Documentation

LS-DYNA

ES-2 50th - Version 7.0

ES-2re 50th - Version 7.0

User's Manual
Manual Release 0.0 for Model 7.0
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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 R7.1.2 MPP	97170	97170
971 R7.1.3 MPP	114888	114888
R9.2	119543	119543

Table 1: LS-DYNA versions.

With the version 7.0 of the Euro-SID 2 50th model the following keyword files are delivered:

File name	Content
es2_v7.0_mm_ms_kg.key	Dummy model, the file name might vary depending on the system of units
es2_v7.0_nullshells.key	Optional contact shells
es2_v7.0_all_units_load_curves_work.key	Dummy curves for working on the model with a pre-processor
es2_v7.0_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 bye 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	611274	308234
Solids	13000	639967	400086
Beams	10000	12642	512
Shells	339000	650823	187337
Discrete elements	10500	10517	16
Mass elements	10512	10520	9
Accelerometer	1001	1019	9
Set nodes	1005	1202	6
Set parts	1001	1544	32
Parts	1	1004	531
Materials	1001	3003	190

Sections	1001	1198	198
Hourglass	1001	1006	6
Joint stiffness	1001	1018	17
Contacts	1001	1030	26
Local coordinate systems	1001	1043	43
Load curves / tables	1001	1181	181
Time history nodes	10001	10021	9
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 _PARTSET_DISTRIBUTE	*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

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

Table 7: Other keywords used in the model.

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

*ASSEMBLY	*DUMMY_END
*DUMMY_START	*H_POINT
*UNITS	*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

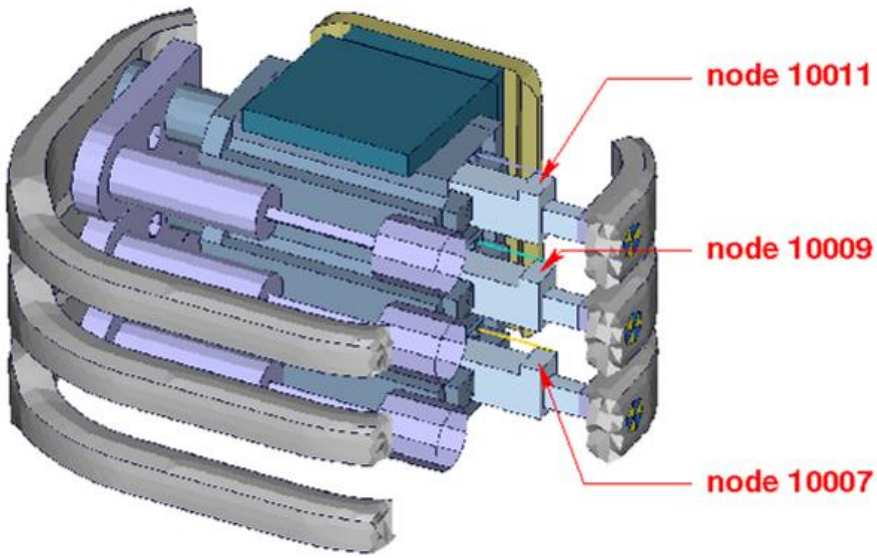


Figure 1: Nodes for extracting rib accelerations

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	acceleration upper rib	Local y-acceleration
Middle Rib	10009	acceleration middle rib	Local y-acceleration
Lower Rib	10007	Acceleration lower rib	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 2 nodes will not be supported any longer.

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

Table 10: Rib intrusion elements from deforc

3.3 Spine accelerations

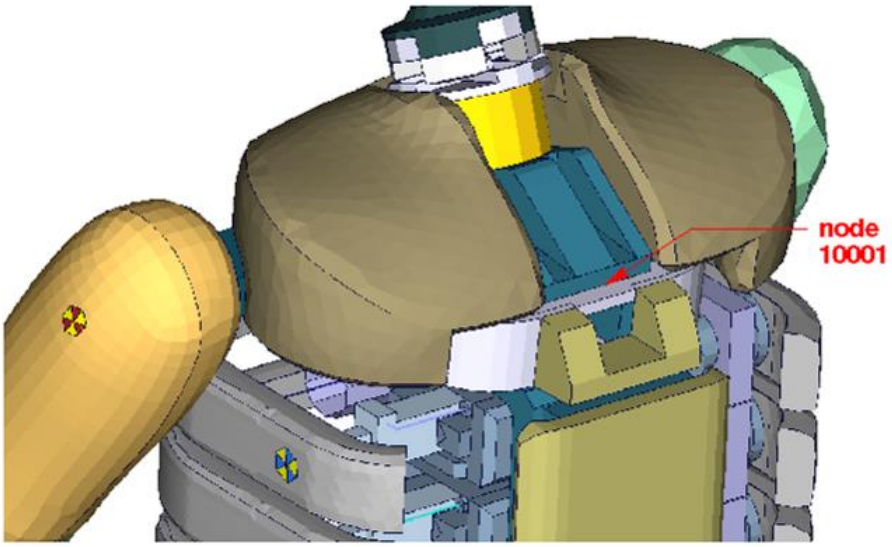


Figure 2: Node for extracting upper spine acceleration

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

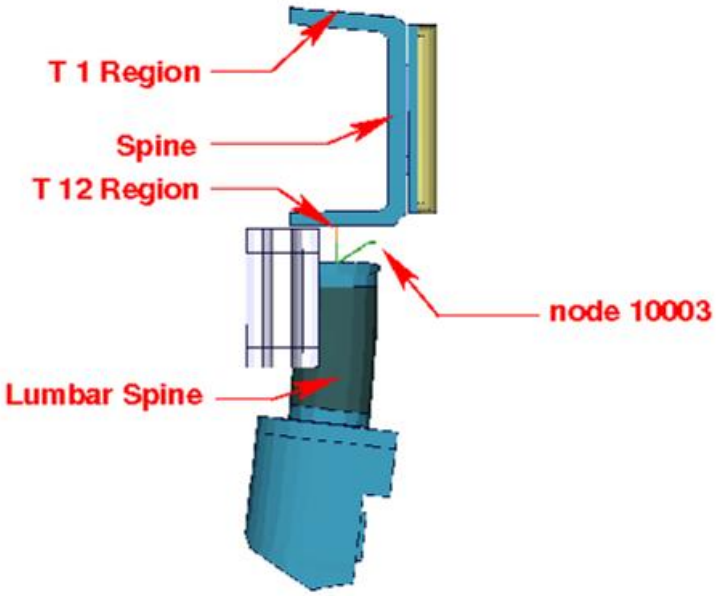


Figure 3: Node for extracting lower spine acceleration

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	10061	Acceleration upper spine	y-acceleration
Lower Spine	10003	Acceleration lower spine	y-acceleration

Table11: Spine acceleration nodes

3.4 Pelvis acceleration

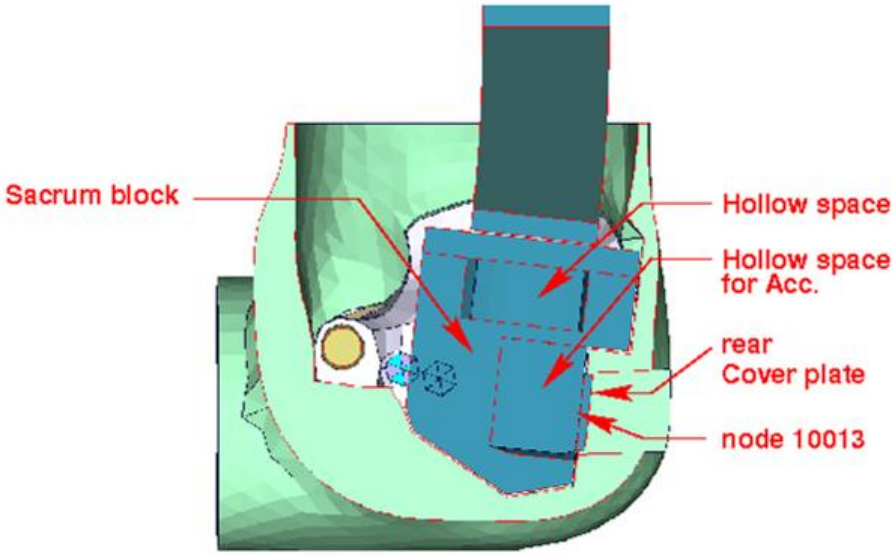


Figure 4: Node for extracting pelvis acceleration

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	accelerometer pelvis	Local y-acceleration

Table 12: Pelvis accelerometer node.

3.5 Head acceleration

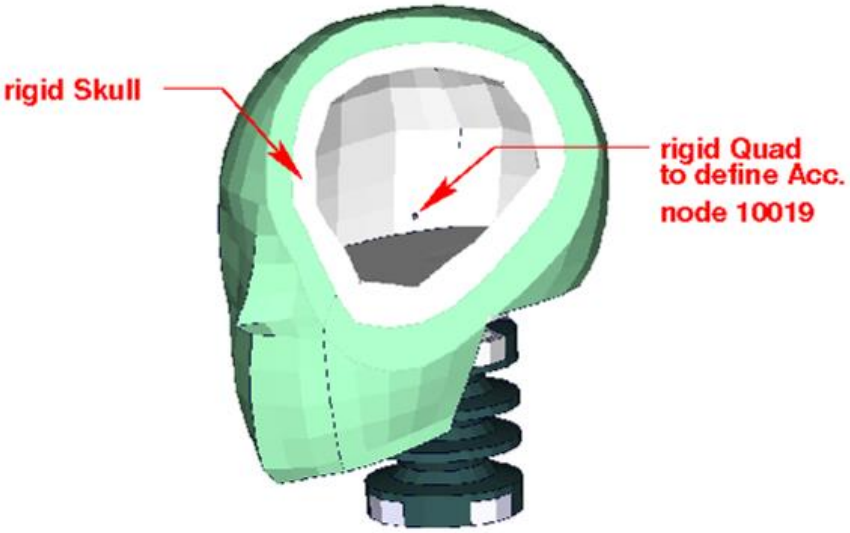


Figure 5: Node for extracting head acceleration

Figure 5 shows the head model; the aluminum skull is merged with the marked rigid quad. Node 10019 is located on the quad. An accelerometer is defined.

Item	Node-ID	Label	Available components
Head	10019	accelerometer head	local x-,y-,z- acceleration

Table 13: Head accelerometer node

3.6 Pubic Symphysis force

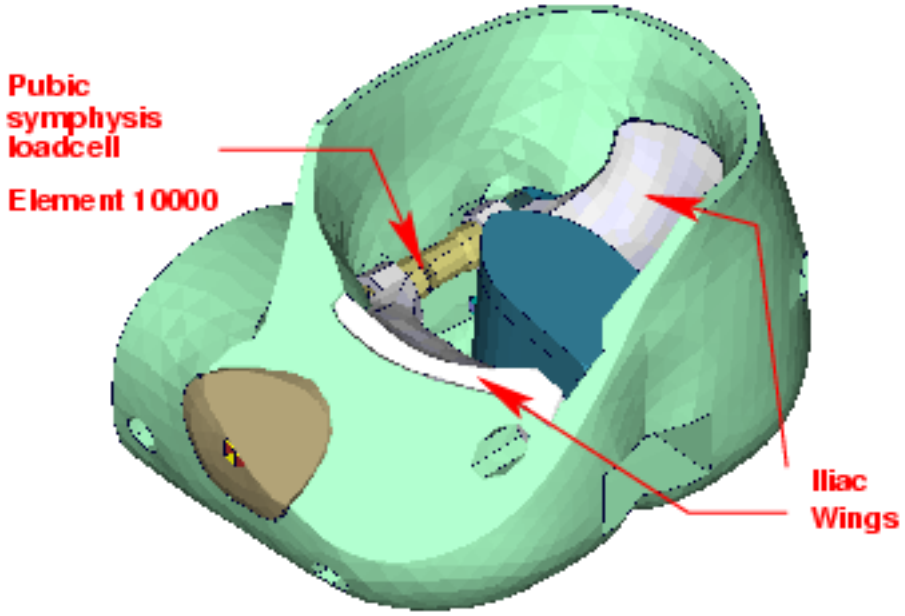


Figure 6: location for extracting signals of pubic symphysis load cell

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	Pubic symphysis load cell	Shear-S force

Table14: Pubic force beam

3.7 Shoulder force

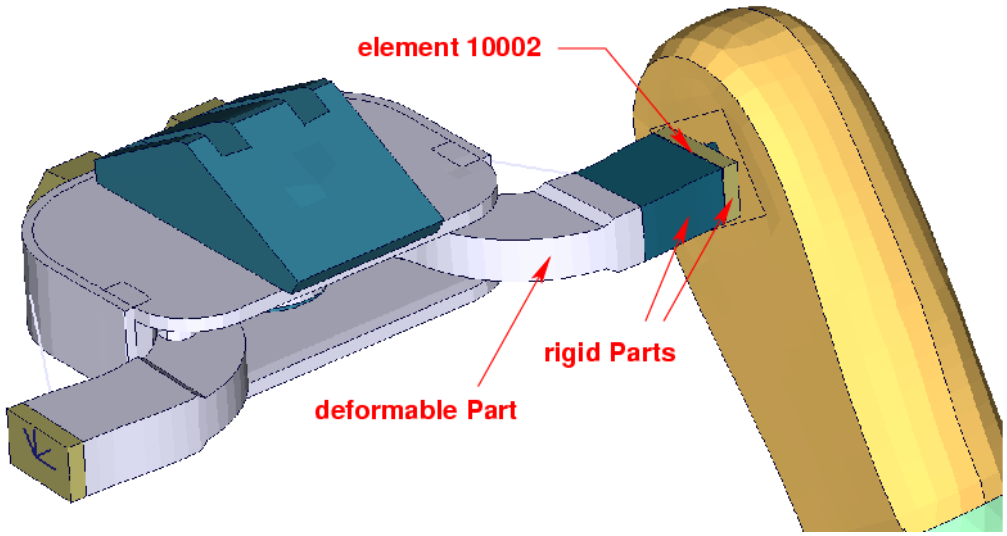


Figure 7: clavicle box with adapted clavicle to measure shoulder forces

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	Clavicle load cell	force axial shear-S

Table 15: Shoulder force beam

3.8 Back plate load cell

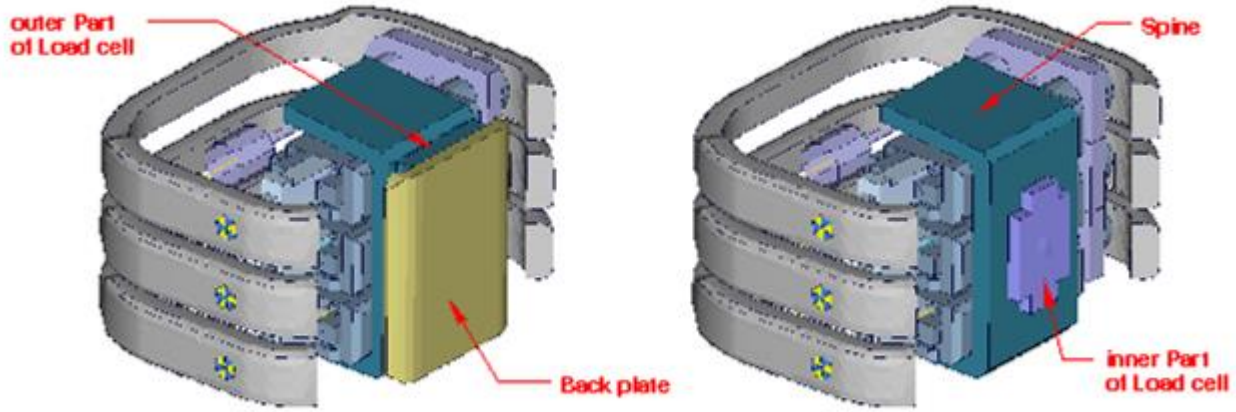


Figure 8: spine box with back plate

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.

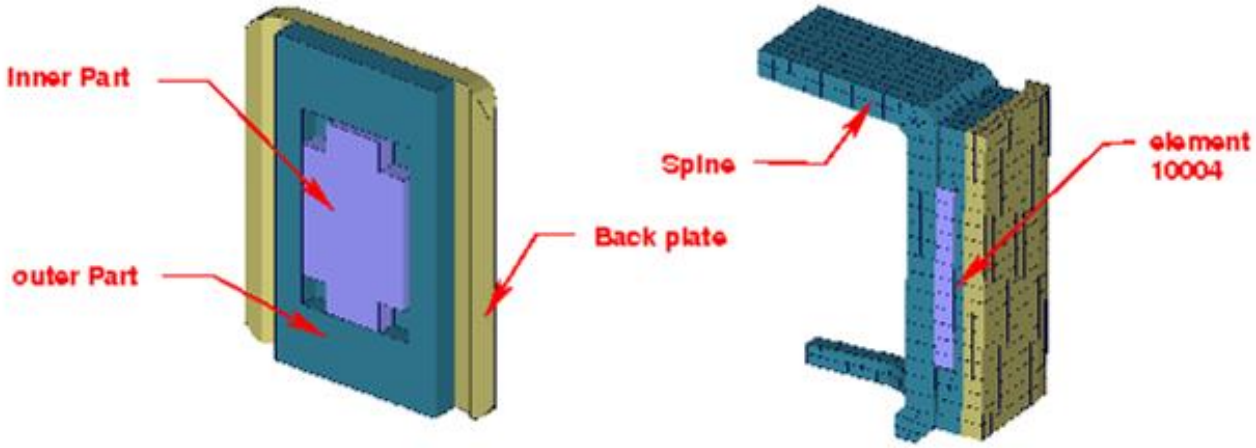


Figure 9: model of back plate load cell

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 x-direction y-direction Back plate moment About z-direction	10004 10004	Back plate load cell Back plate load cell	force axial shear-S moment moment-T

Table 16: Back plate forces and moment beam

3.9 Neck load cells

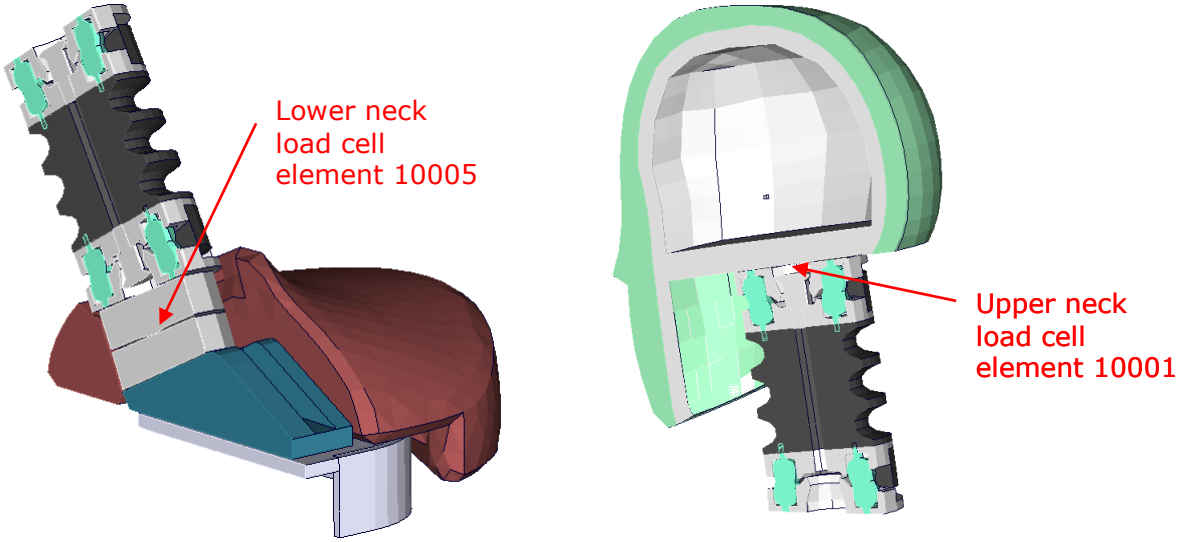


Figure 10: models of lower and upper neck load cell

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	upper neck load cell	force shear-S
Upper neck moment About x-direction	10001	upper neck load cell	moment torsion
Lower neck force y-direction	10005	lower neck load cell	force shear-S
lower neck moment About x-direction	10005	lower neck load cell	moment torsion

Table17: Neck force and moment beams

3.10 T12 load cell (lumbar spine)

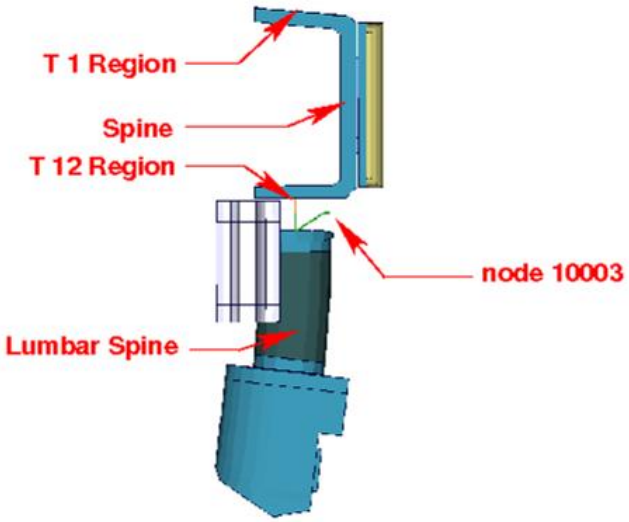


Figure 11: overview spine to sacrum with T12 load cell

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	t12 load cell	force shear-S
T12 moment About x-direction	10006	t12 load cell	torsion
T12 moment About z-direction	10006	t12 load cell	moment-t

Table18: T12 force and moment beam

3.11 Lower lumbar load cell

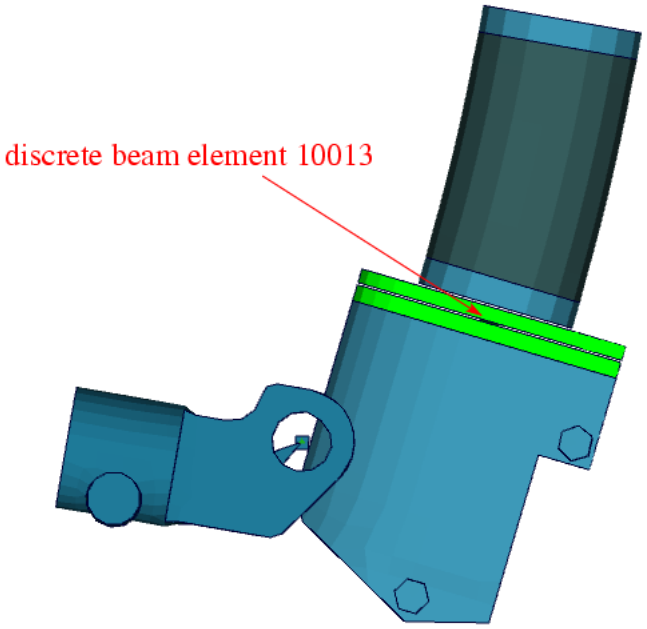


Figure 12: lower lumbar load cell

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	lower lumbar load cell	force shear-S
T12 moment About x-direction	10013	t12 load cell	torsion
Lower lumbar moment About z-direction	10013	lower lumbar load cell	moment-t

Table19: Lower lumbar force and moment beam

3.12 Abdominal forces

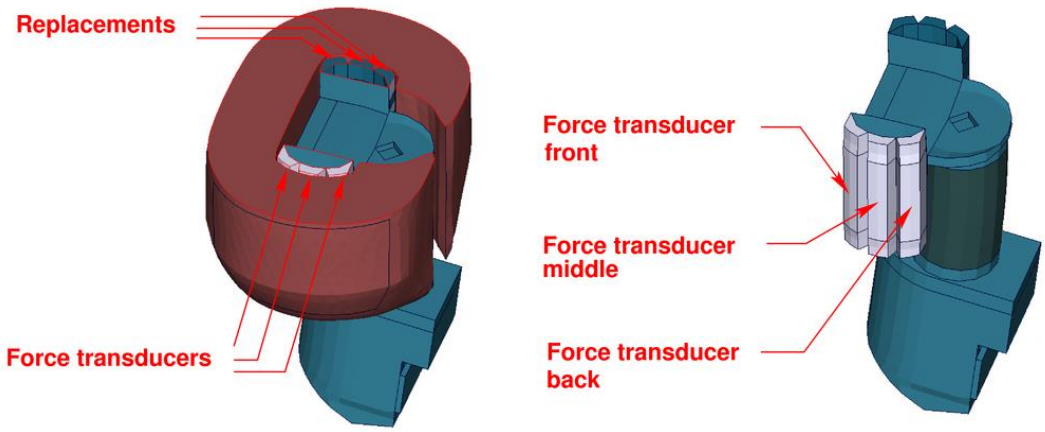


Figure 13: models of abdominal force transducers and replacements

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

As a new feature from the ES-2 version 5.0 there are discrete beam element for the evaluation of the abdominal forces available. Thus, it is possible to model an uni-axial load cell. This method is recommended to evaluate abdomen force.

