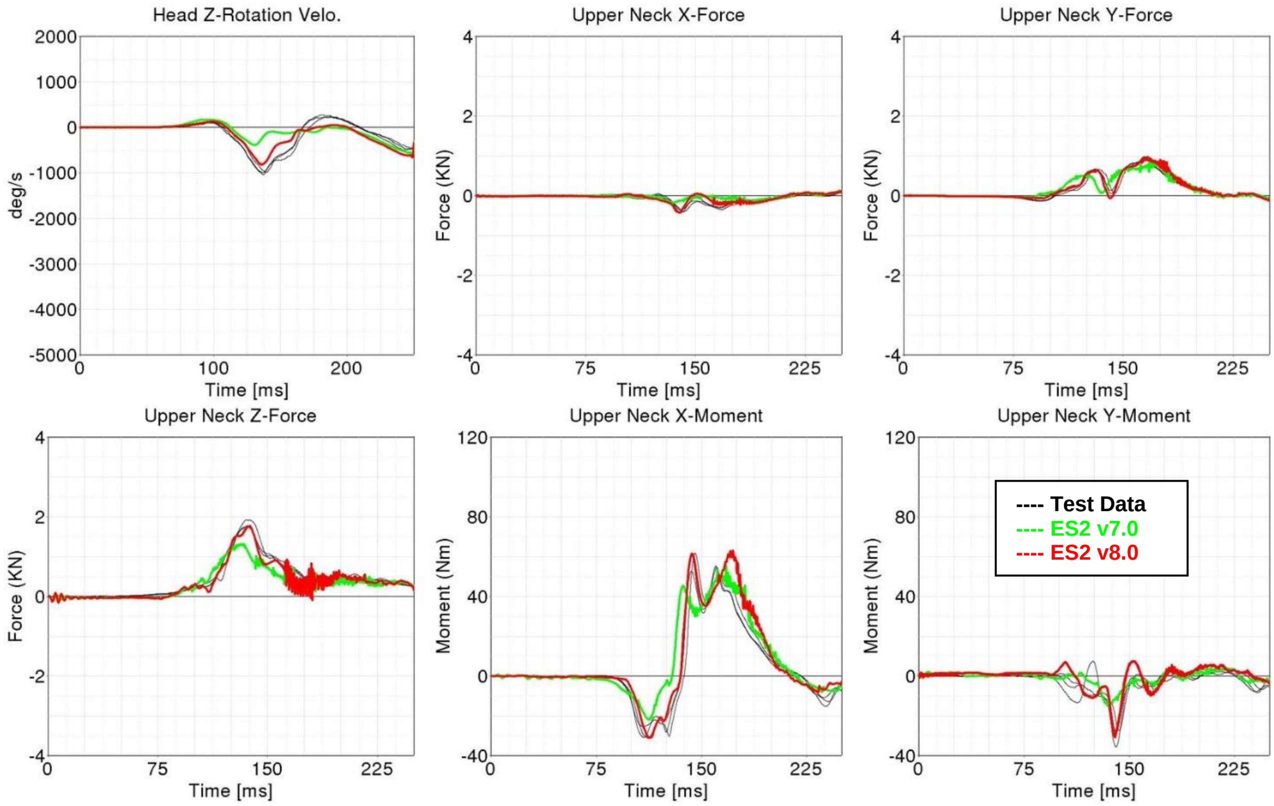
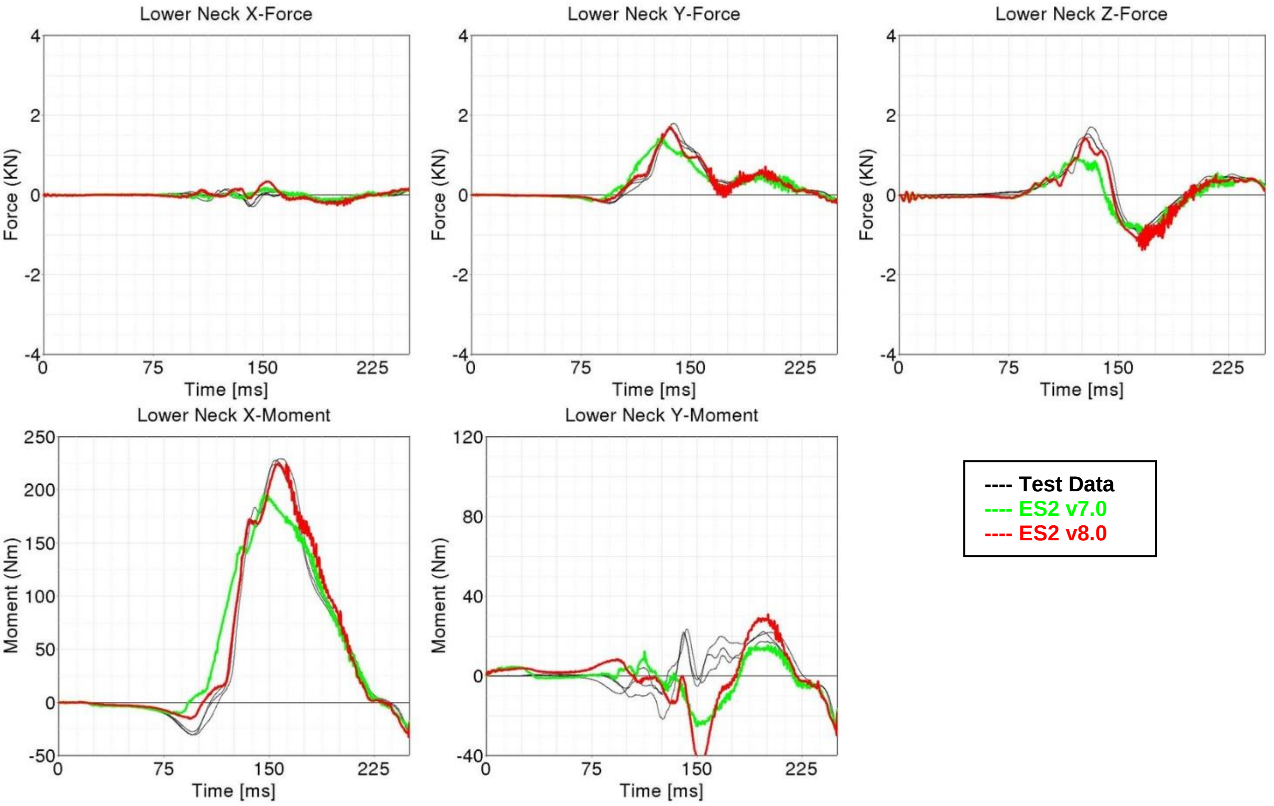