Item	Beam-ID	Label	Component
Abdominal force front	10014	abdomen load cell front	shear-S
Abdominal force middle	10015	abdomen load cell middle	shear-S
Abdominal force back	10016	abdomen load cell back	shear-S

Table21: Abdomen forces beams

3.13 Femur load cells

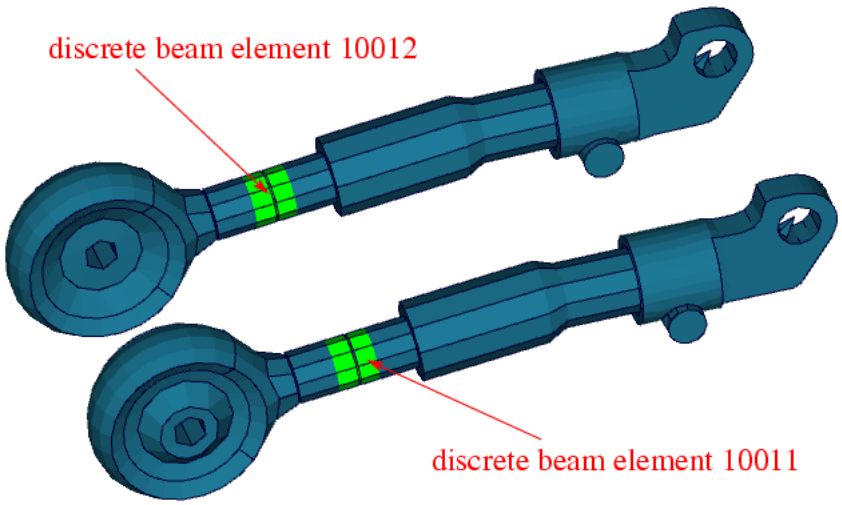


Figure 14: femur load cells

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	femur load cell leg left	force shear-S
Femur moment left about x-direction	10011	femur load cell leg left	moment torsion
Femur force right y-direction	10012	femur load cell leg right	force shear-S
Femur moment right about x-direction	10012	femur load cell leg right	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.

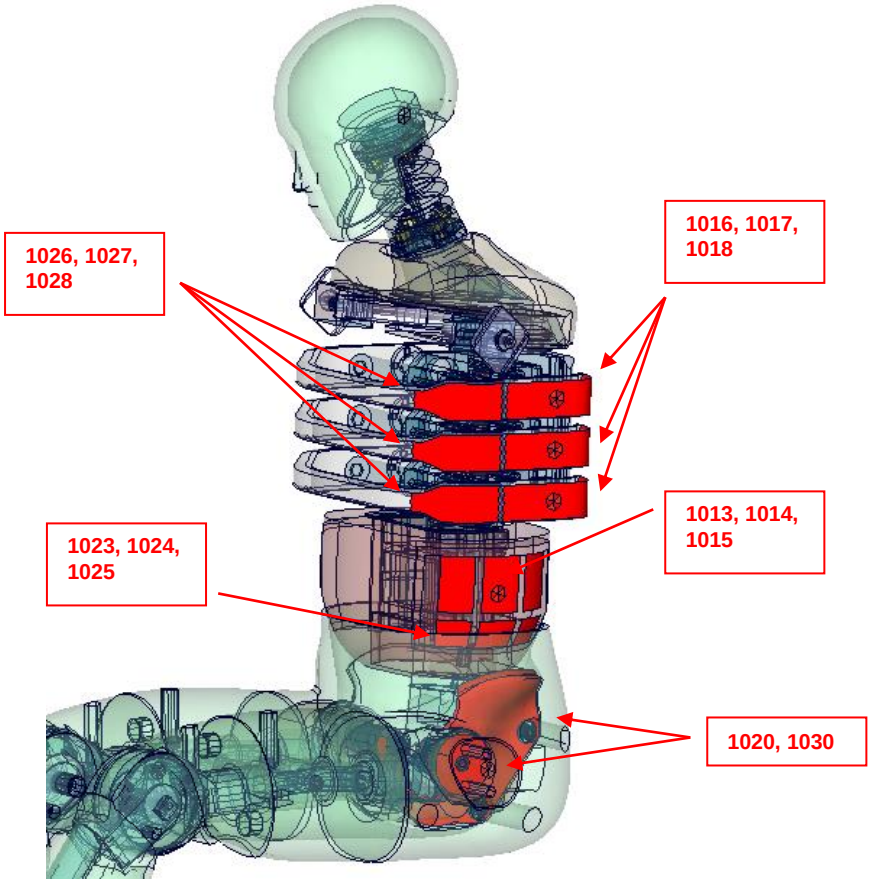


Figure 15: force transducer contacts

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

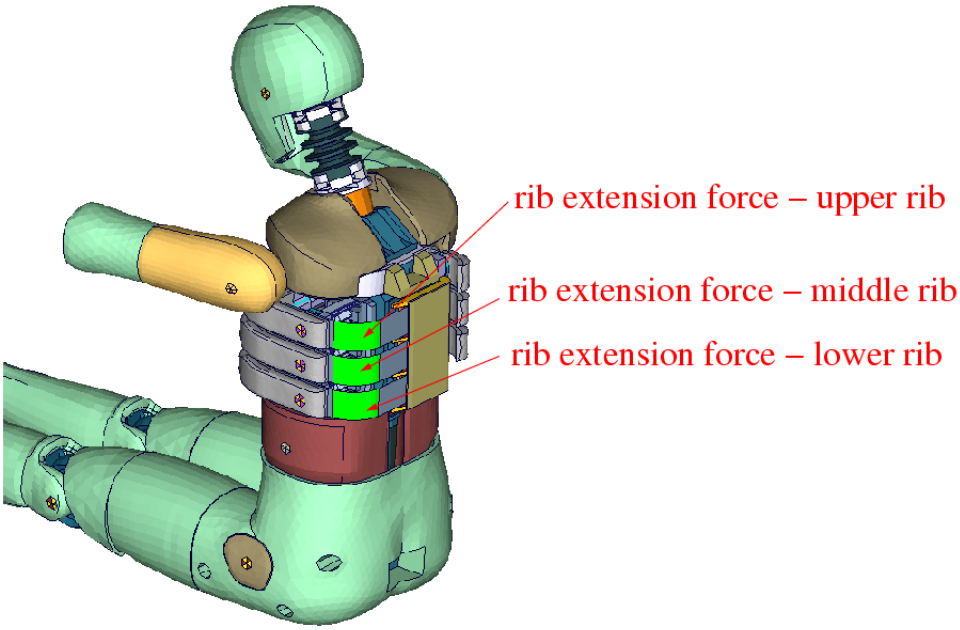


Figure 16: force transducer contacts of rib extension

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

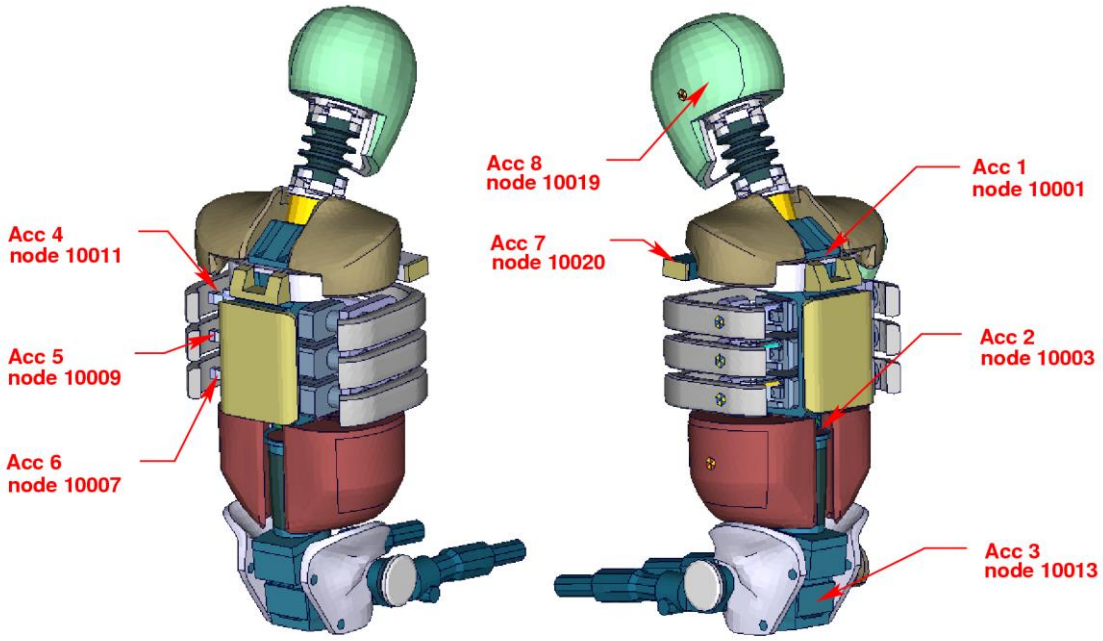


Figure 17: location of the accelerometers

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	acceleration upper spine
Lower spine	2	10003	acceleration lower spine
Pelvis	3	10013	acceleration pelvis
Upper rib	4	10011	acceleration upper rib
Middle rib	5	10009	acceleration middle rib
Lower rib	6	10007	acceleration lower rib
Left arm joint	7	10020	acceleration clavicle
Head	8	10019	acceleration head

Table25: ES-2 accelerometers

5. Local Coordinate Systems

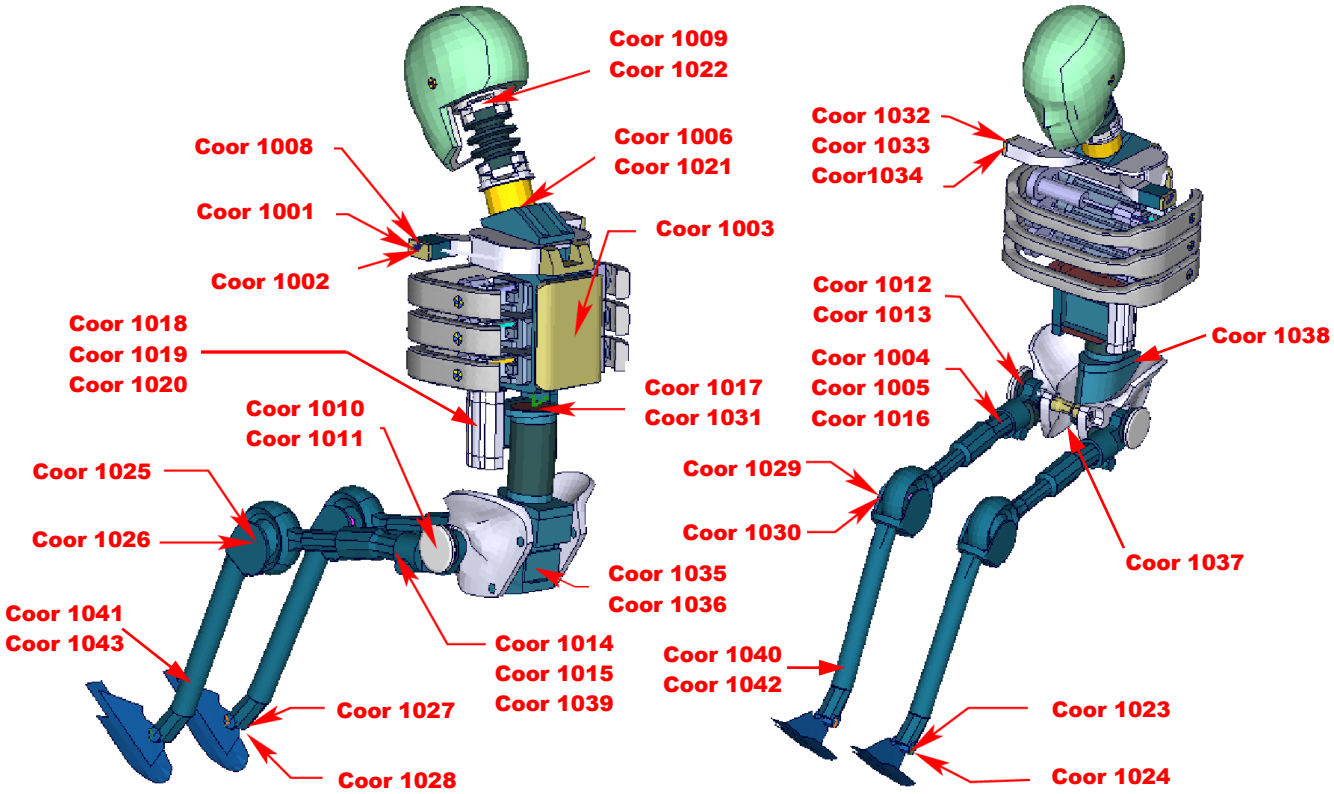


Figure 18: ES-2 skeleton with local coordinate systems

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_v7.0_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

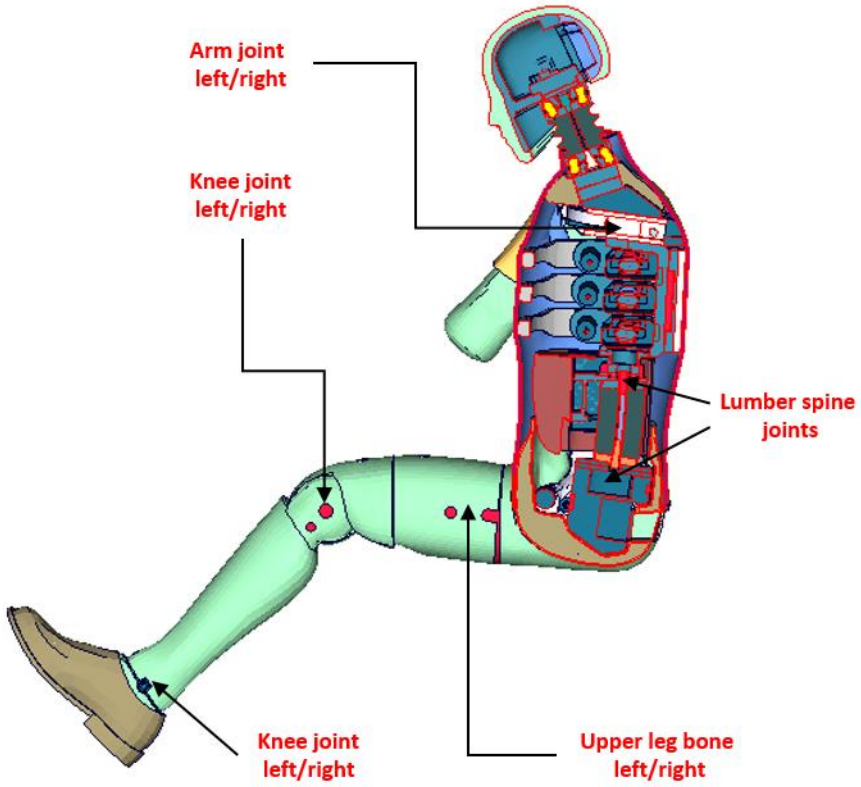


Figure 19: cut through the model with joints

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: -52 and 52 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)

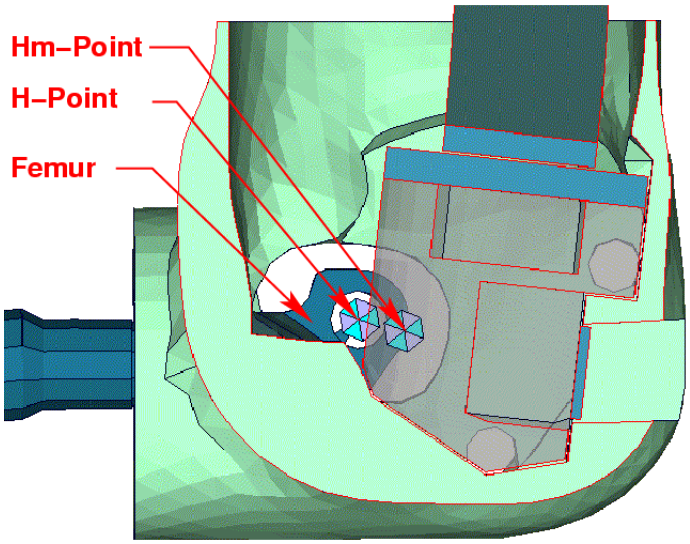


Figure 20: location of H- and Hm-point

Figure 20 shows the location of H- and Hm-Point. More details are give 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

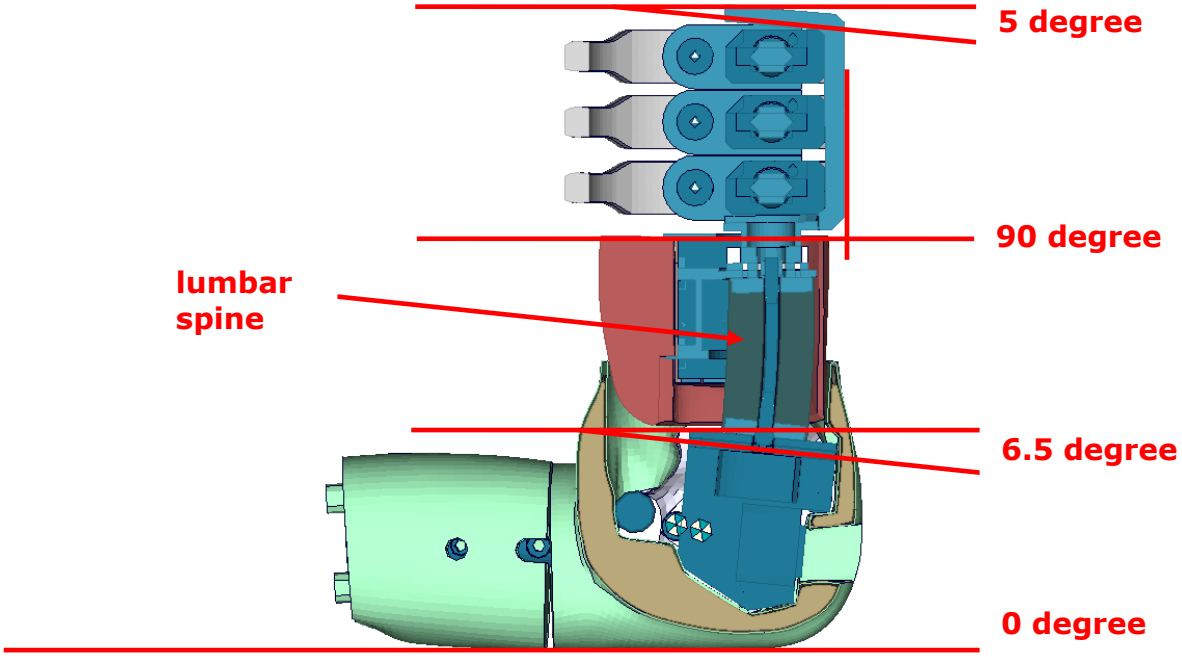


Figure 21: angles of important edges of the ES-2 dummy

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 179	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:

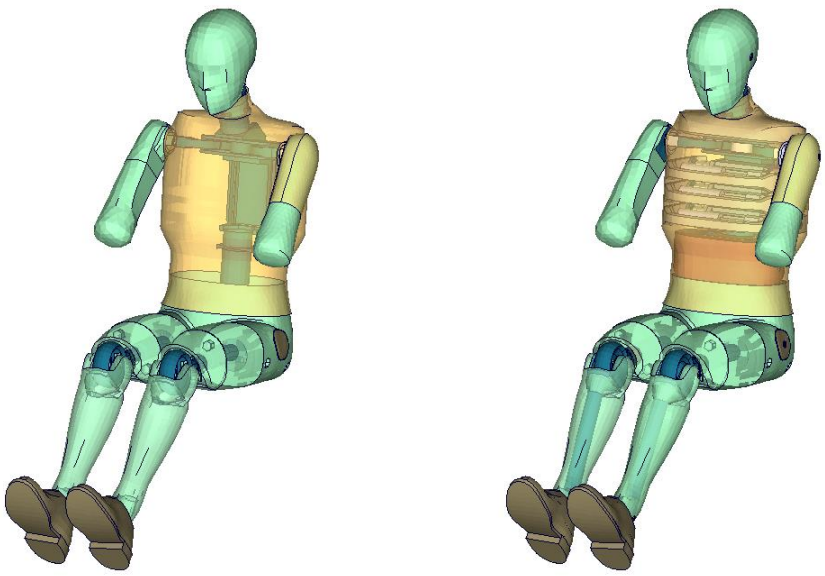


Figure 22: parts used in contact definition

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_v7.0_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 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

- The model should be used with a time step size of 1 microsecond 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.
- No mass less nodes are in the input files of the dummy
- The model is free of initial penetrations.
- The model is validated under physical aspects and in use of all offered validation tests. All over many load cases are now validated, but it can occur that some loading conditions on the dummy are not captured under all these test. So user is still responsible to check loading conditions and compare to validation levels in validation tests of section performance in this manual.

8. Release notes from v6.0 to v7.0

The following major modifications are made:

8.1 Geometric modifications

- New solid jacket covered by null shells inner and fabric material shells outer
- New finer mesh for shoulder foam to prevent errors in shoulder foam

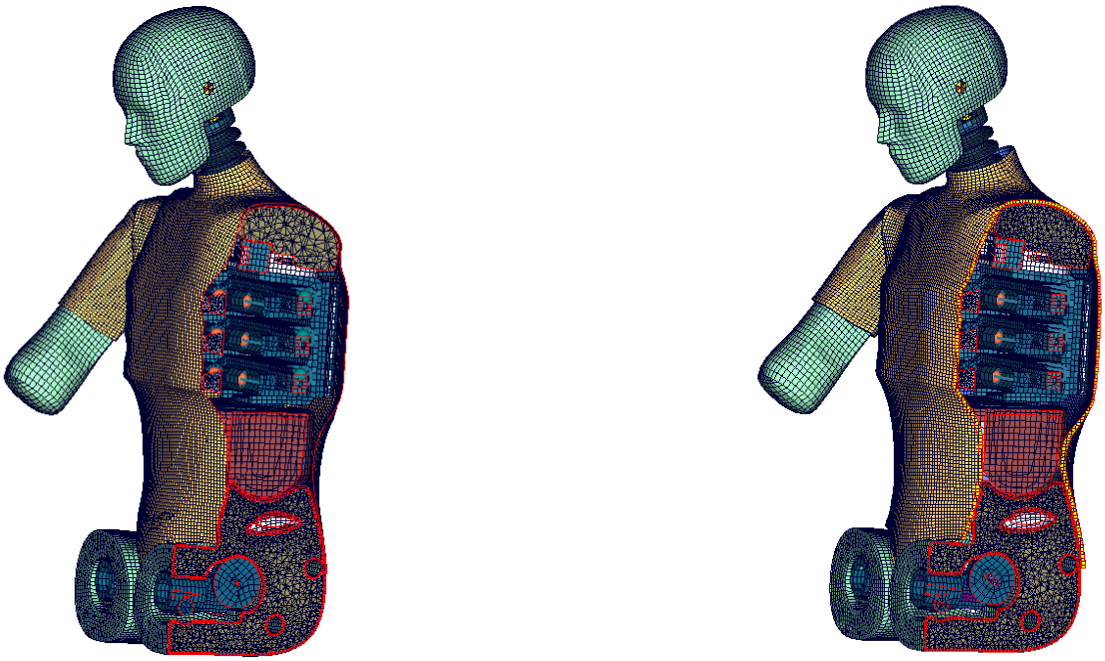


Figure 23: Cut through Dummy torso ES-2 v6.0 (left) and v7.0 (right)

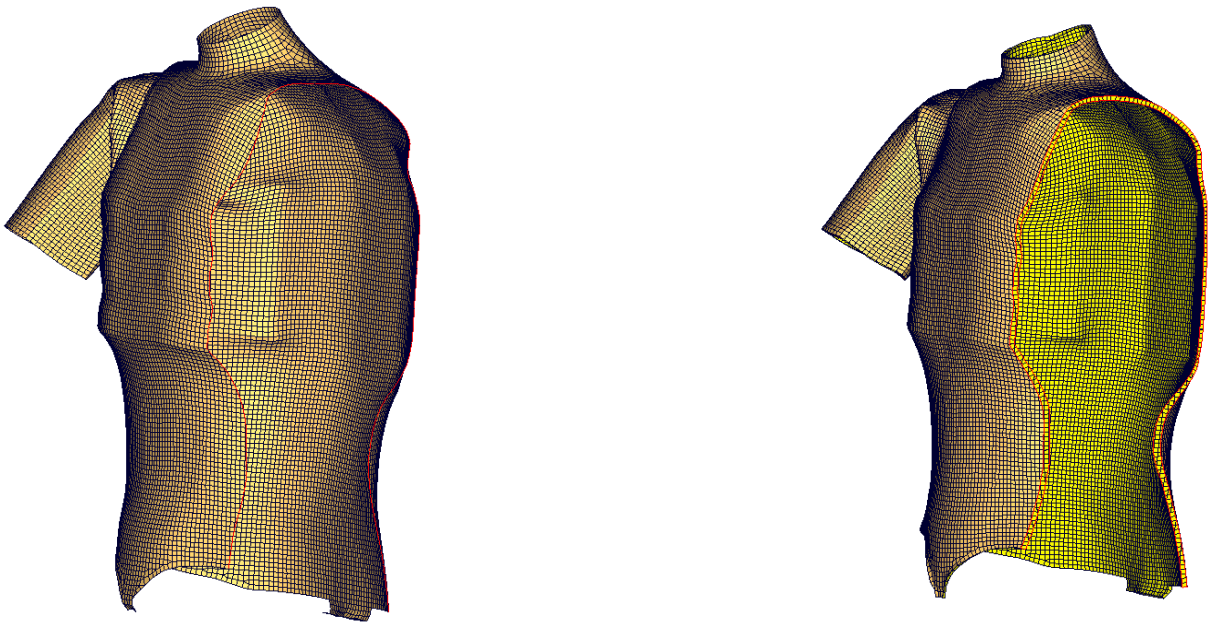


Figure 24: ES-2 v6.0 (left) and v7.0 (right) cut through jacket

8.2 Non-geometric dummy model modifications

- Dummy self contact formulation: groupable option is activated
- Lumbar spine and torso assemblies with fake joints are defined to get possibilities for positioning dummy close to test.
- adjustments to arm and clavicle validation
- New script for the dummy positioning via pre-simulation procedure

8.3 Additional remarks

- Validation and calibration test models were improved

9. Description of the R.A.M. variant of the model

The R.A.M. model variant is build for use in DOE studies of Optimizations in smaller models like sled tests of segment runs. The R.A.M. runs much faster than the high validated model from the Manual.
The idea is to have exactly the same model for geometry, but the expensive materials, which are very accurate, are replaced by simpler material models. Due to this, the ES-2 v7.0 R.A.M. model is about 50% faster than the accurate model in the sled tests.

In the following parts of the model the material cards are changed for the R.A.M. model as shown in figure 25. Additionally to them, the material of the solid jacket is changed, it is *MAT_BLATZKO_RUBBER.

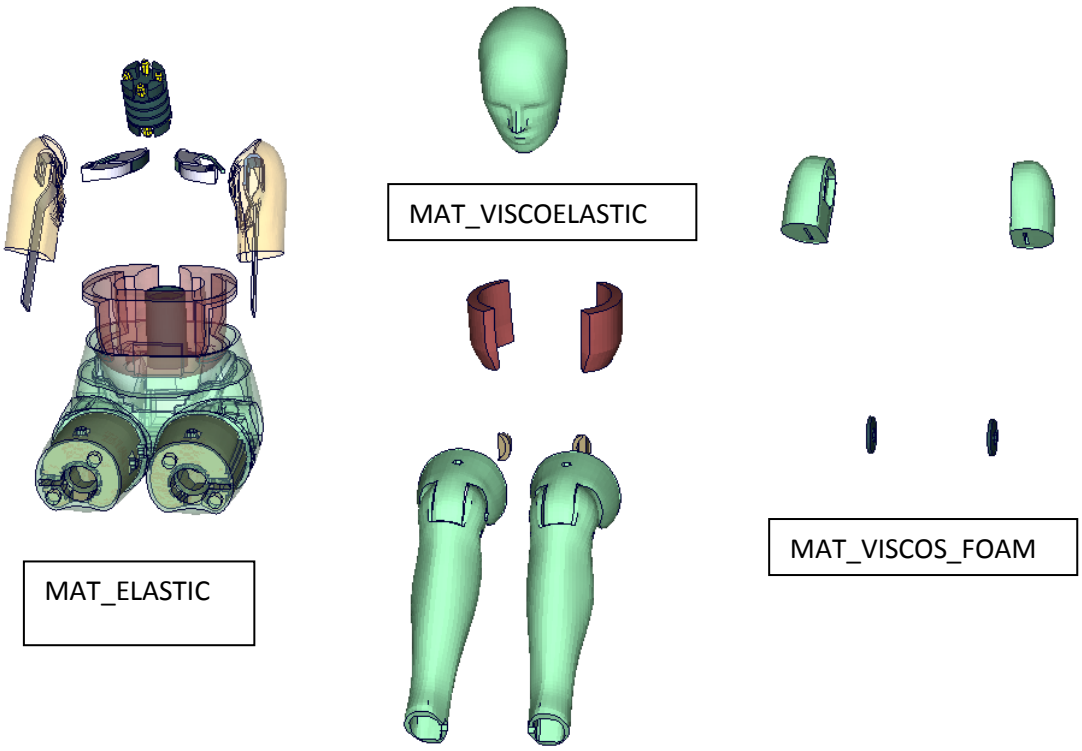


Figure 25: ES-2 v7.0 R.A.M. parts where the material is replaced

These are the main differences in the model. Nearly all other definitions are unchanged and exactly the same as in the high validated model. For some Parts the Hourglass control is switched to an other type.

The R.A.M. is only delivered on request from DYNAmore.

10. Limitations and further work

Chapter 10 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 v7.0 and older. In addition to that ongoing enhancements of the barrier test performance will be done.

11. Performance on component level

11.1 Component Tests

11.1.1 Arm Test

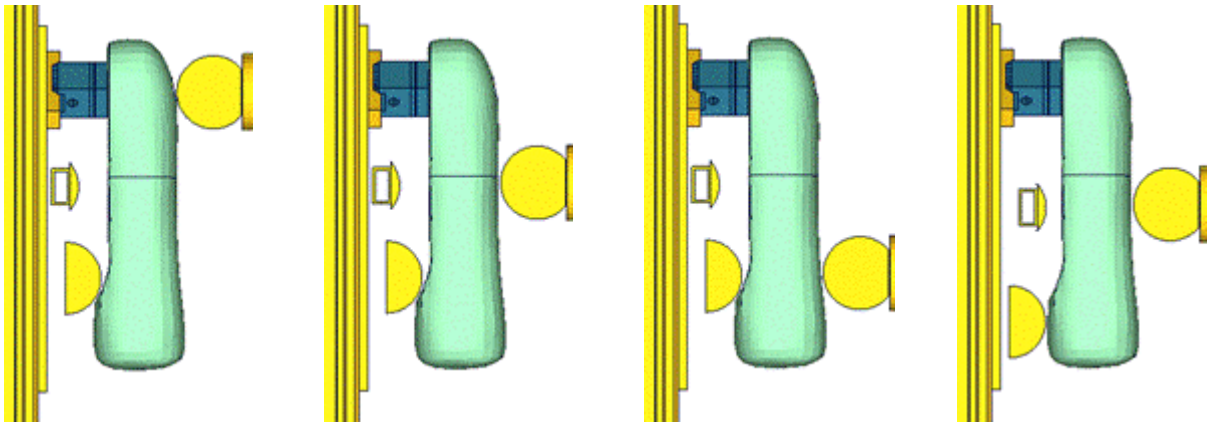
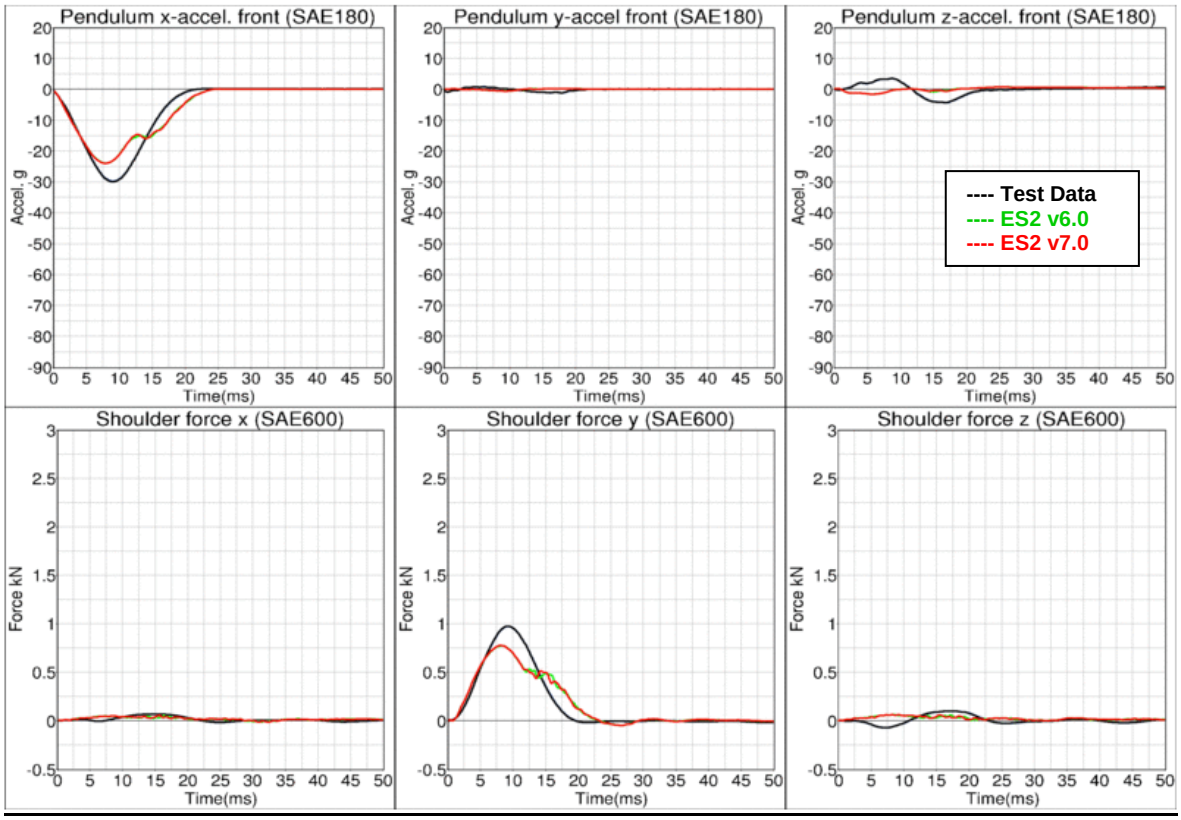


Figure 26: Test setups for Arm test

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 3 different positions with 2 different velocities each. An additional modified configuration is used wherein the arm is impacted at the mid-position with 2 velocities.

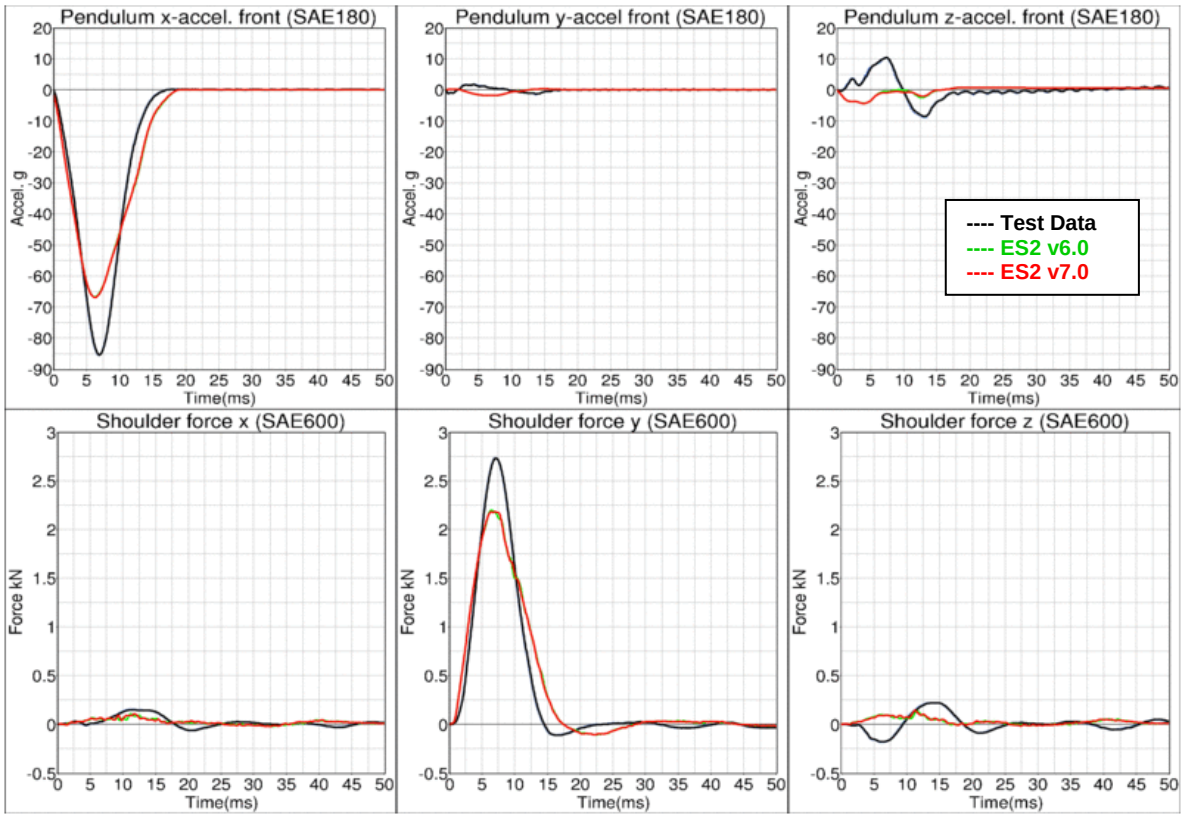
Results for top impact , low velocity

Z1V1

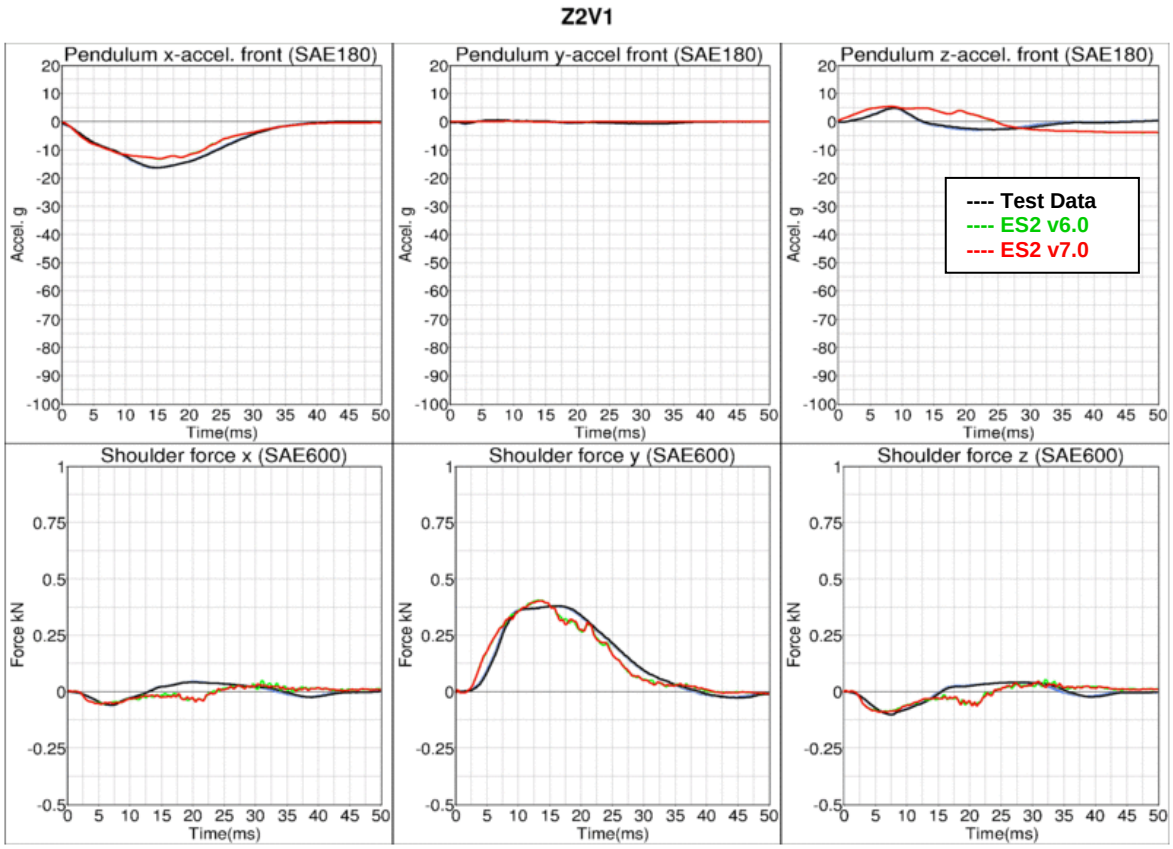


Results for top impact , high velocity

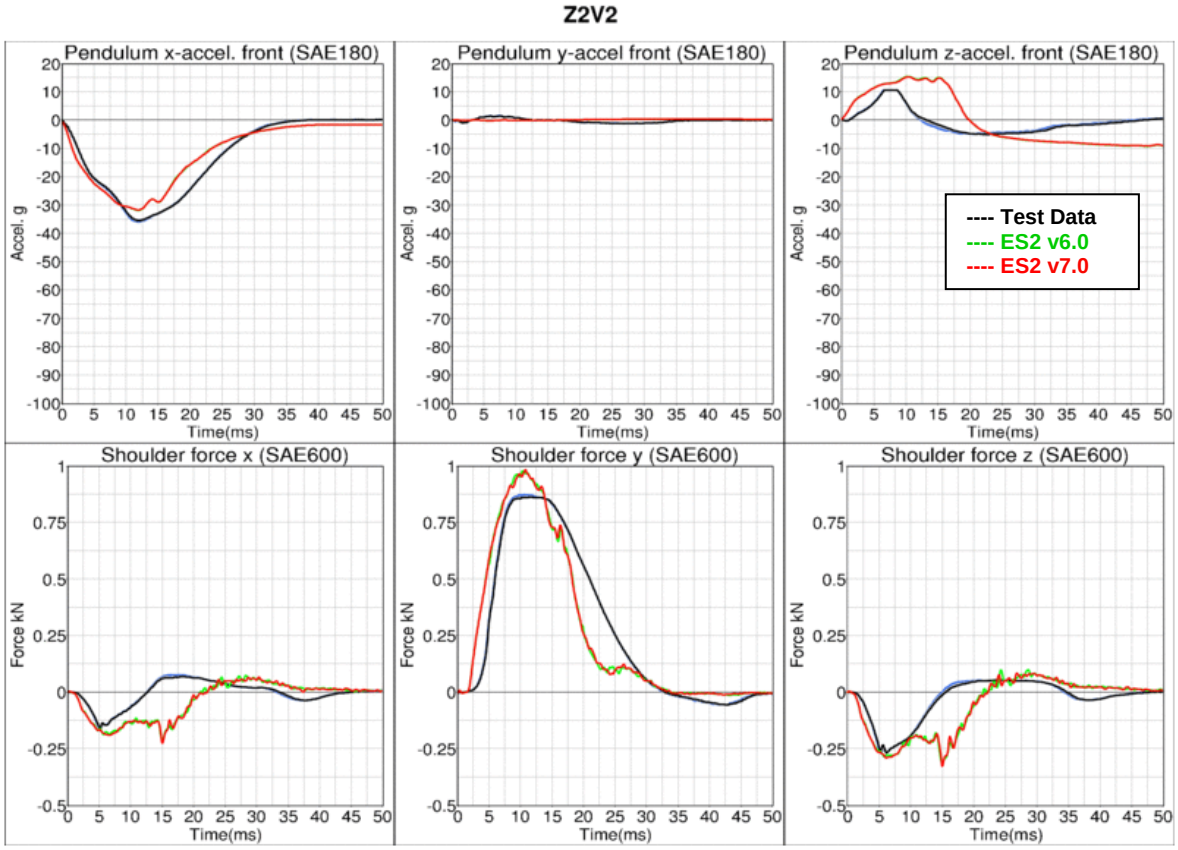
Z1V2



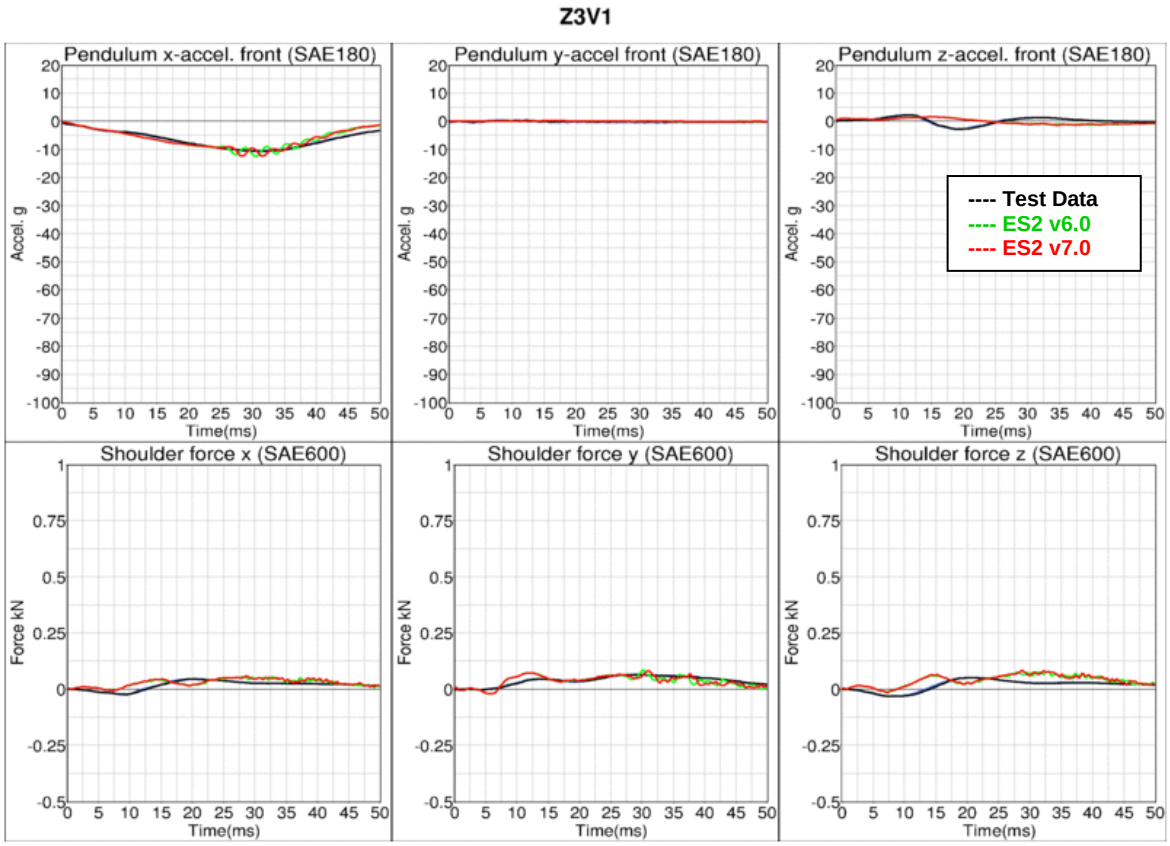
Results for mid-position impact , low velocity



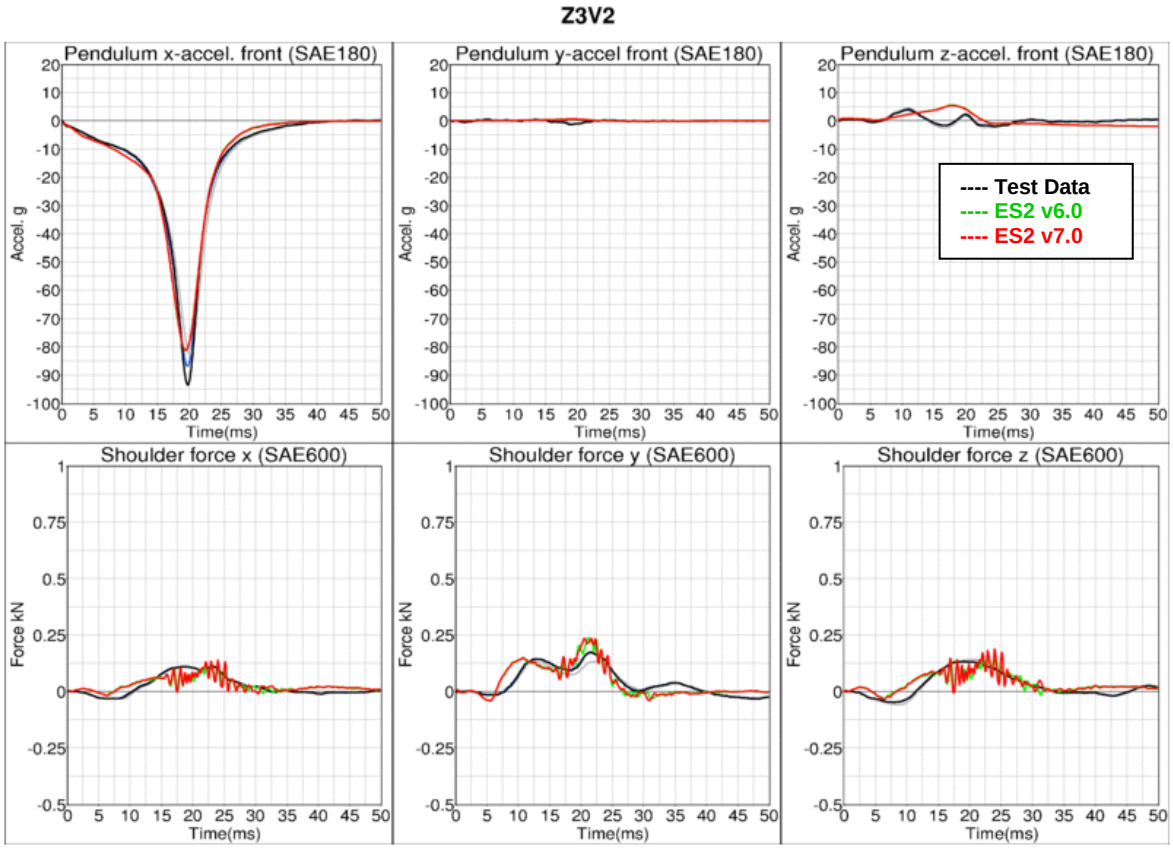
Results for mid-position impact , high velocity