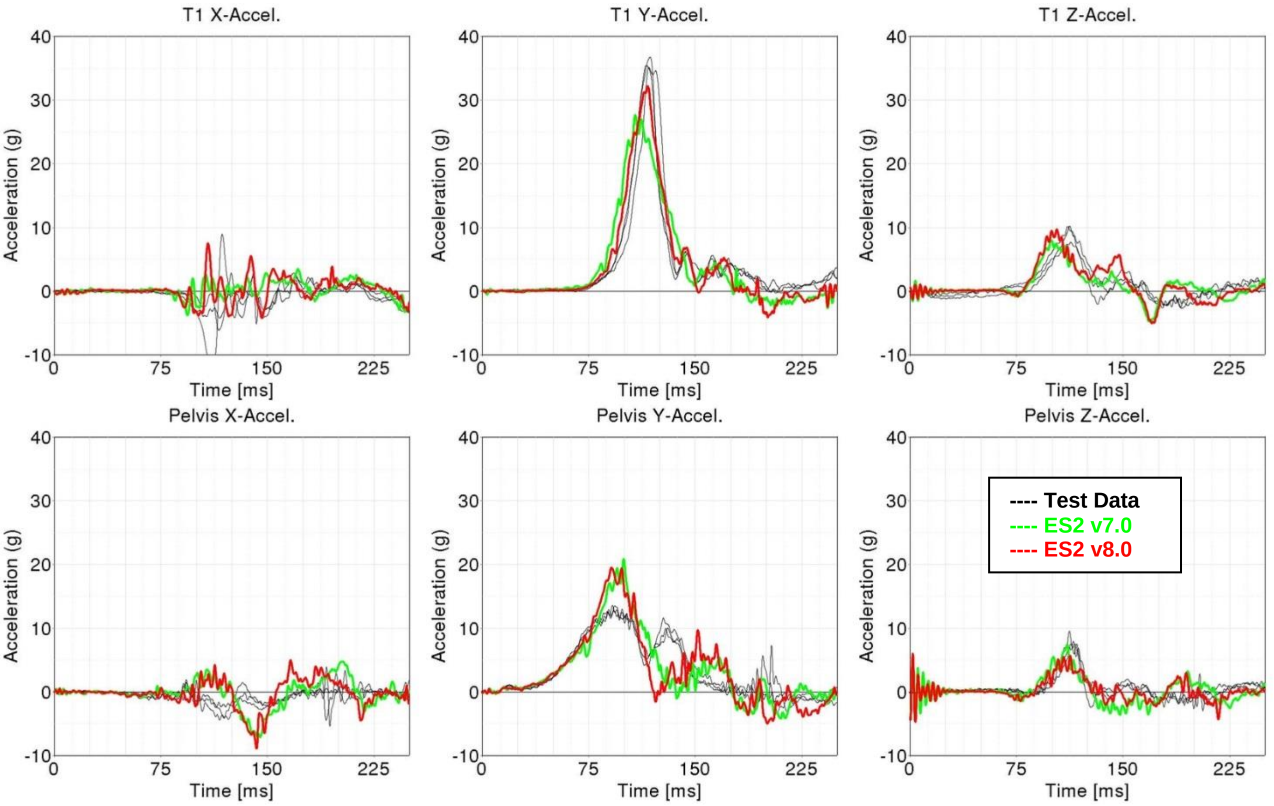
Figure 56: ARP-sled-test without armrest