Results for bottom impact , low velocity

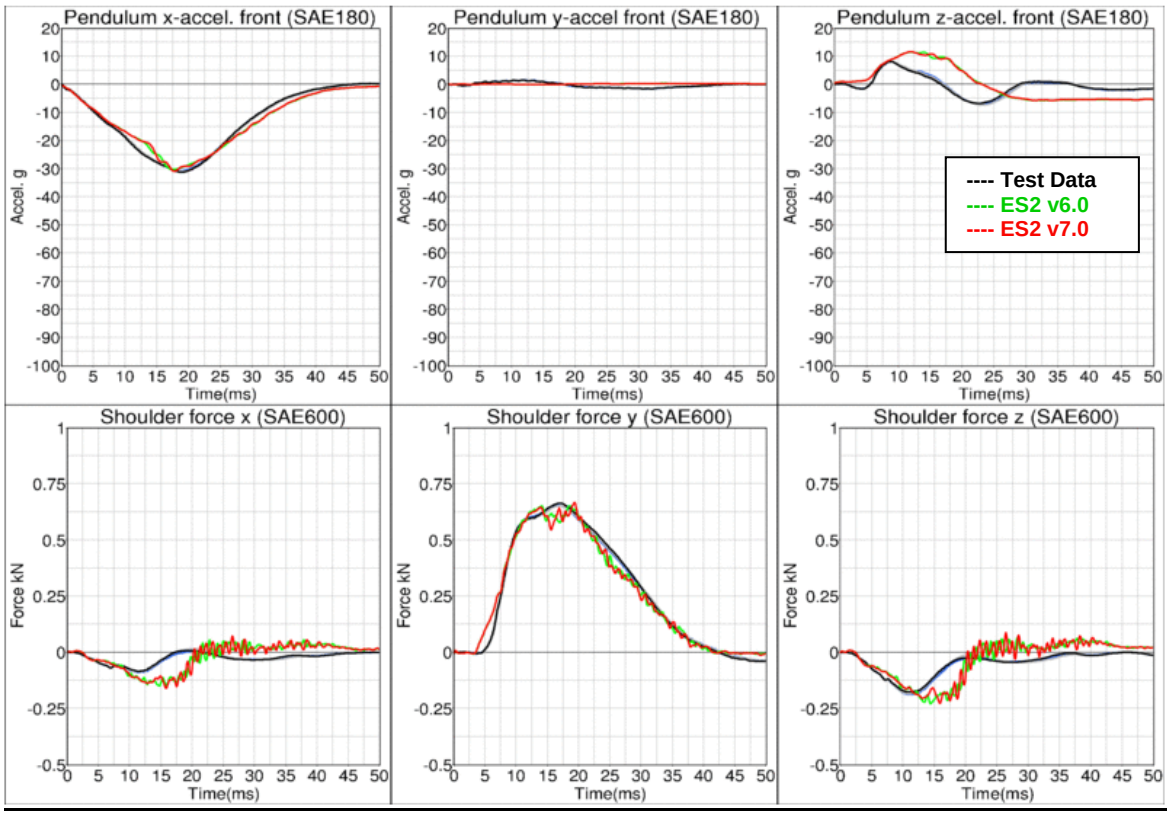


Results for bottom impact , high velocity



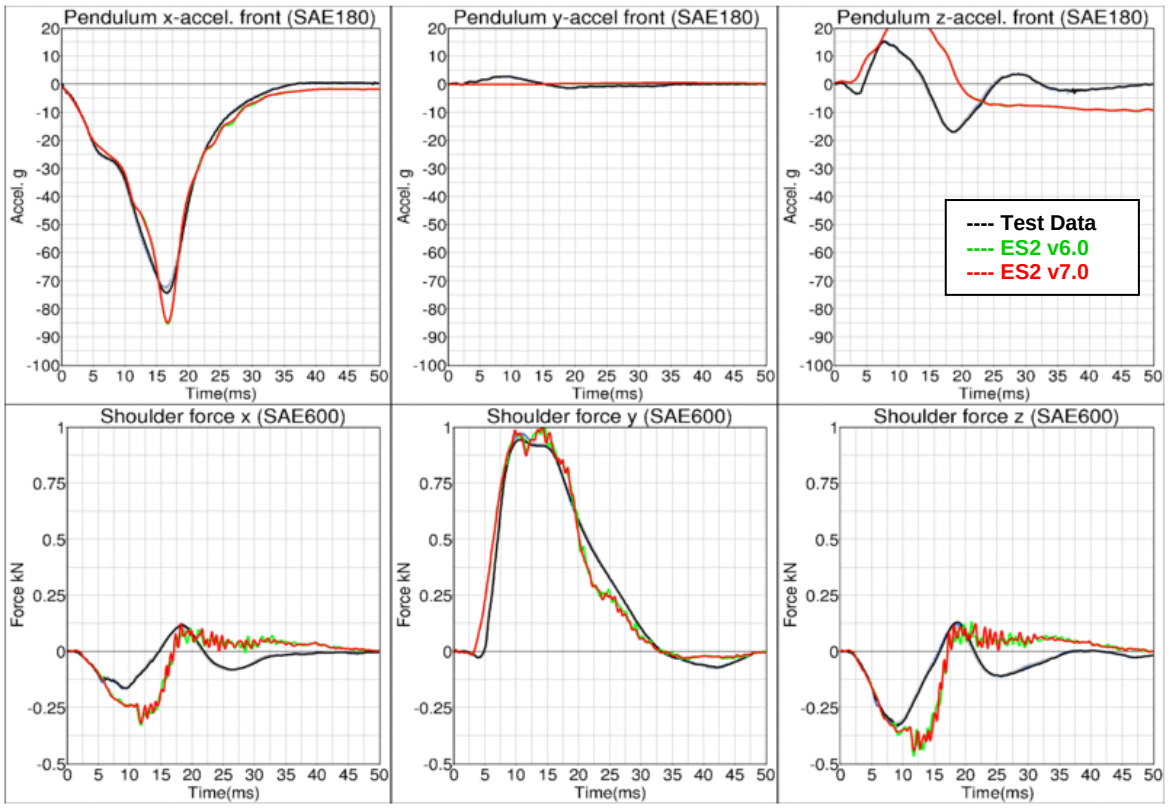
Results for mid-position impact , low velocity (Add. configuration)

Z2V2E



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

Z2V3E



11.1.2 Clavicle test

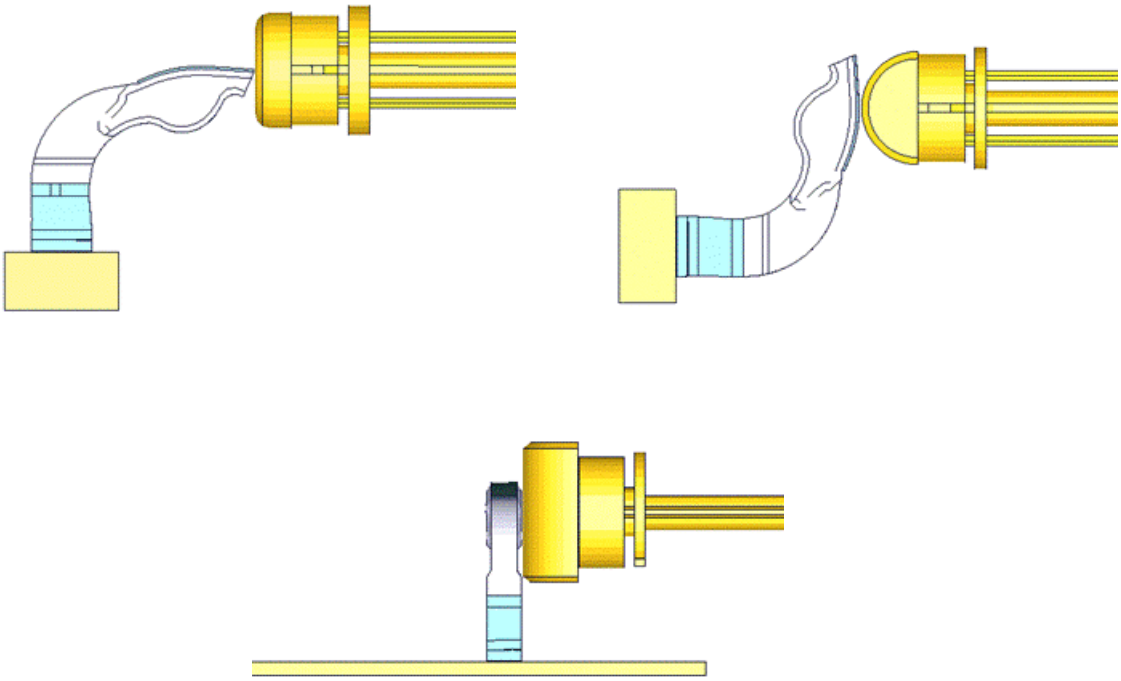
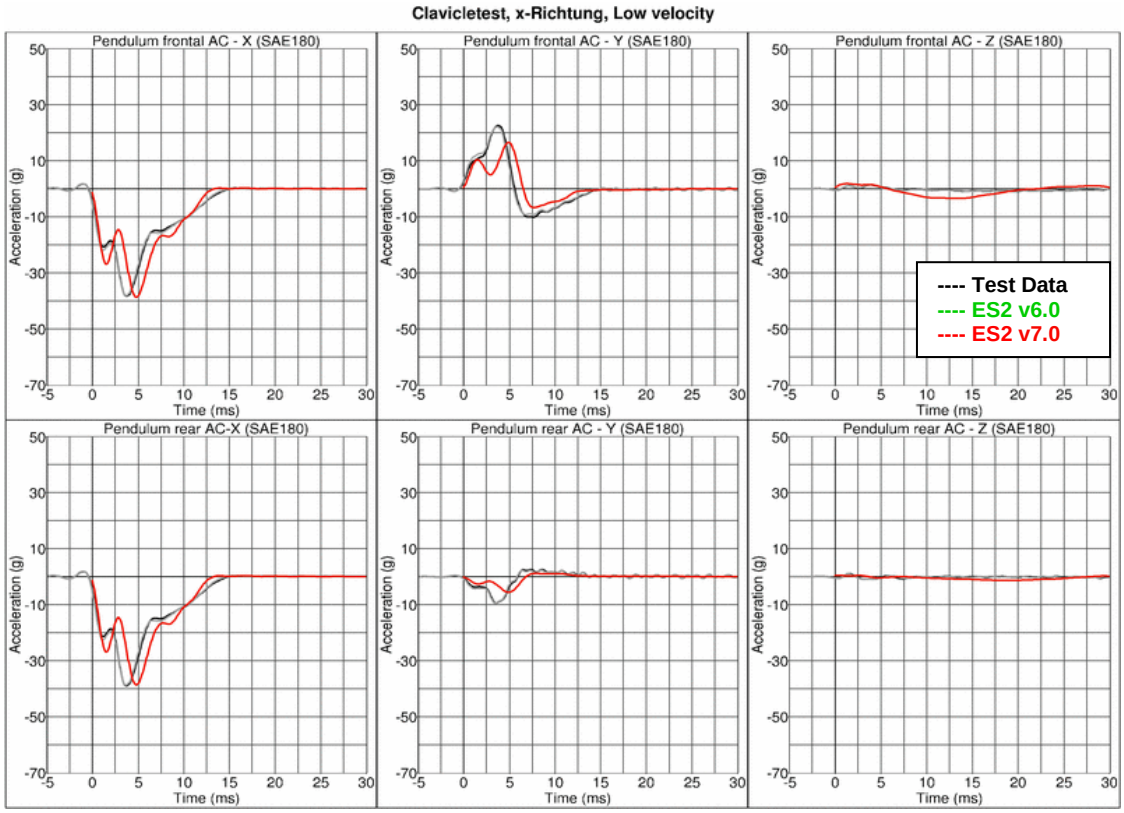
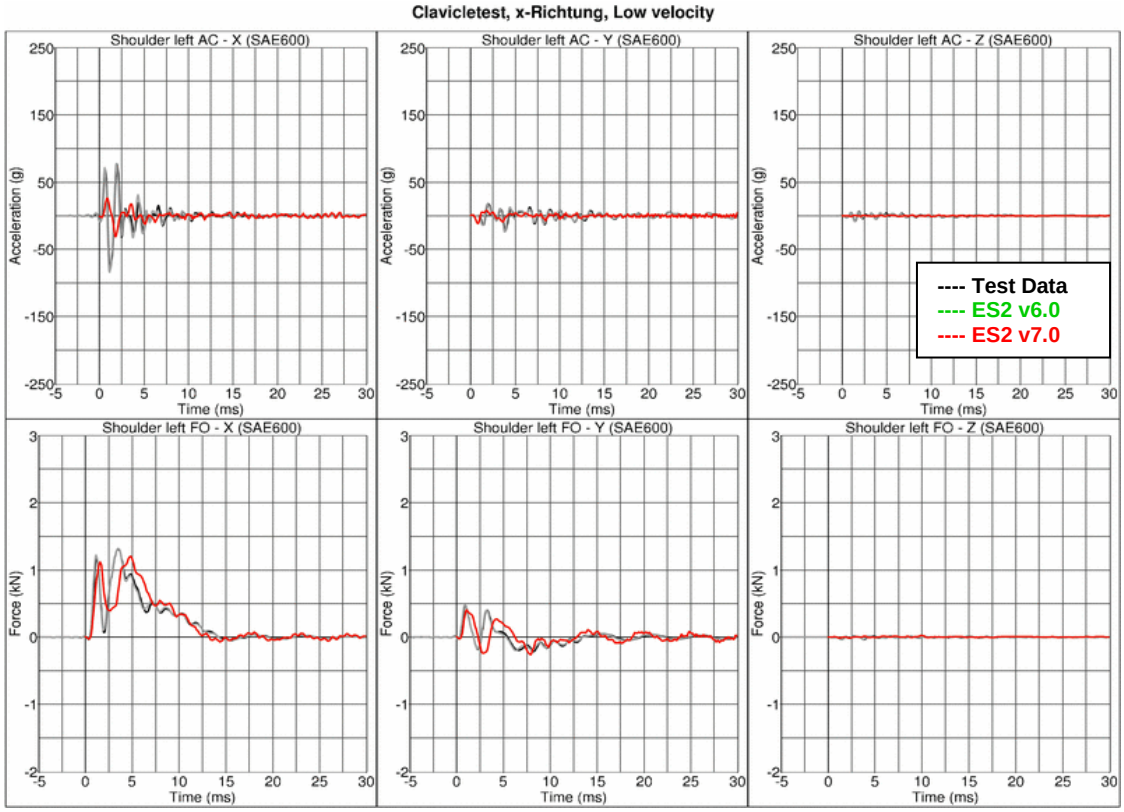


Figure 27: Clavicle test: Pendulum impact on Clavicle in x- , y- and z-direction respectively

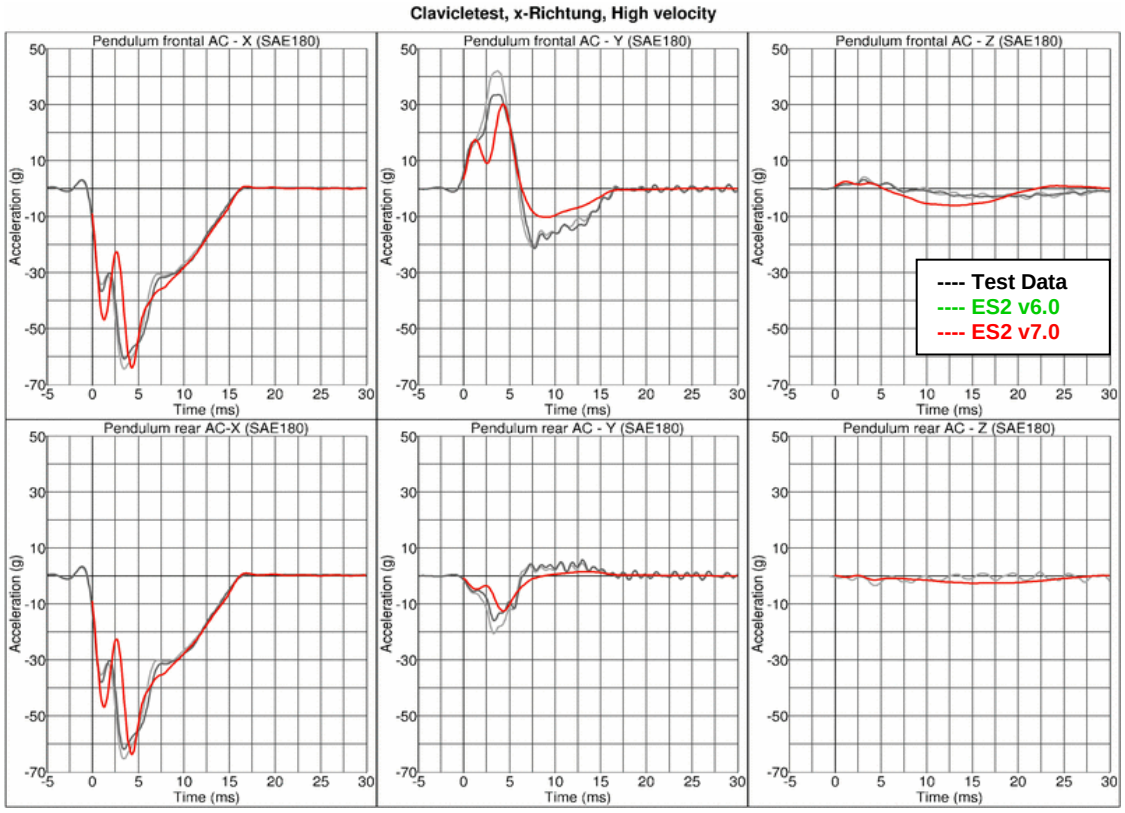
In the clavicle test, the clavicle is impacted by a pendulum in 3 different directions with 2 velocities each. The test setup for the 3 different directions of impact are shown in the figure above.

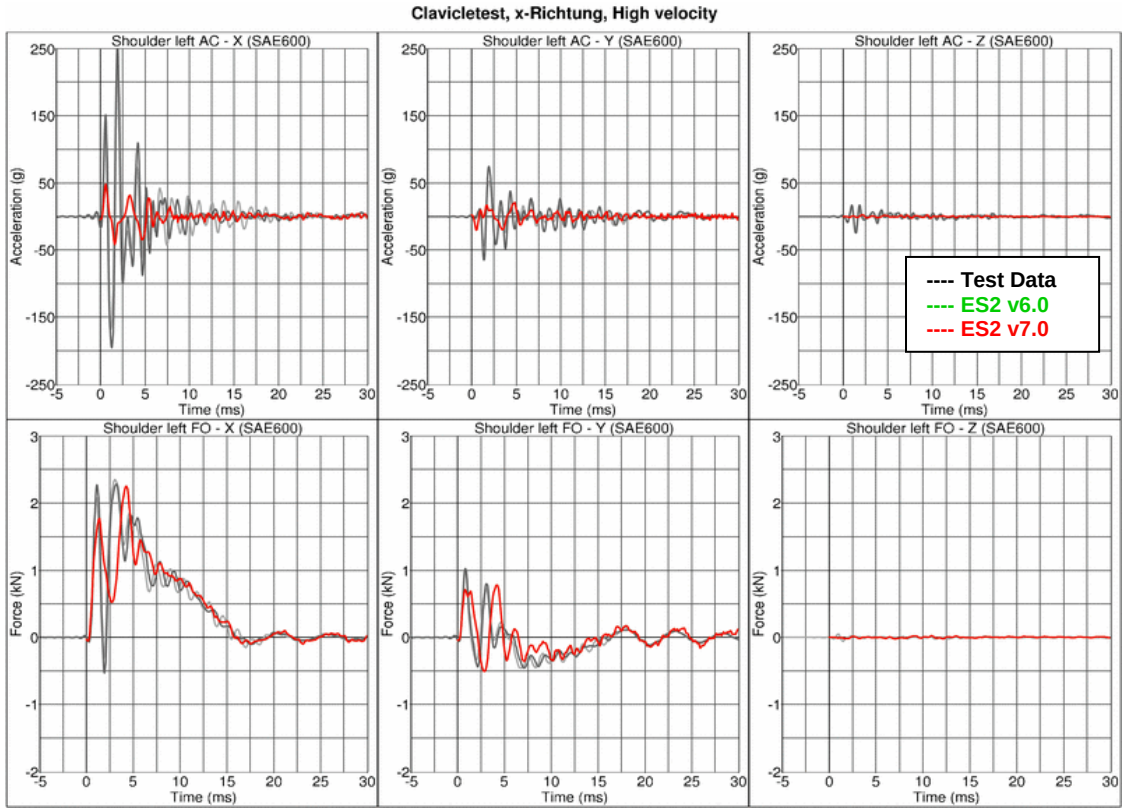
Results for X-direction impact , low velocity



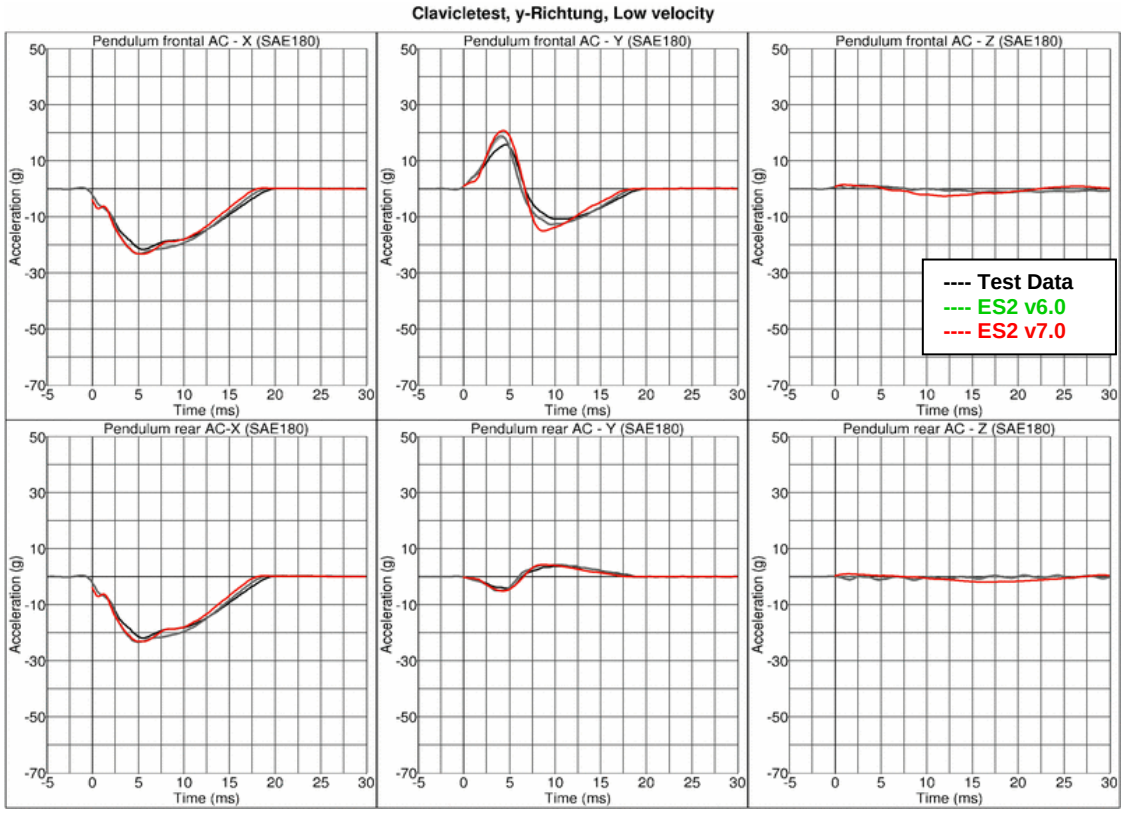


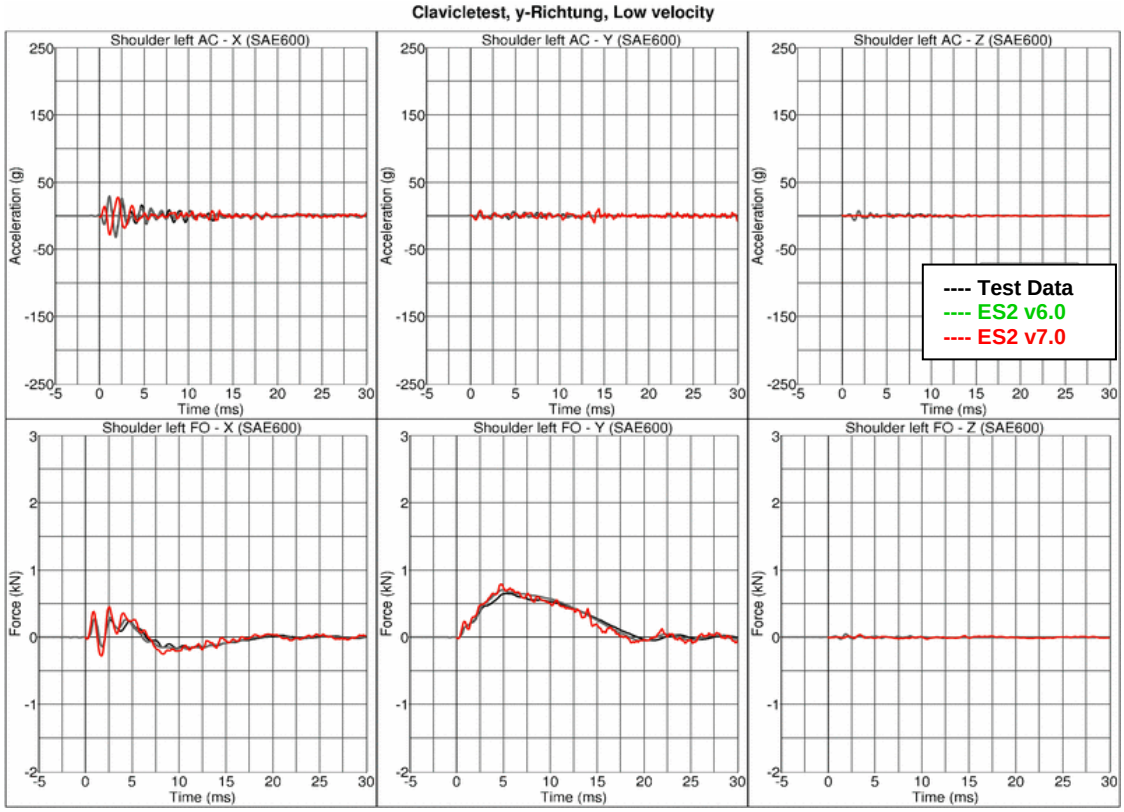
Results for X-direction impact , high velocity



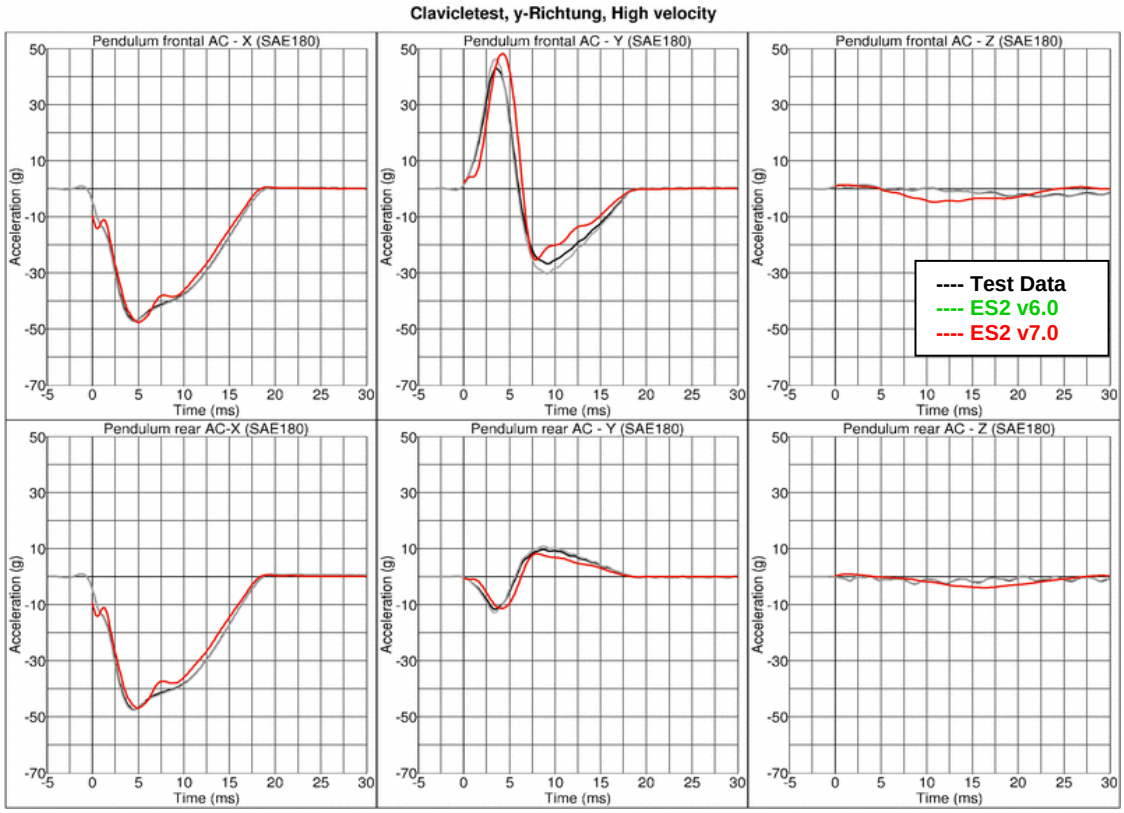


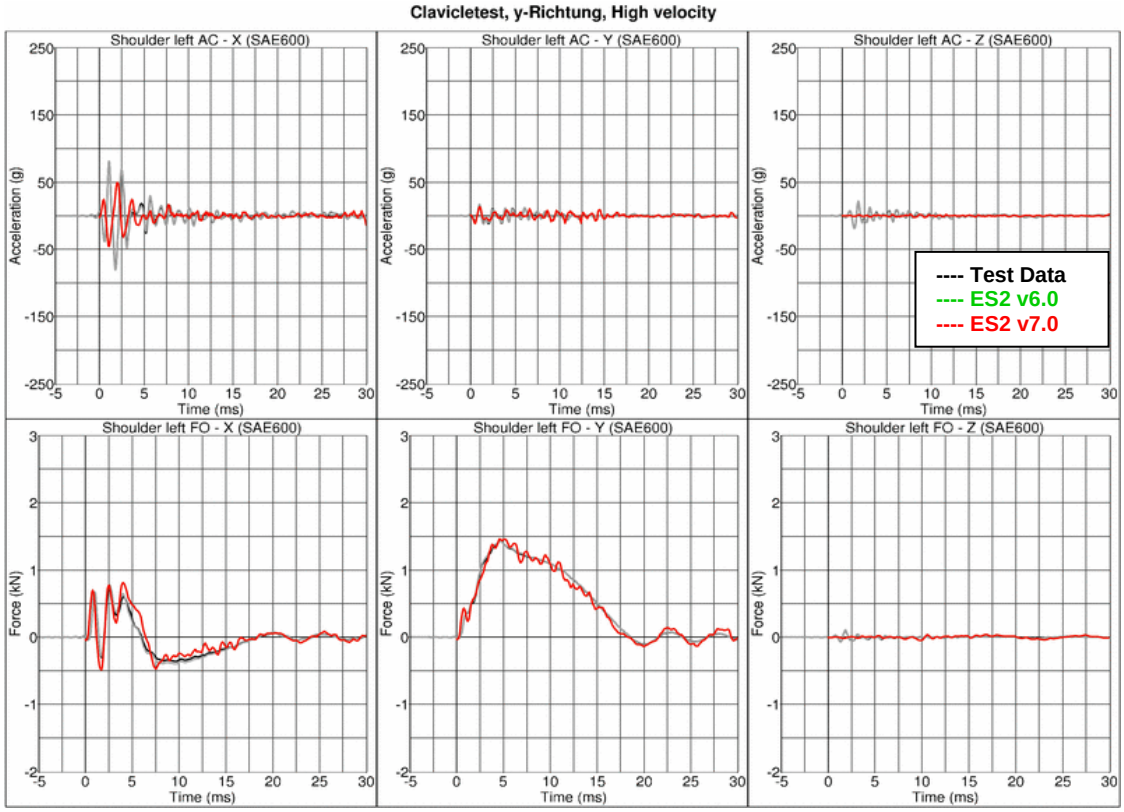
Results for Y-direction impact , low velocity



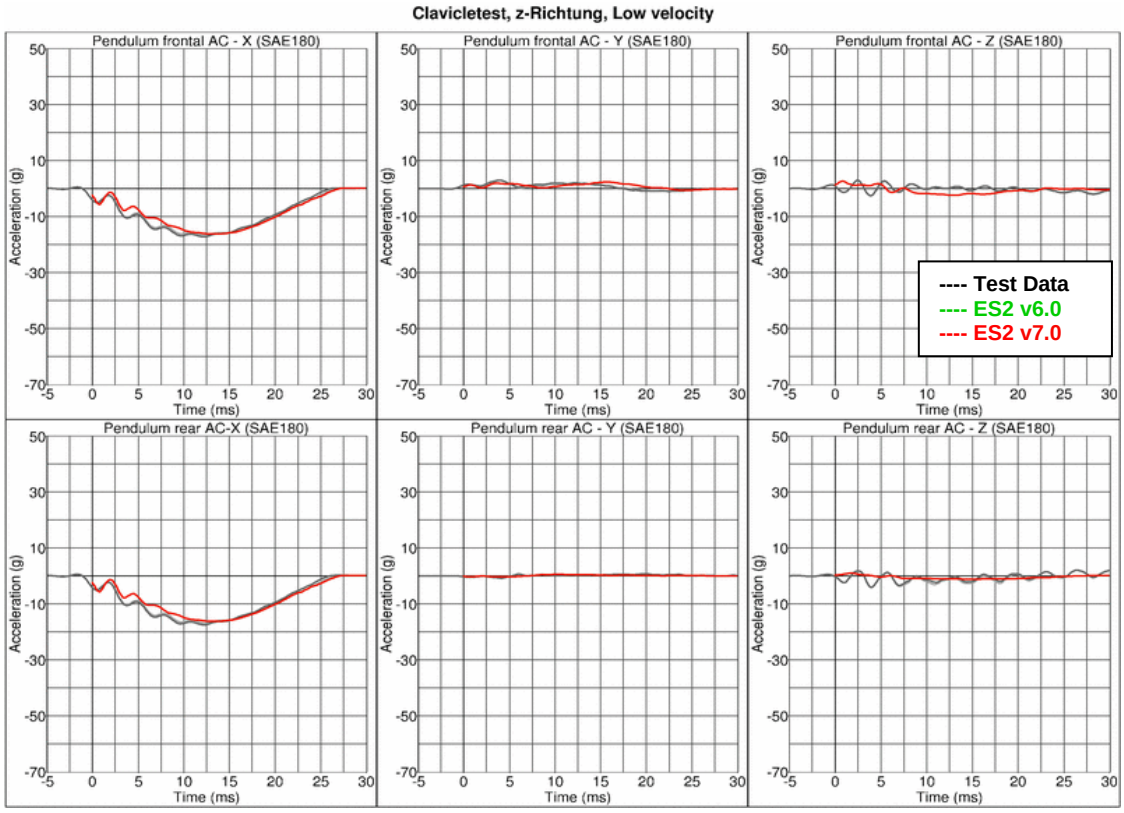


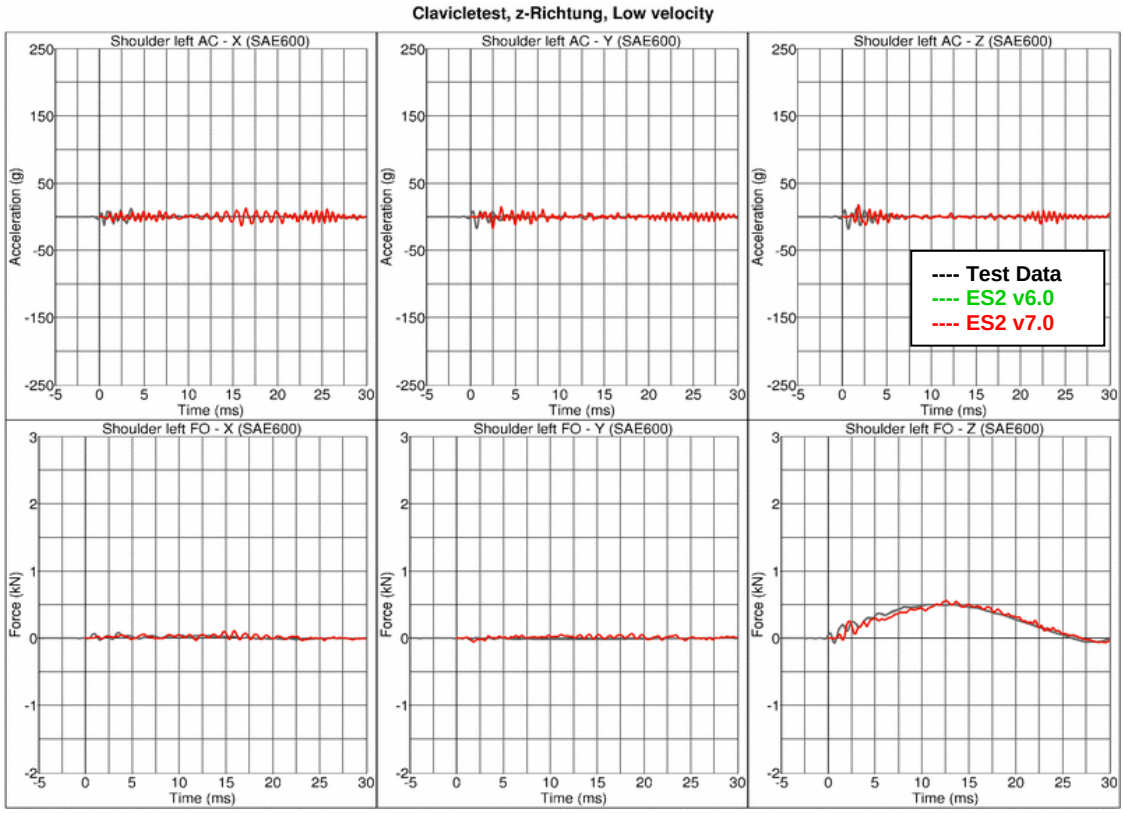
Results for Y-direction impact , high velocity



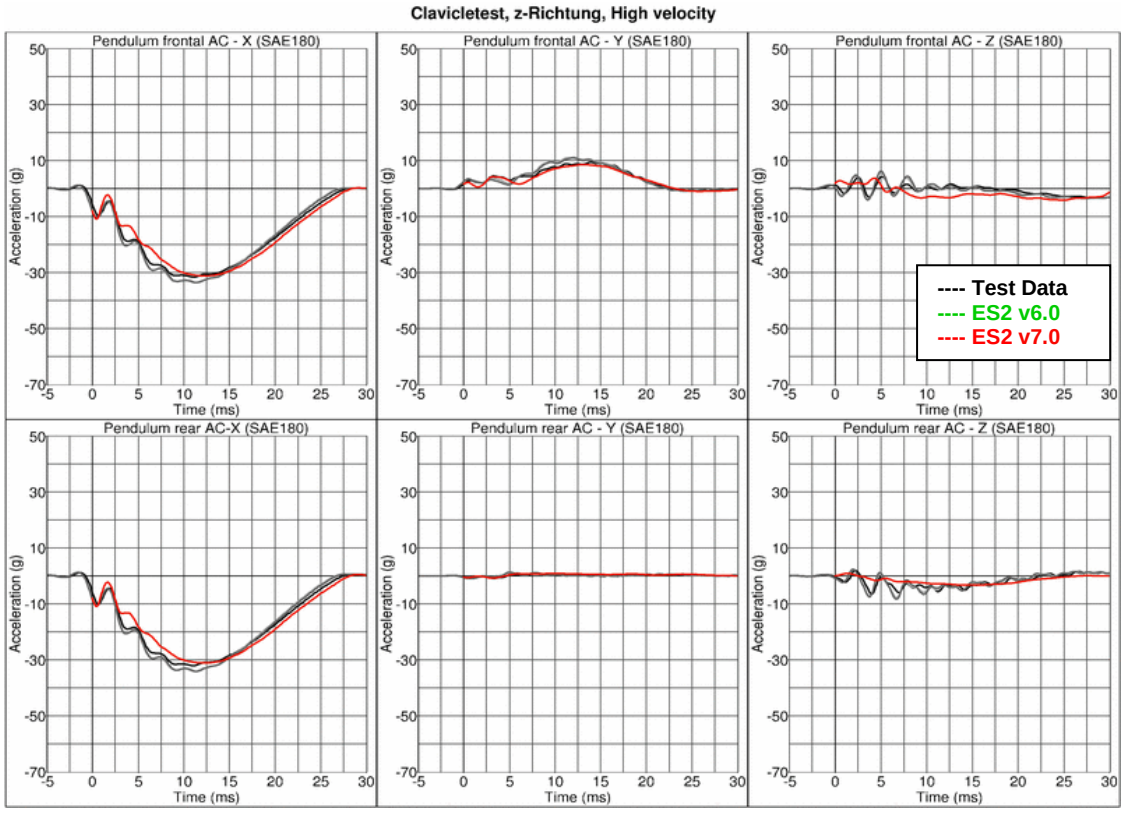


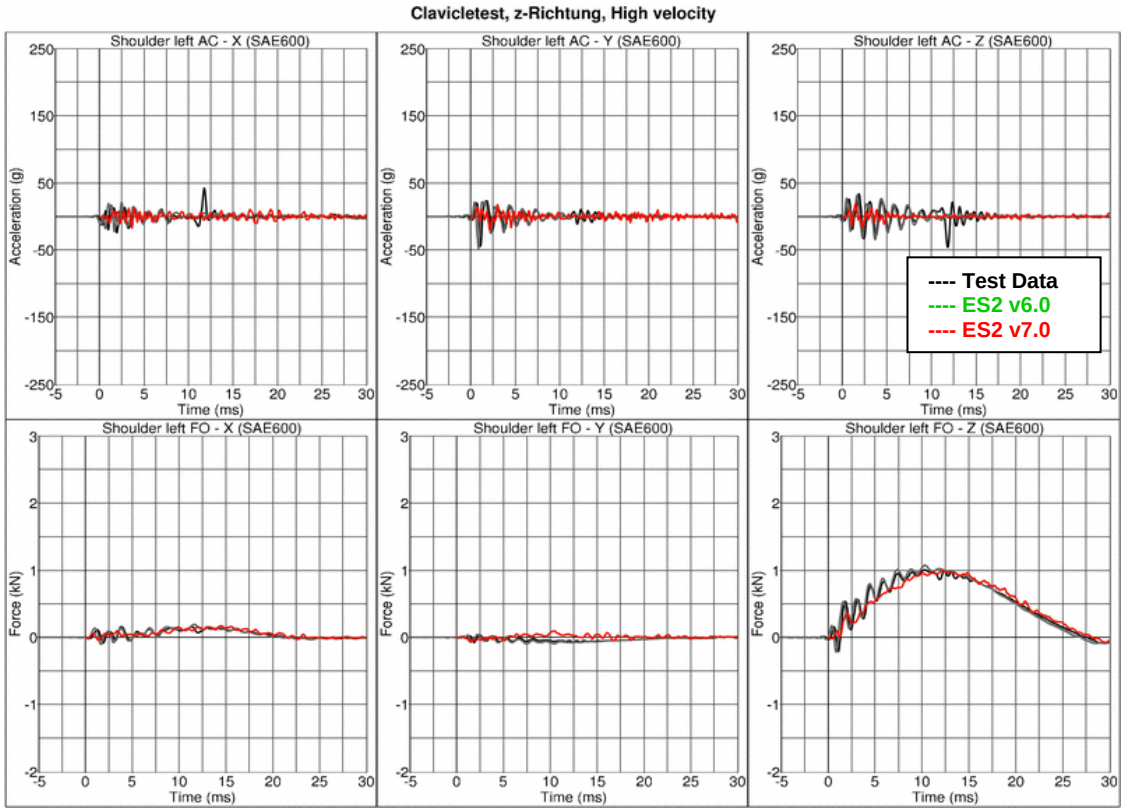
Results for Z-direction impact , low velocity





Results for Z-direction impact , high velocity





11.1.3 Clavicle Box test

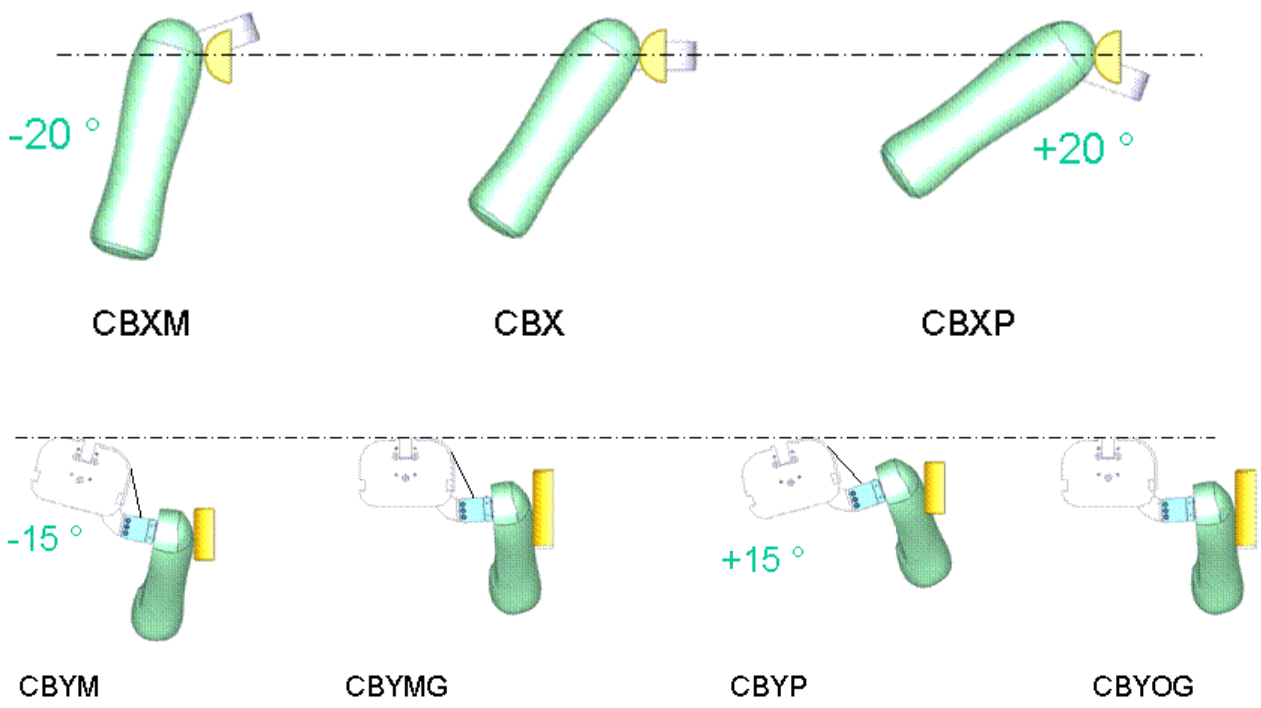
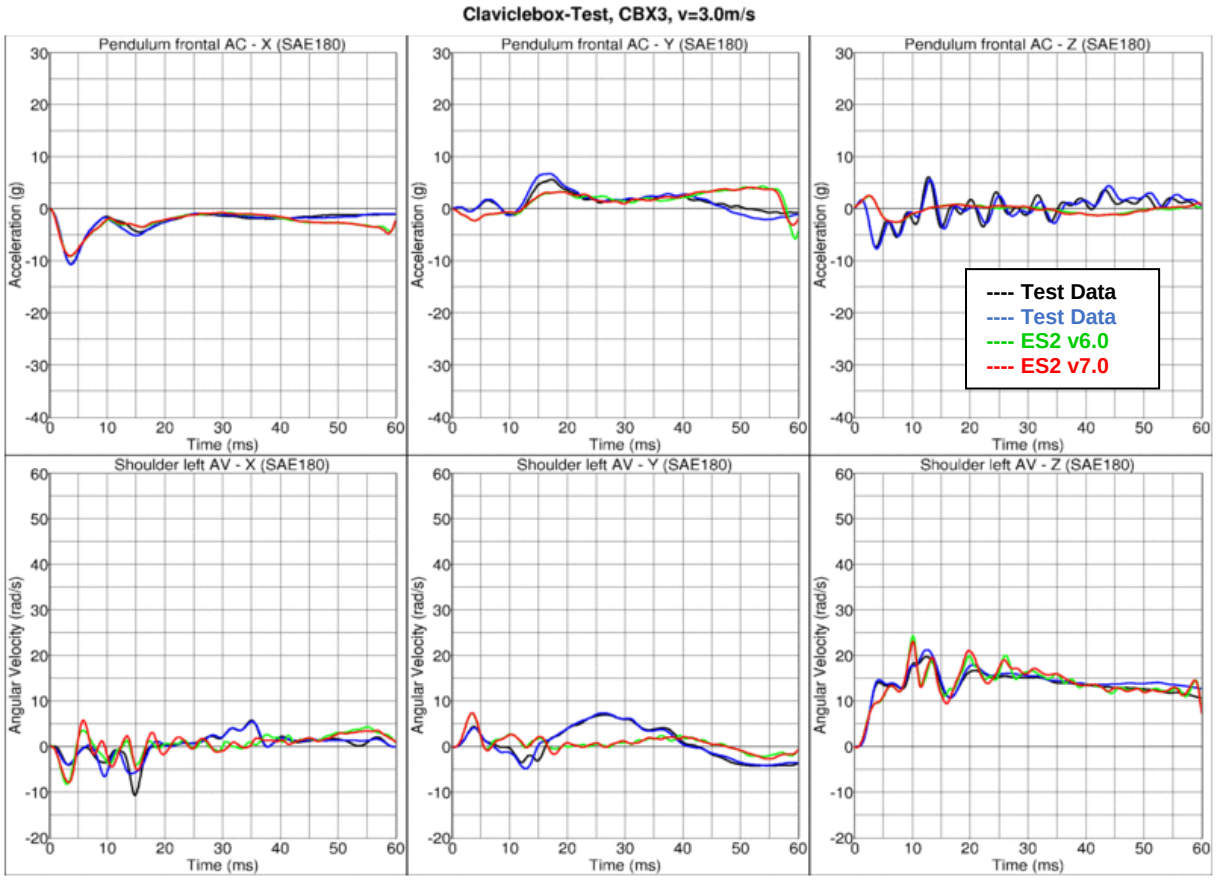
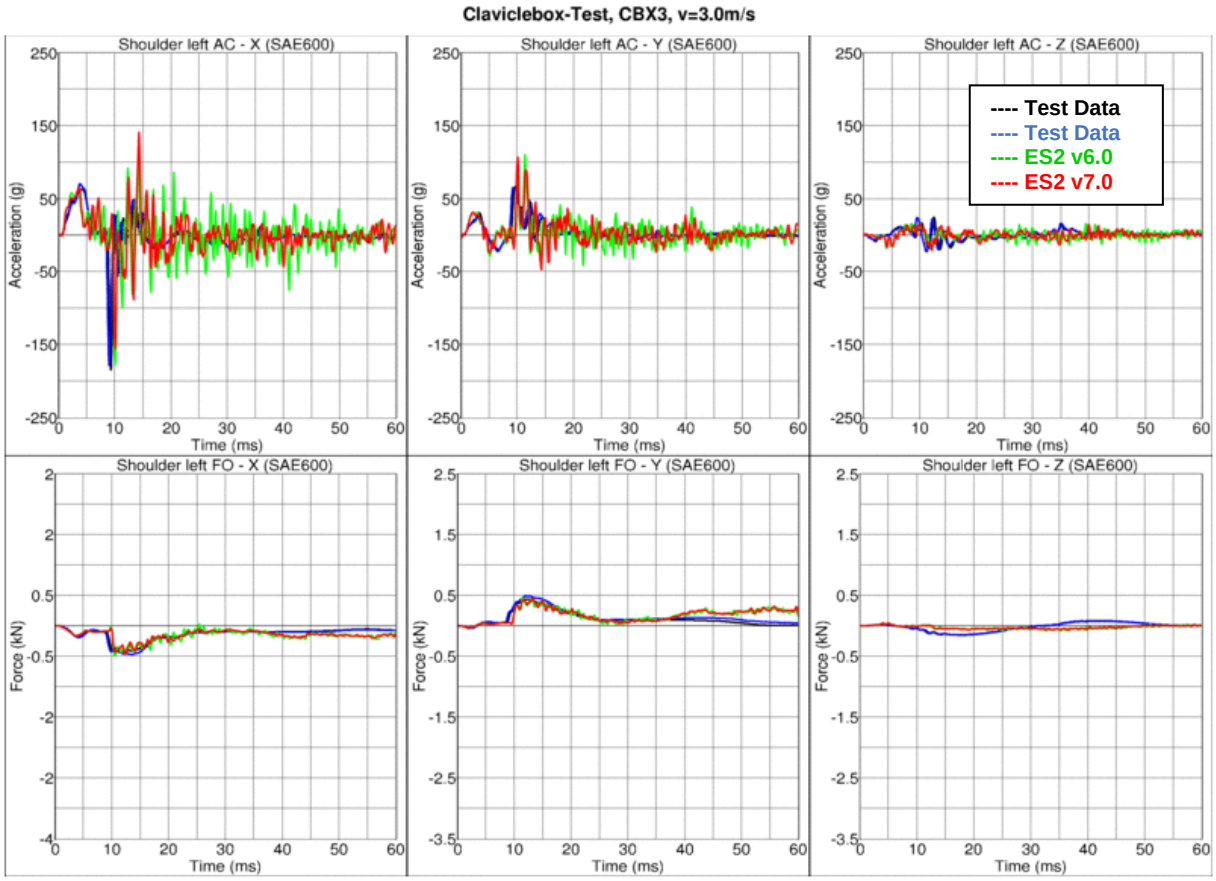