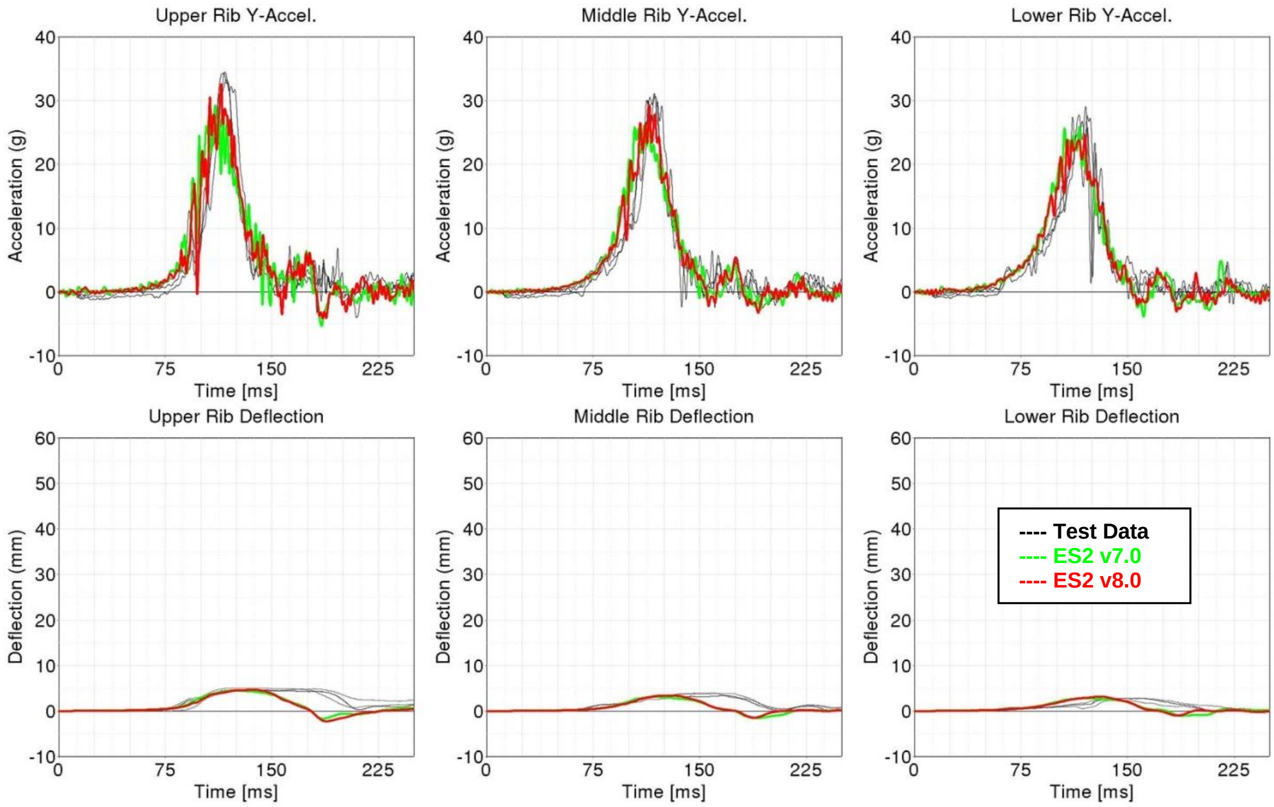
Results without armrest

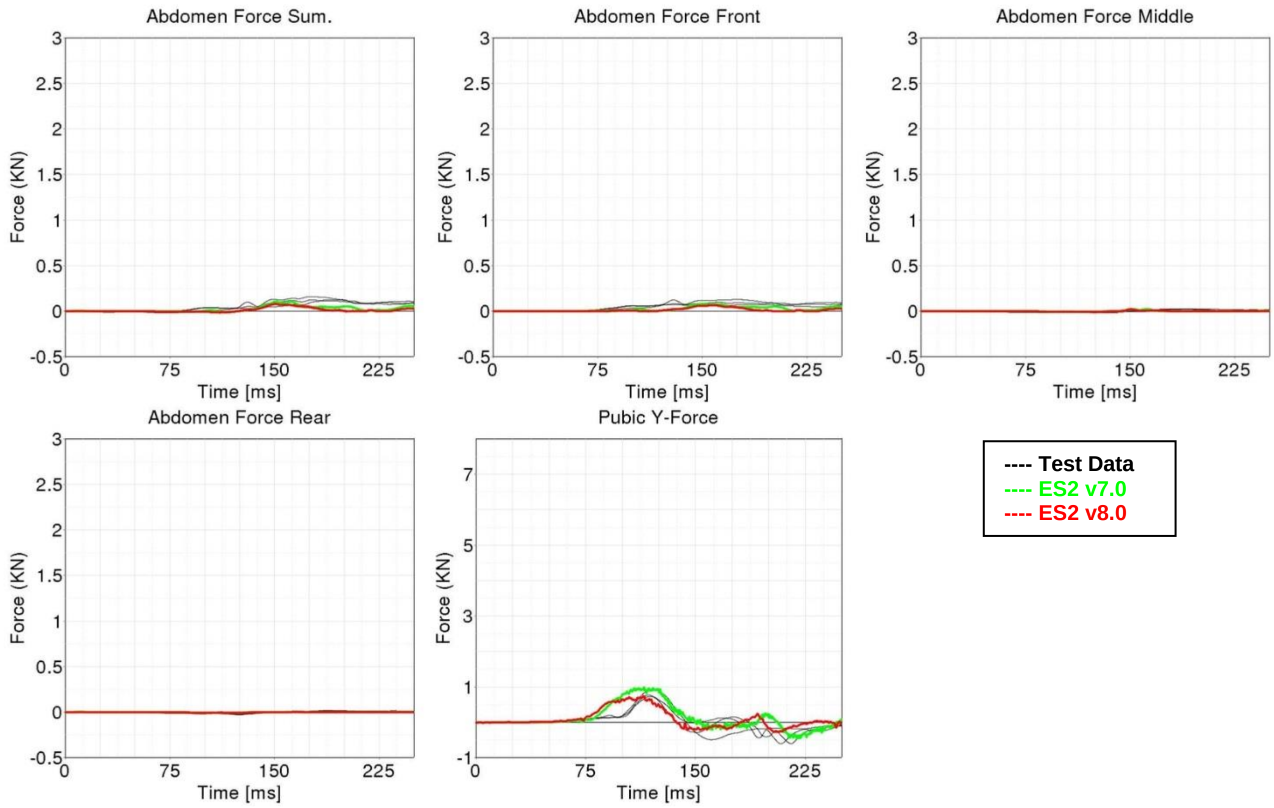





Lower Neck X-Force
Lower Neck Y-Force
Lower Neck Z-Force
Force (KN)
Time [ms]
Lower Neck X-Moment
Lower Neck Y-Moment
Moment (Nm)
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


T1 X-Accel.
T1 Y-Accel.
T1 Z-Accel.
Acceleration (g)
Time [ms]
Pelvis X-Accel.
Pelvis Y-Accel.
Pelvis Z-Accel.
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


Upper Rib Y-Accel.
Middle Rib Y-Accel.
Lower Rib Y-Accel.
Acceleration (g)
Time [ms]
Upper Rib Deflection
Middle Rib Deflection
Lower Rib Deflection
Deflection (mm)
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0


Abdomen Force Sum.
Abdomen Force Front
Abdomen Force Middle
Force (KN)
Time [ms]
Abdomen Force Rear
Pubic Y-Force
Force (KN)
Time [ms]
---- Test Data
---- ES2 v7.0
---- ES2 v8.0

13. List of Figures