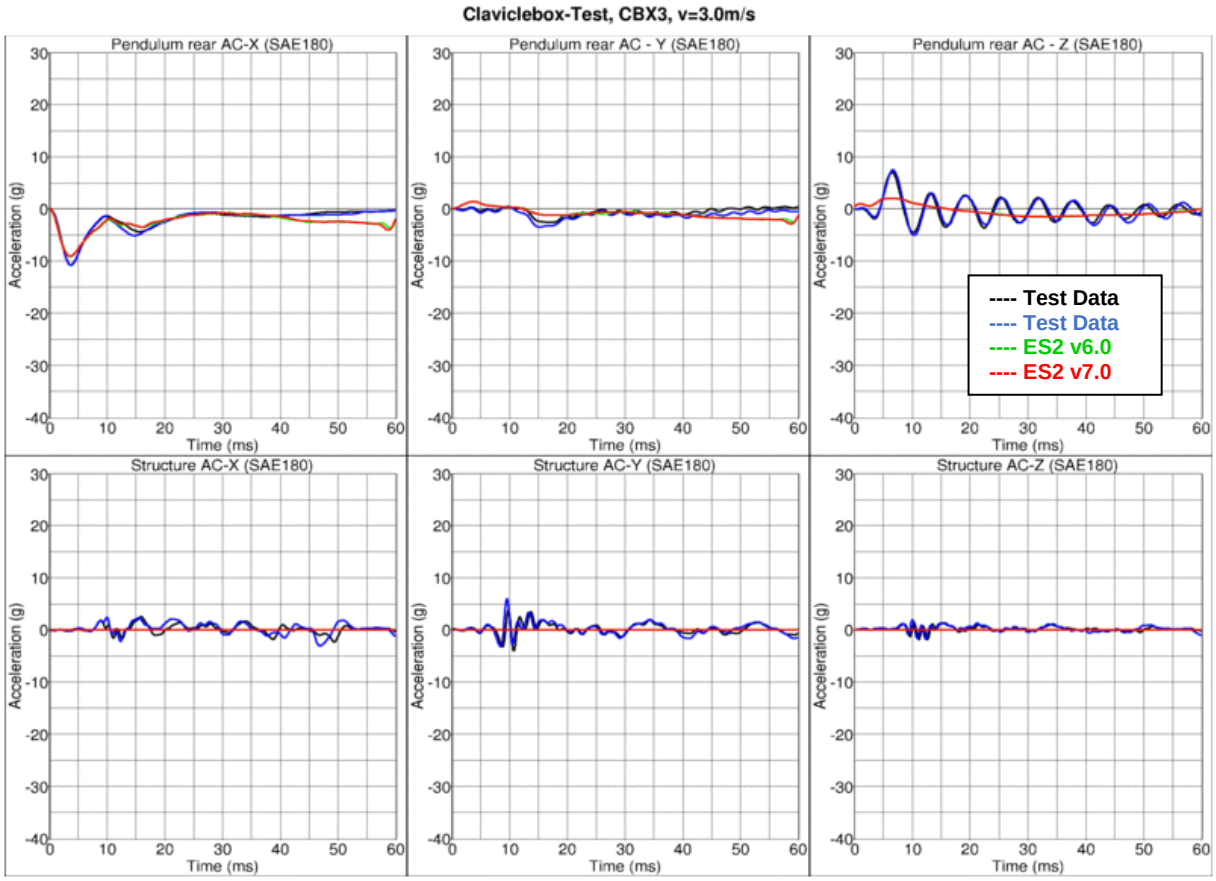
Figure 28: Test configurations for Clavicle Box test

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.

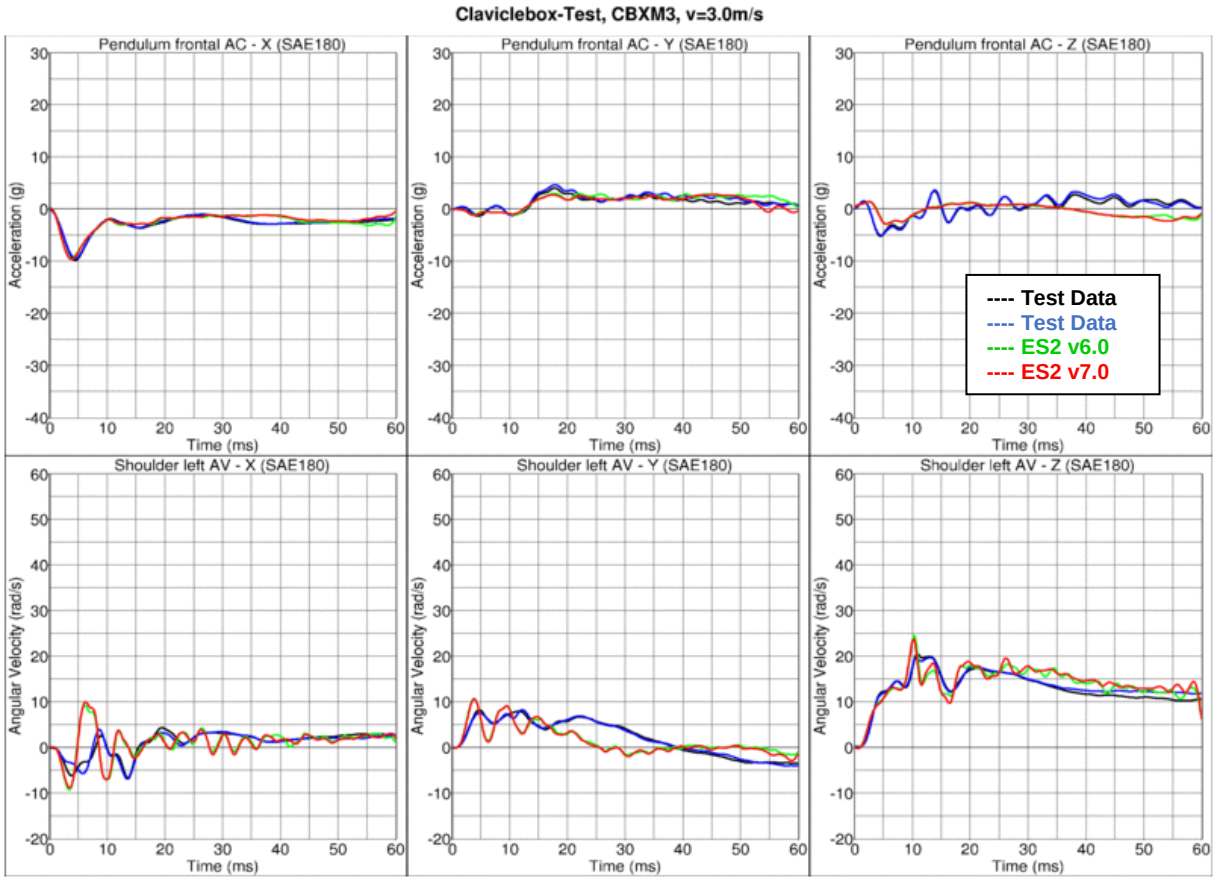
Results for X-direction impact, low velocity (CBX)



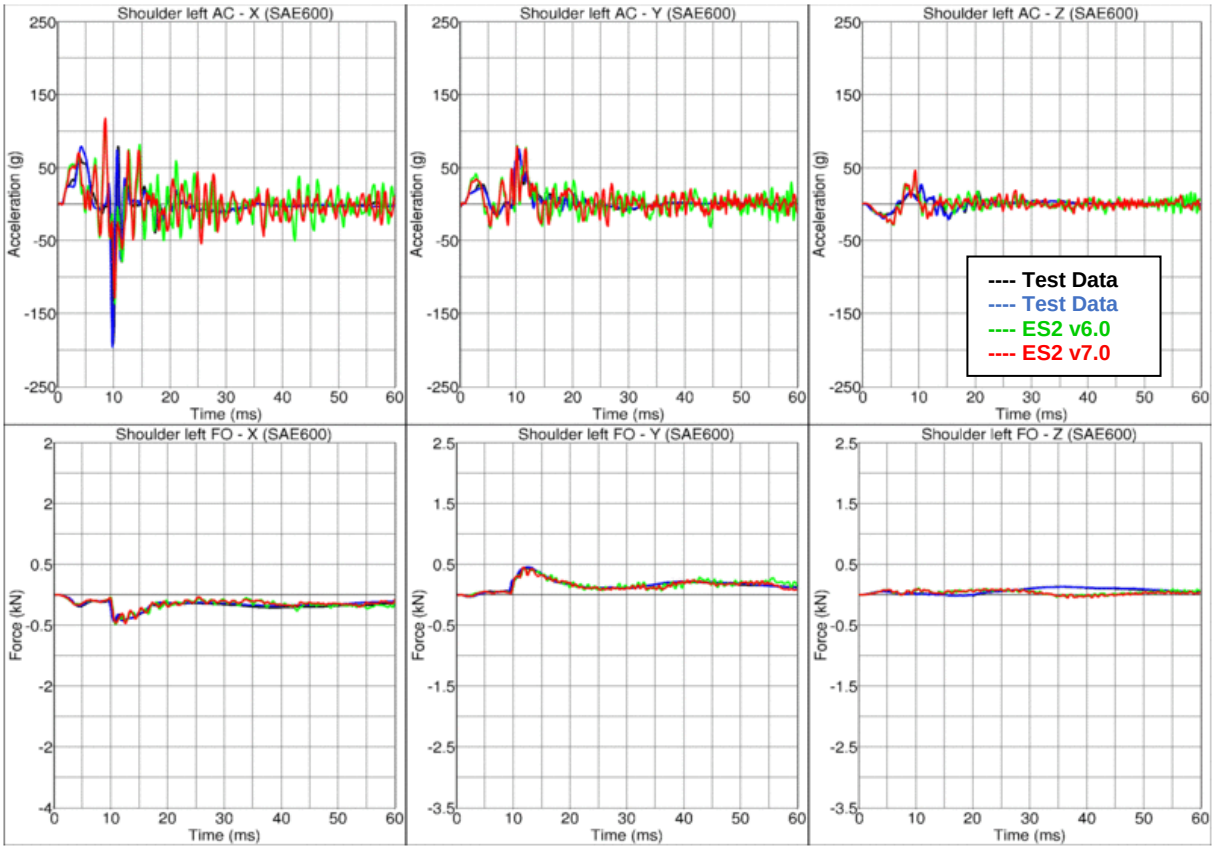




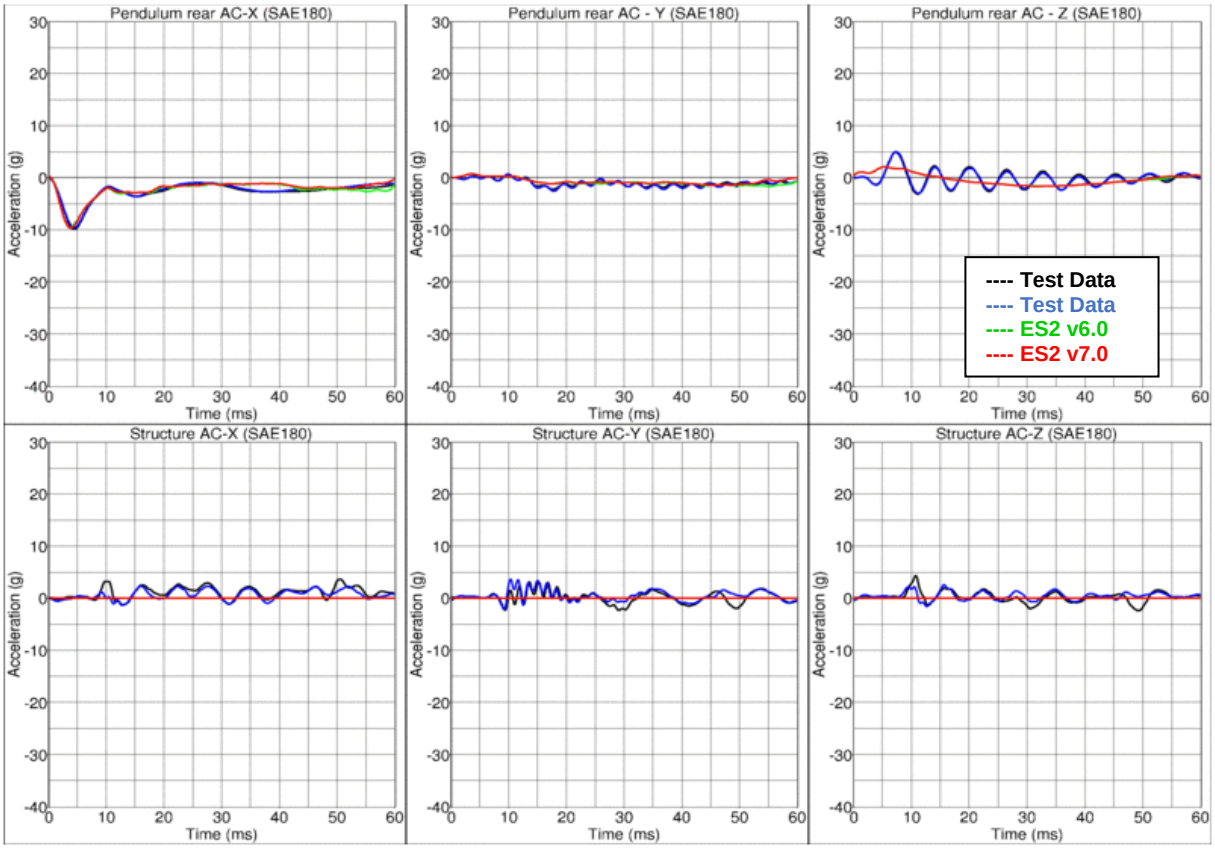
Results for X-direction impact, low velocity (CBXM)



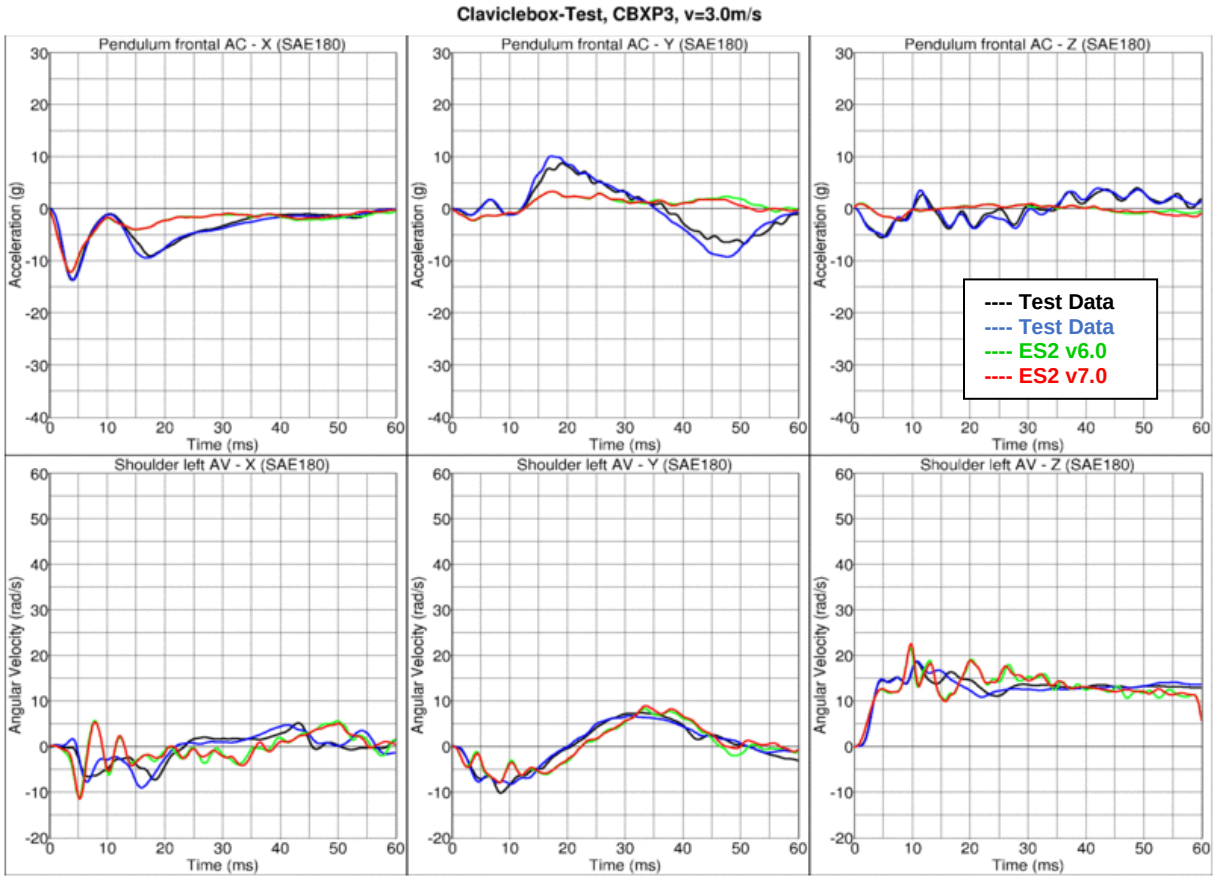
Clavicle box-Test, CBXM3, v=3.0m/s

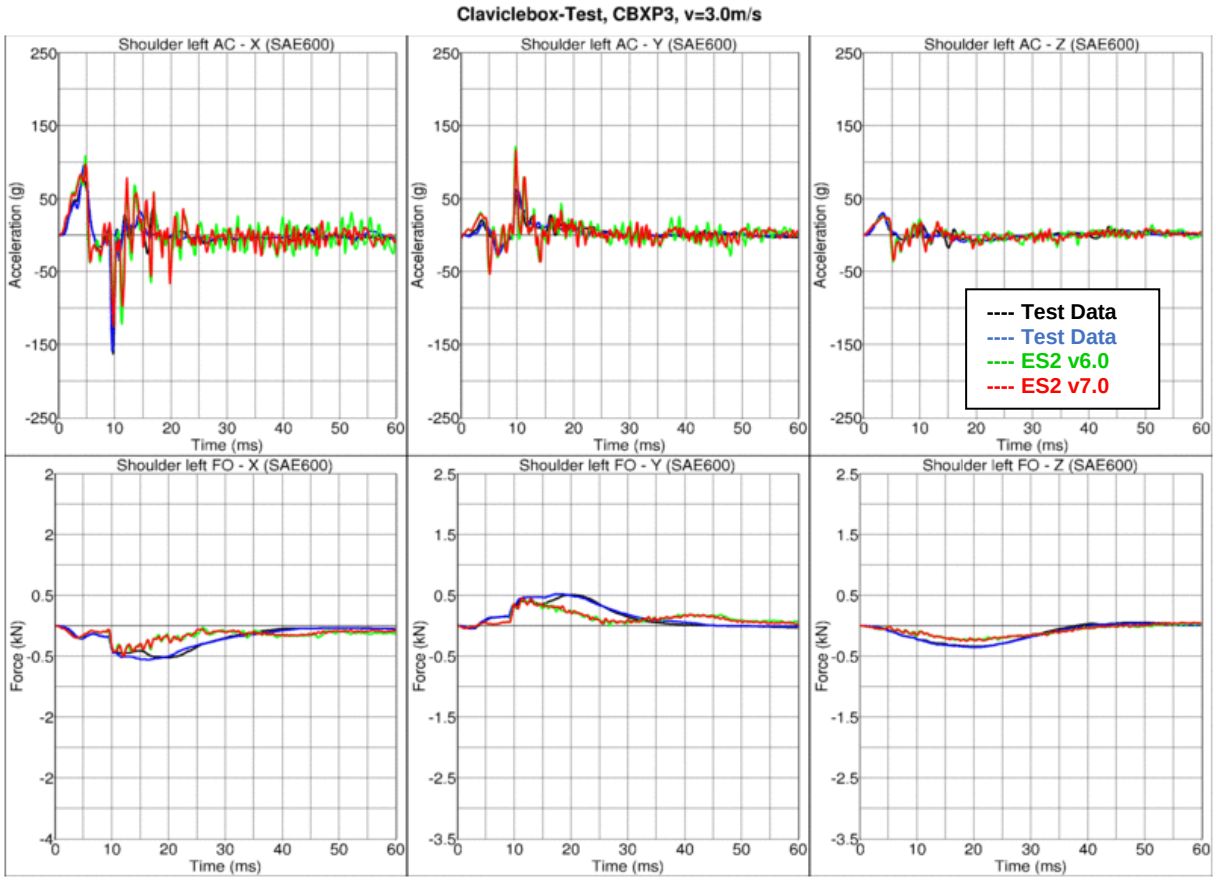


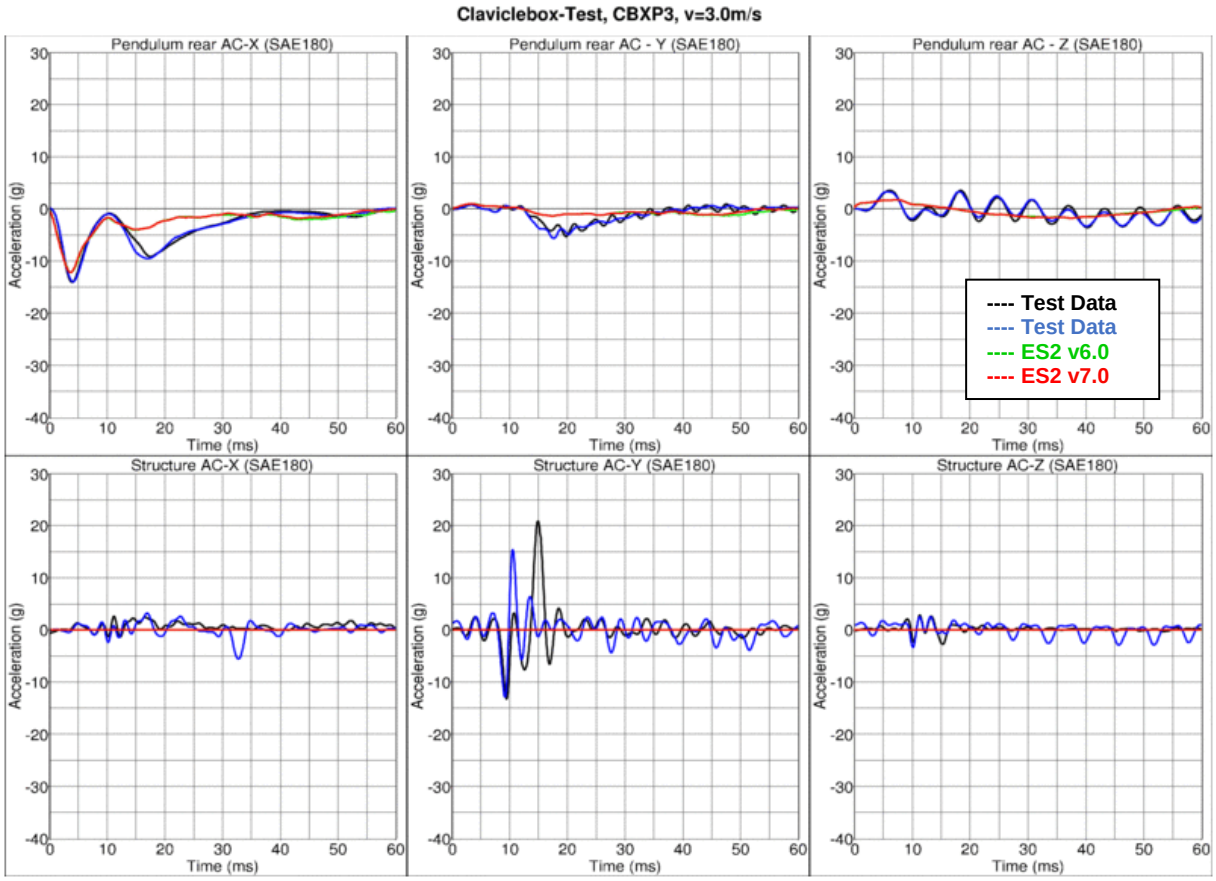
Clavicle box-Test, CBXM3, v=3.0m/s



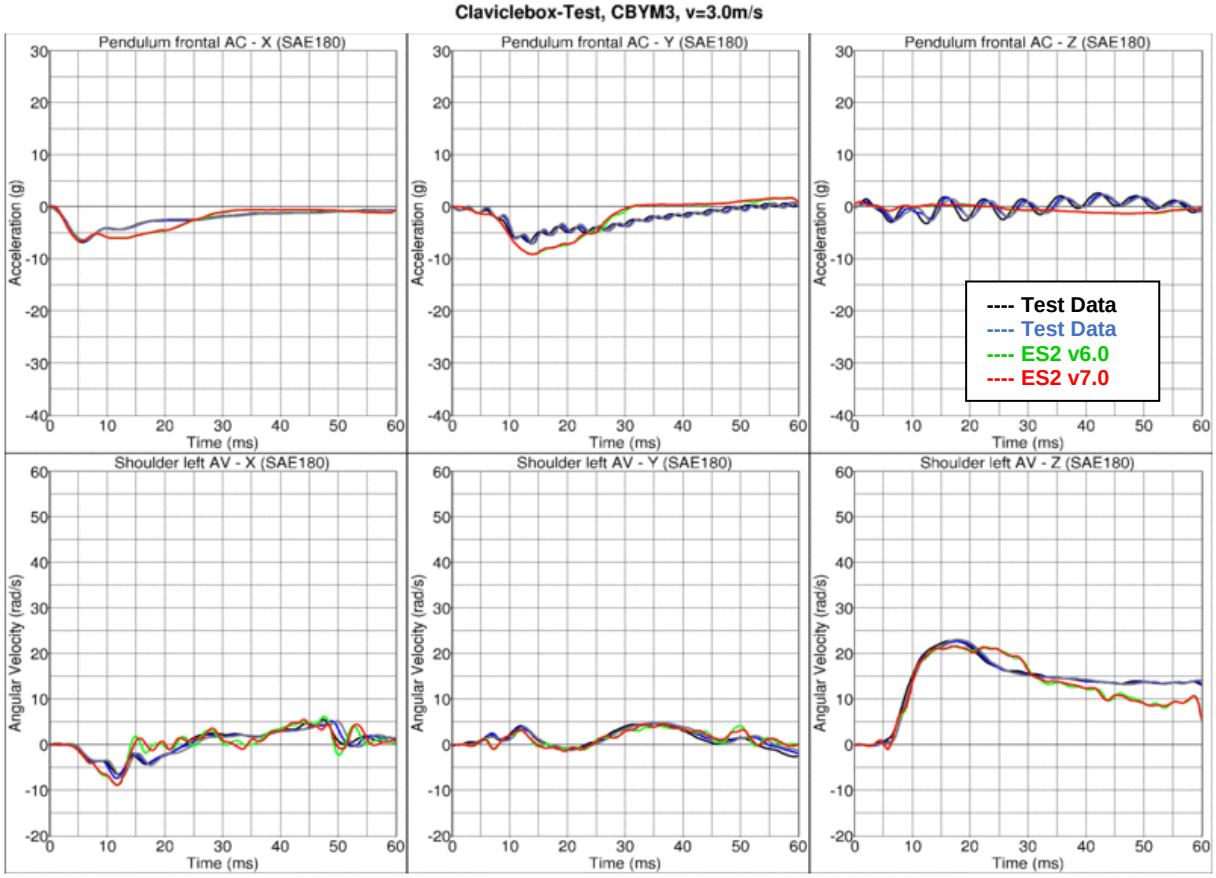
Results for X-direction impact, low velocity (CBXP)



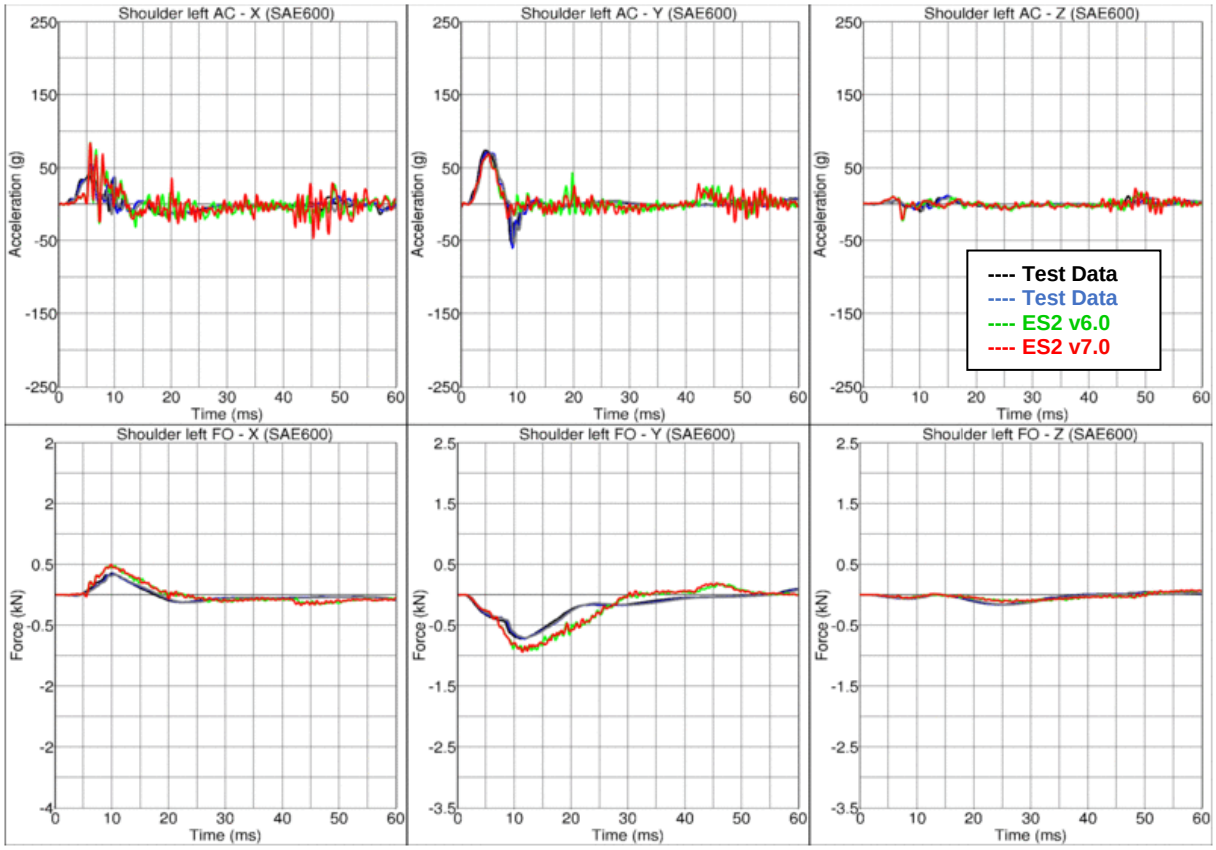




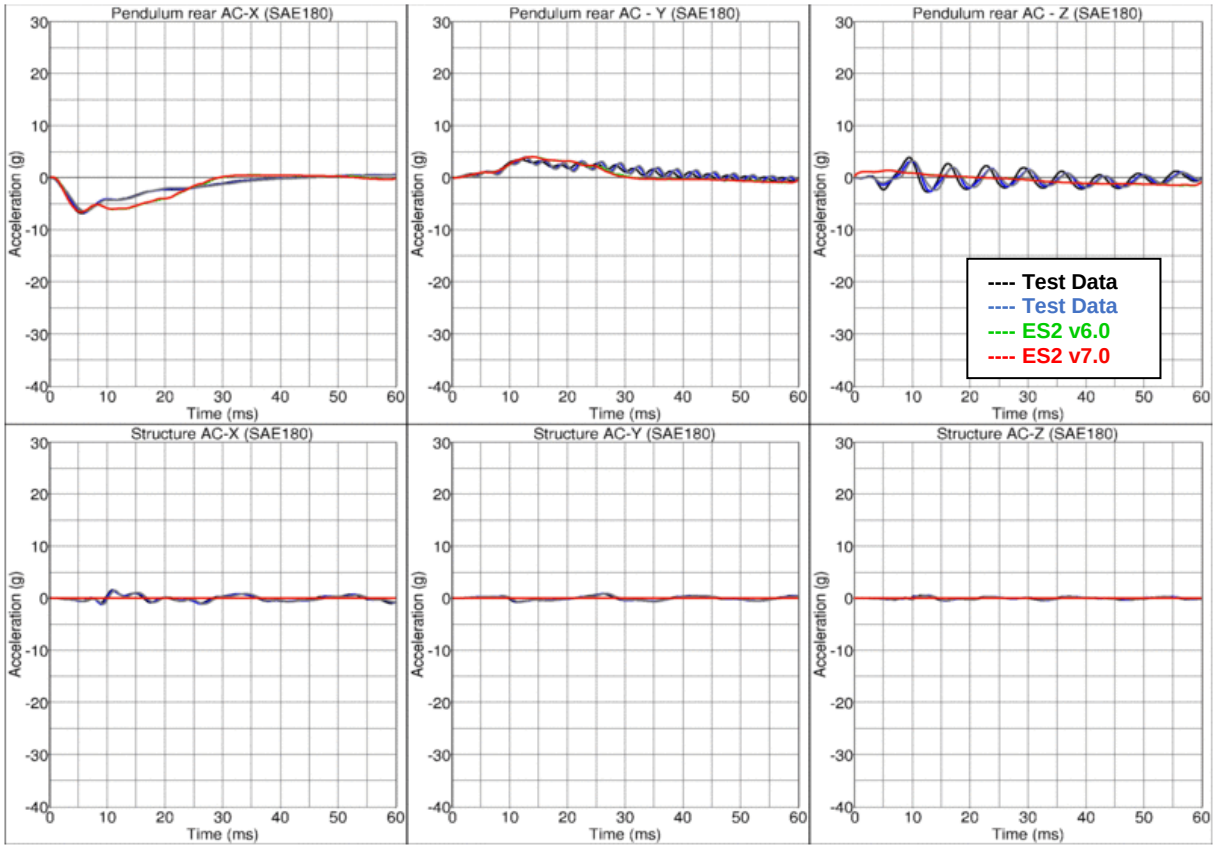
Results for Y-direction impact, low velocity (CBYM)



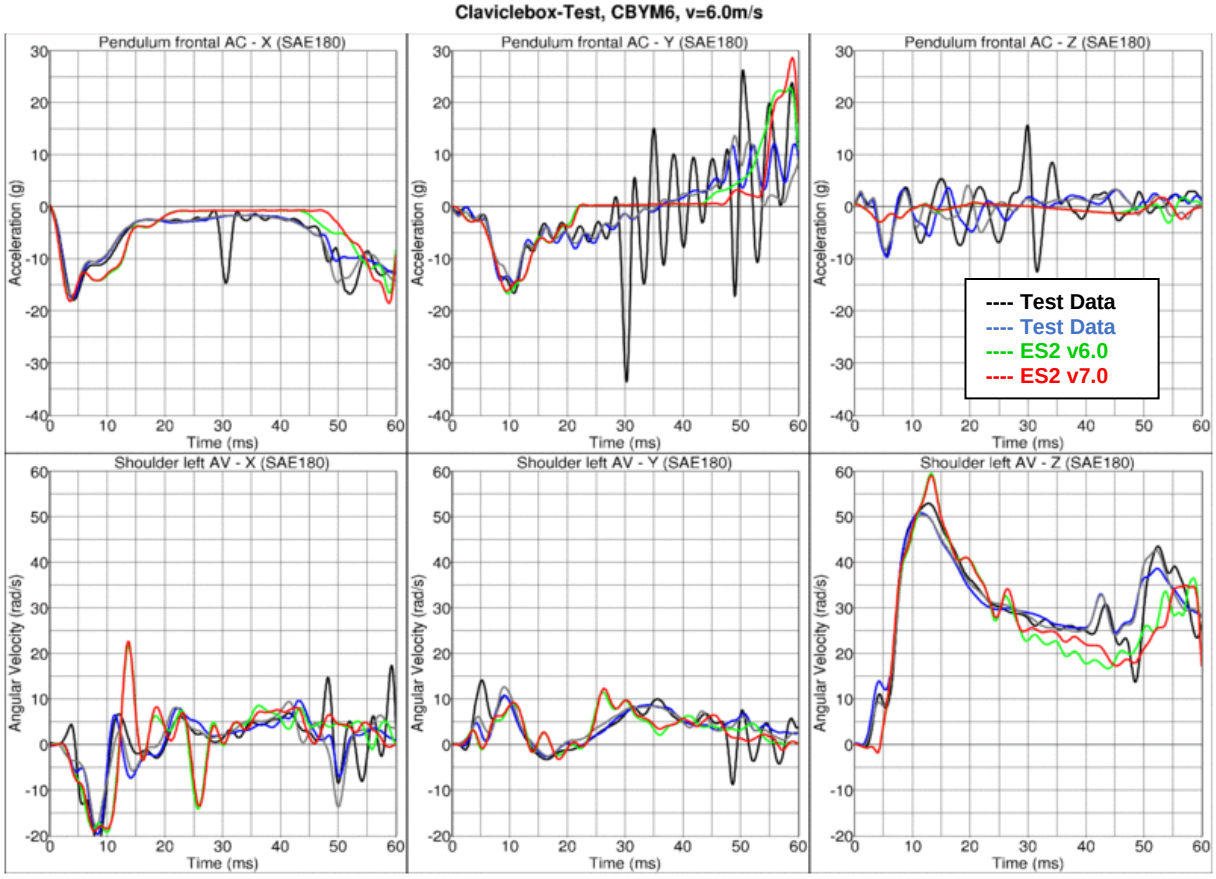
Clavicle box-Test, CBYM3, v=3.0m/s

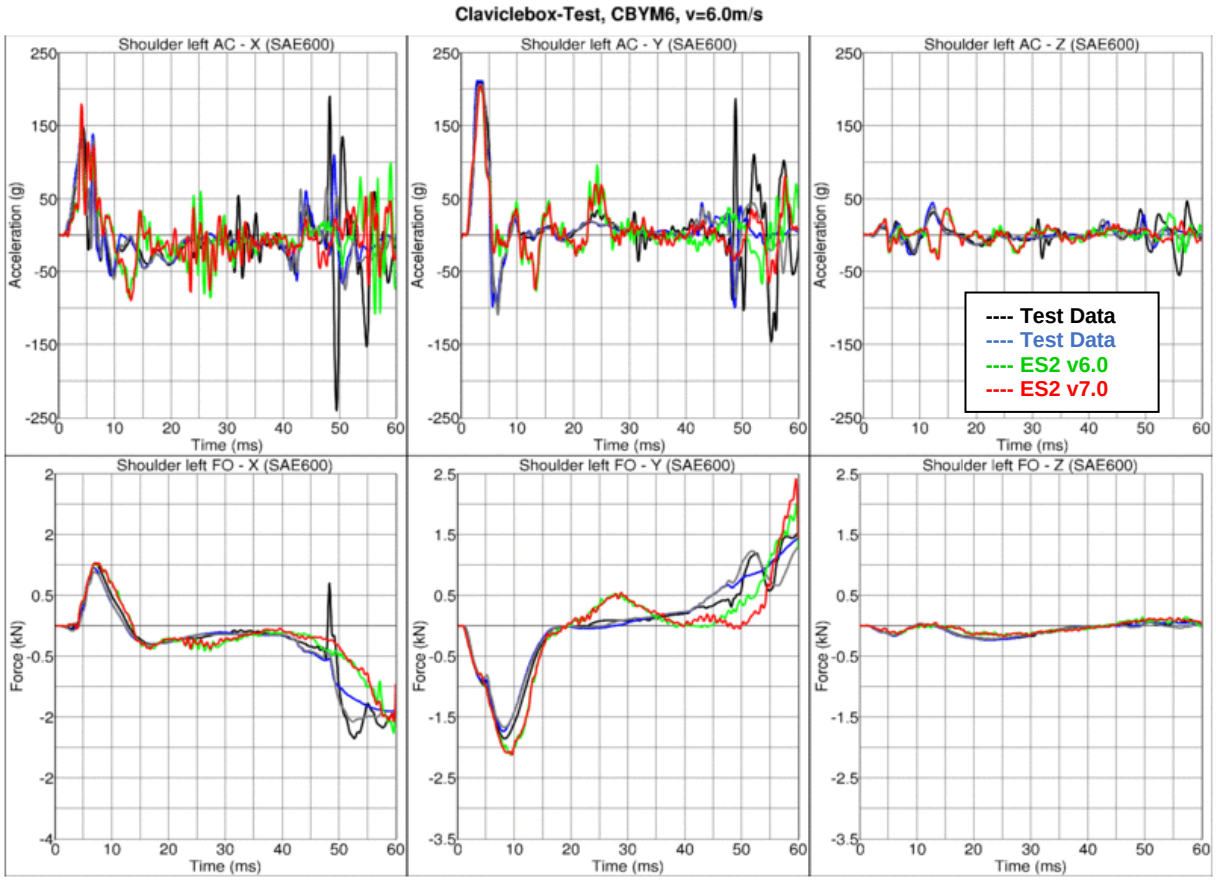


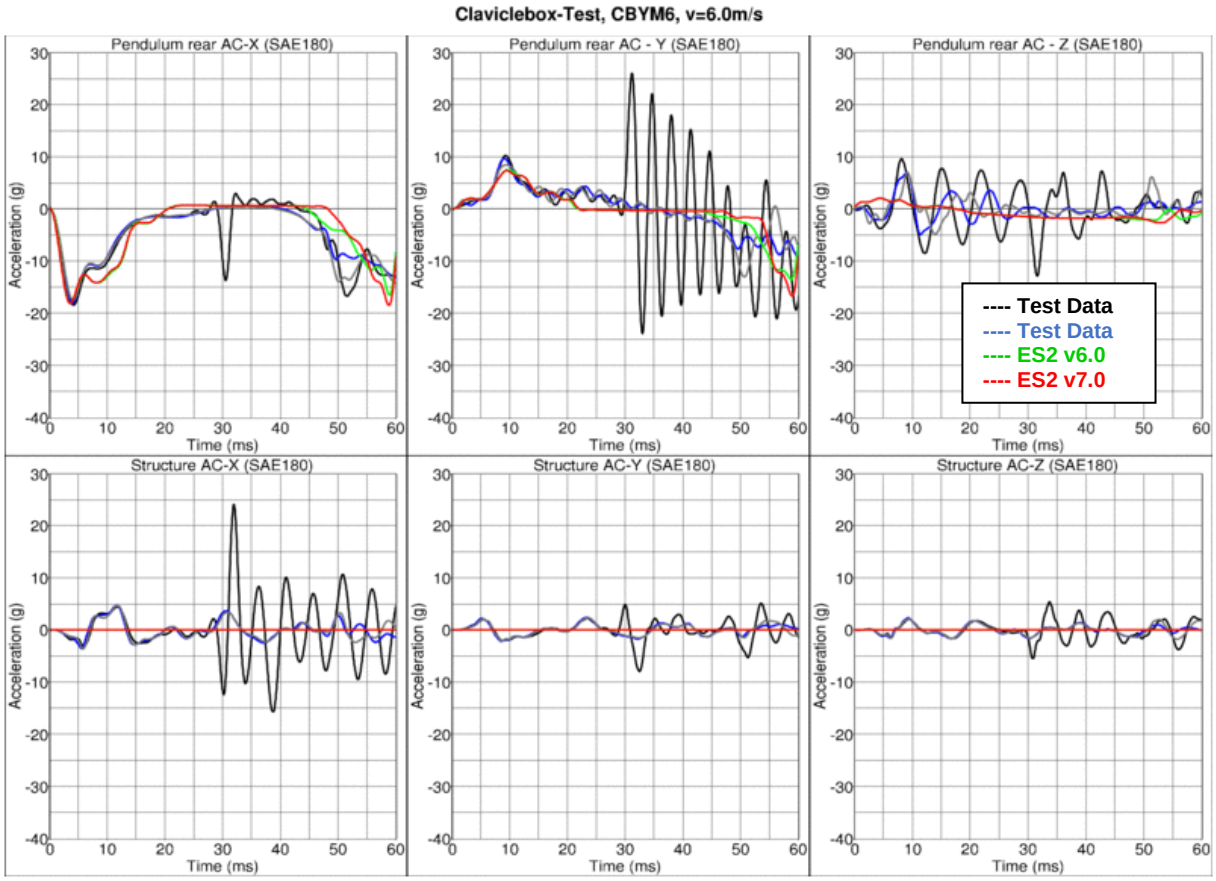
Clavicle box-Test, CBYM3, v=3.0m/s



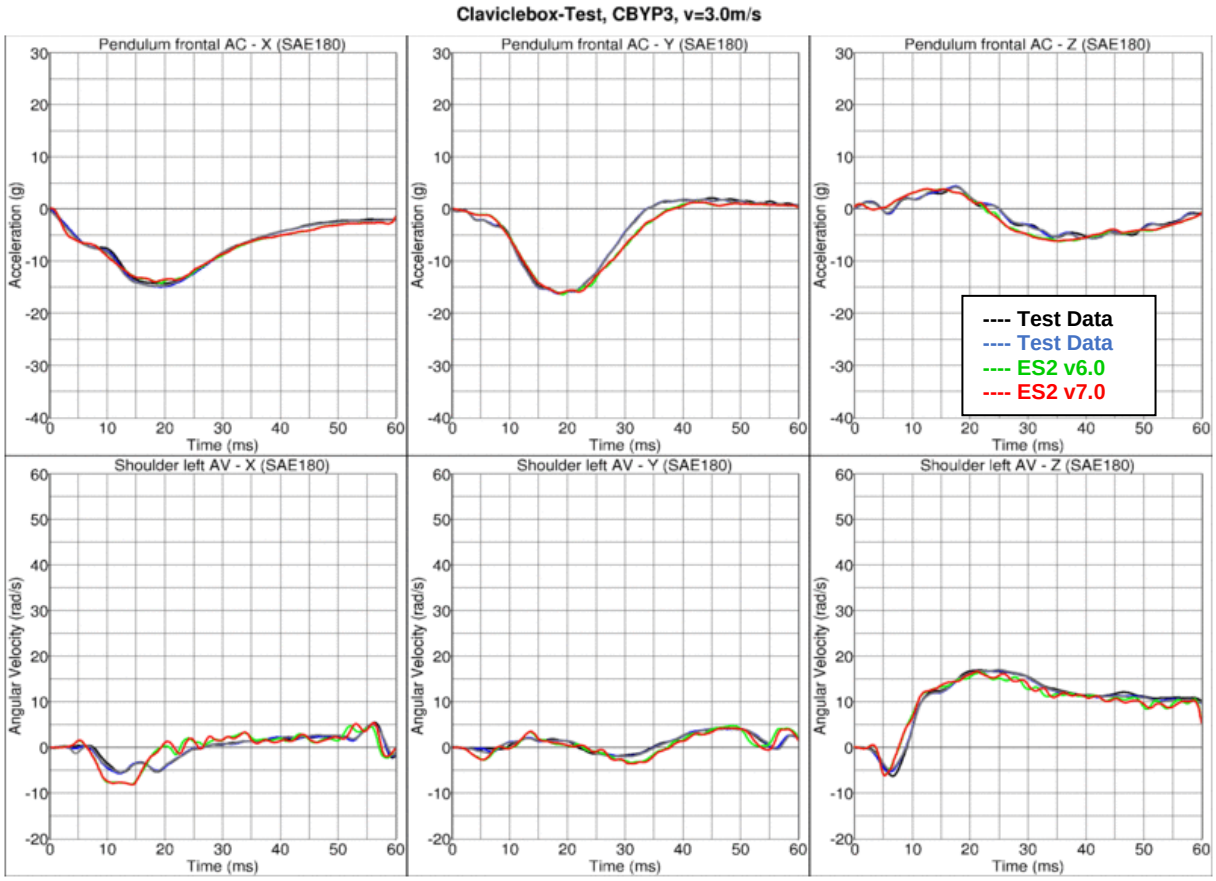
Results for Y-direction impact, high velocity (CBYM)



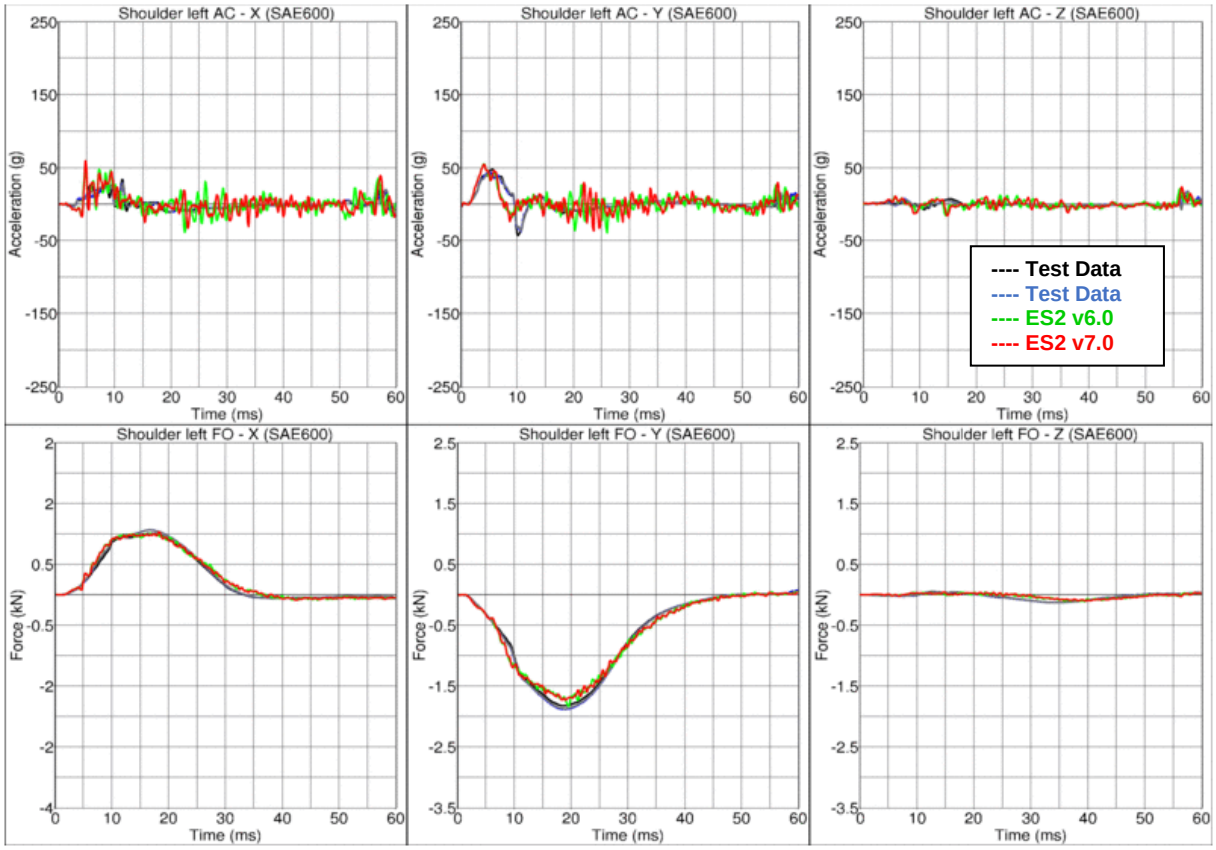




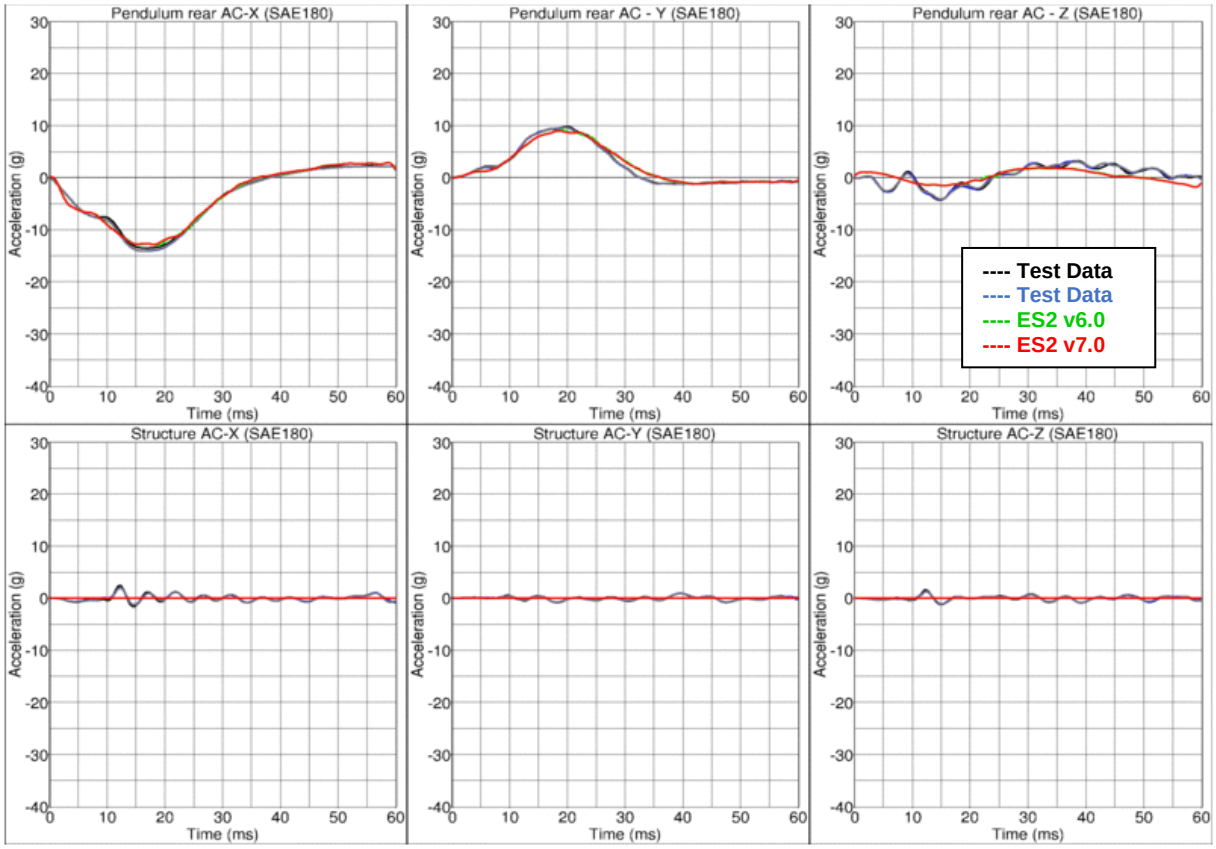
Results for Y-direction impact, low velocity (CBYP)



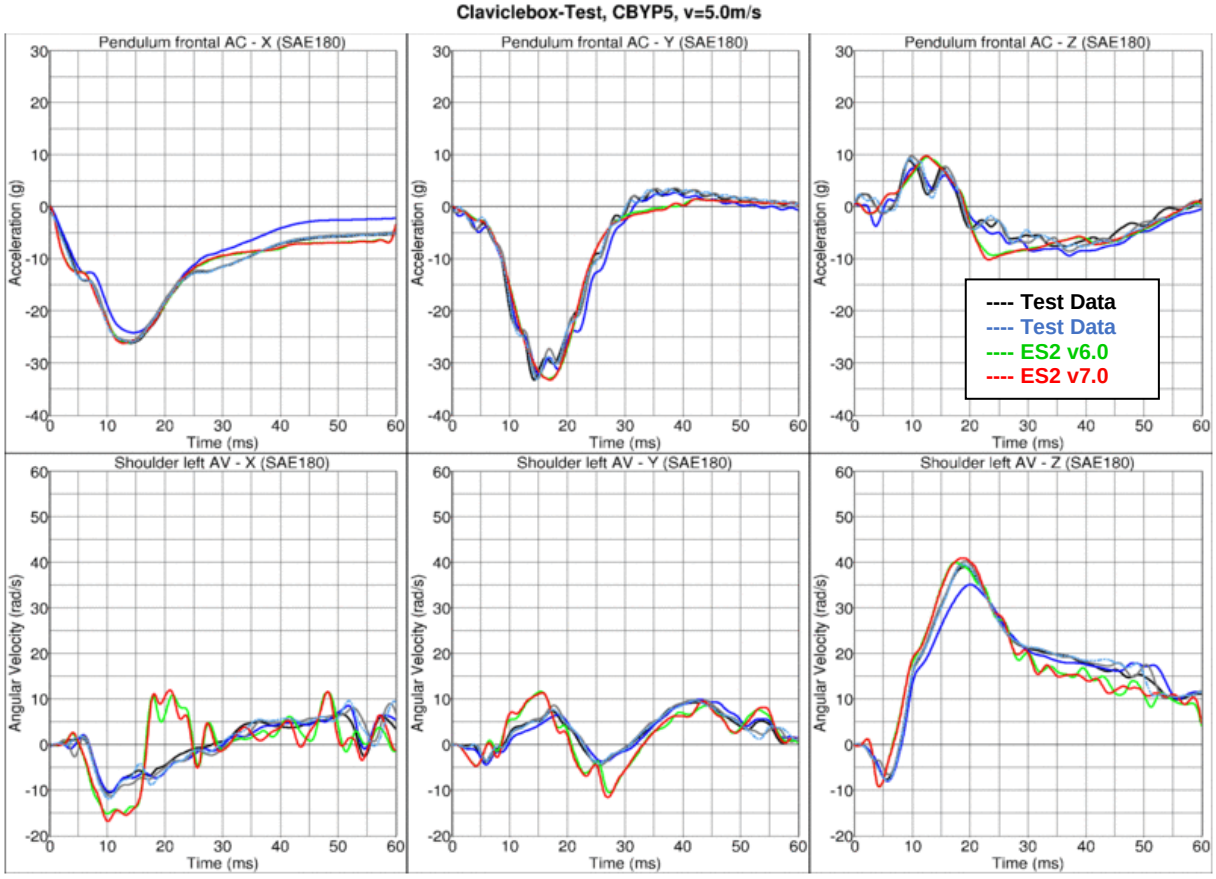
Clavicle box-Test, CBYP3, v=3.0m/s

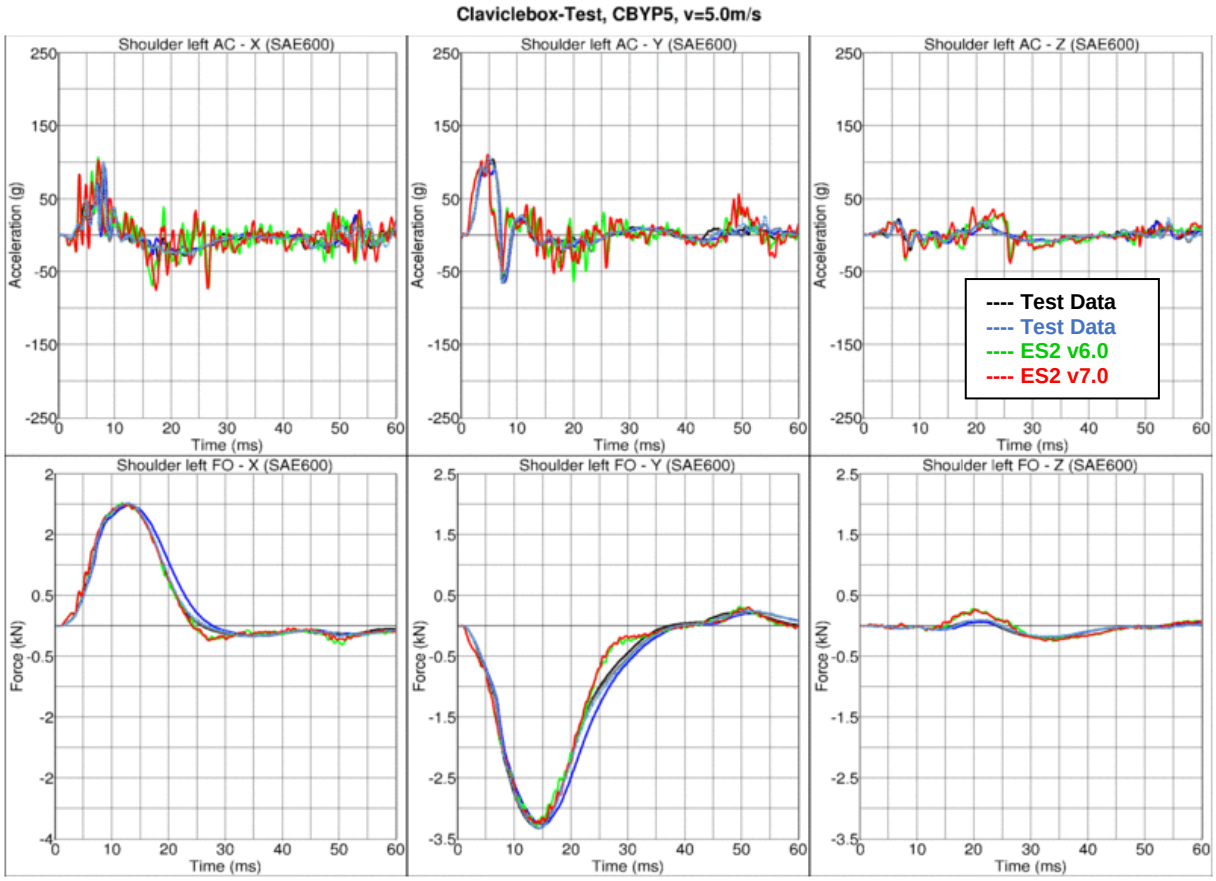


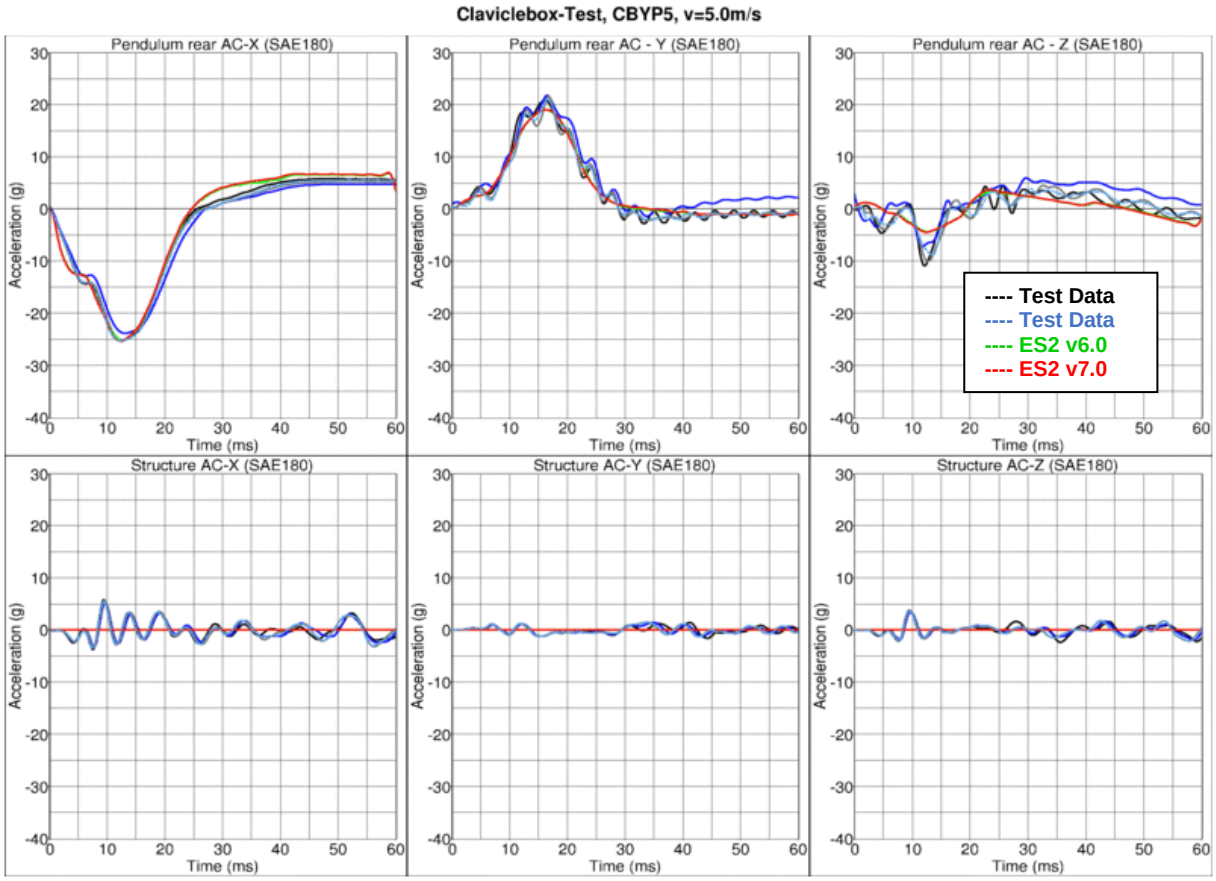
Clavicle box-Test, CBYP3, v=3.0m/s



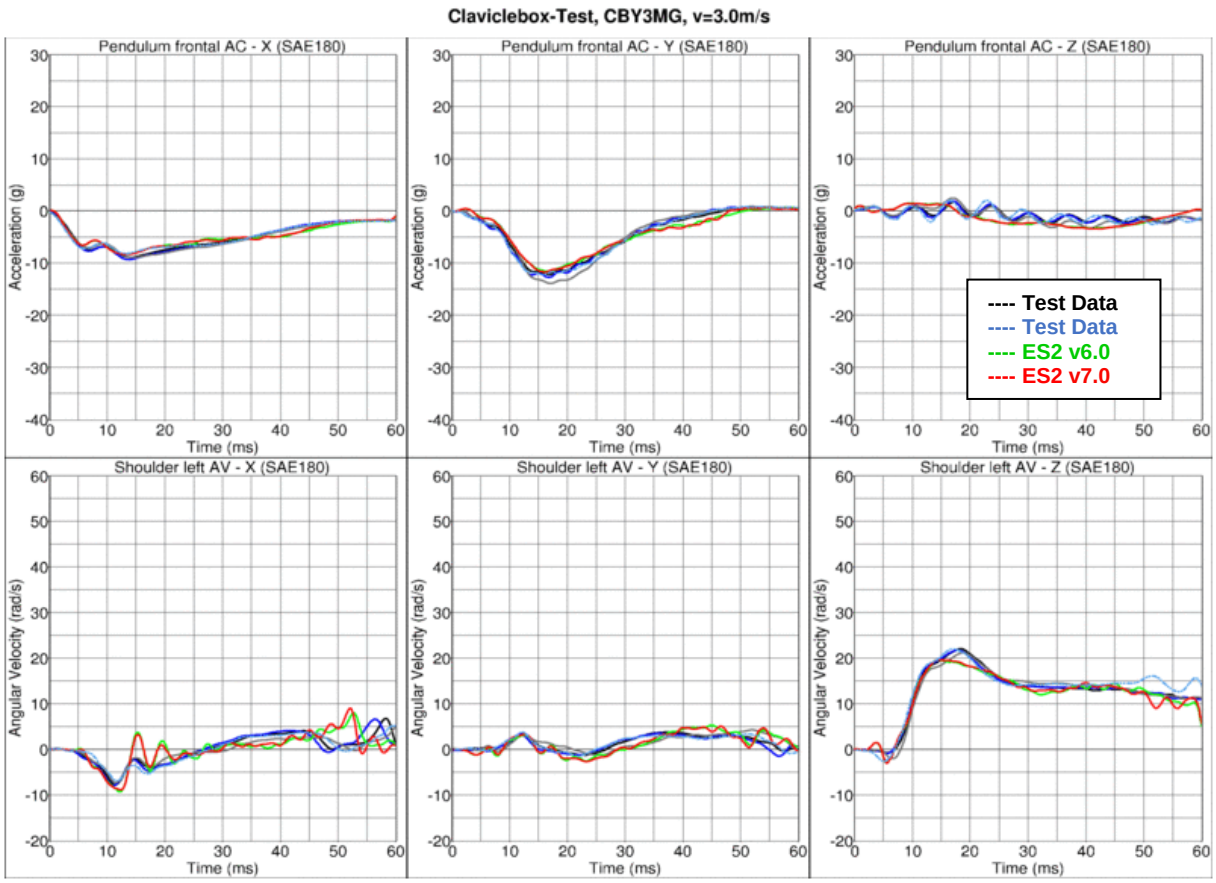
Results for Y-direction impact, high velocity (CBYP)



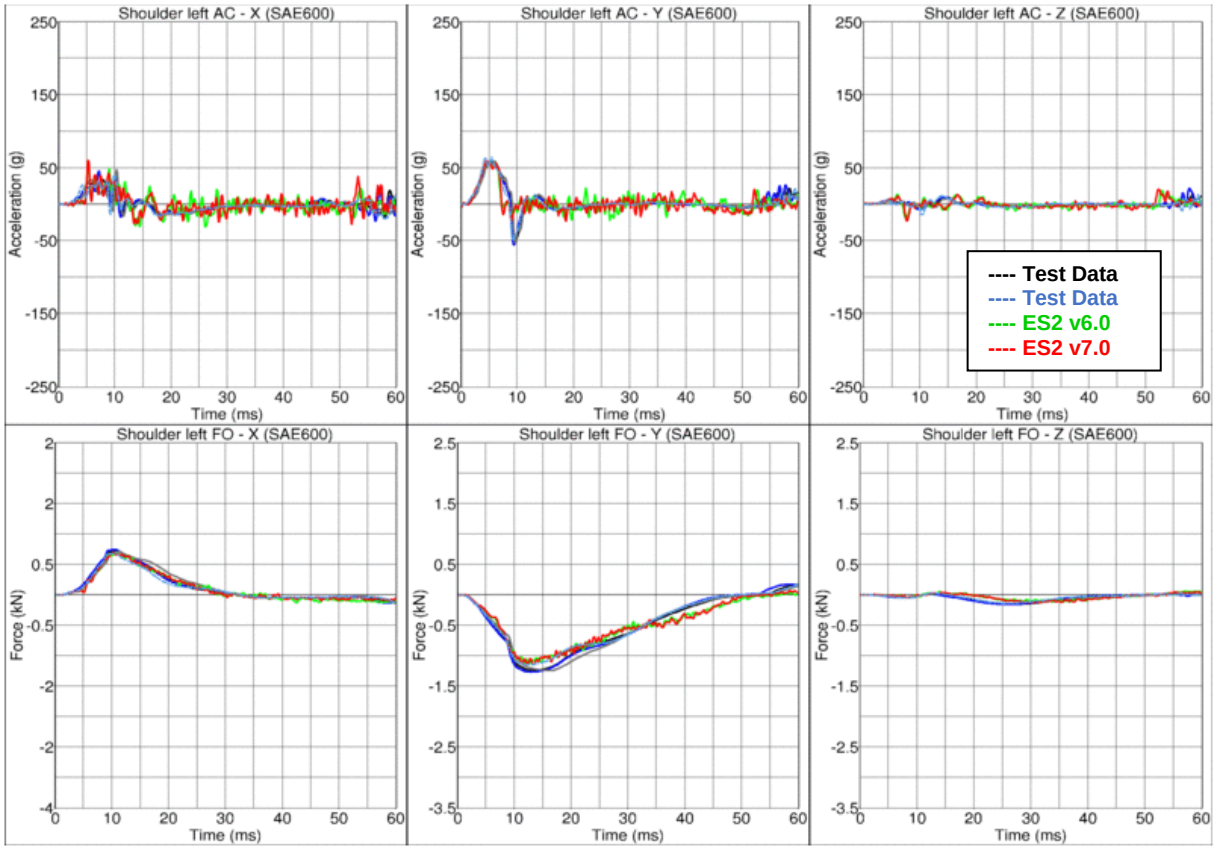




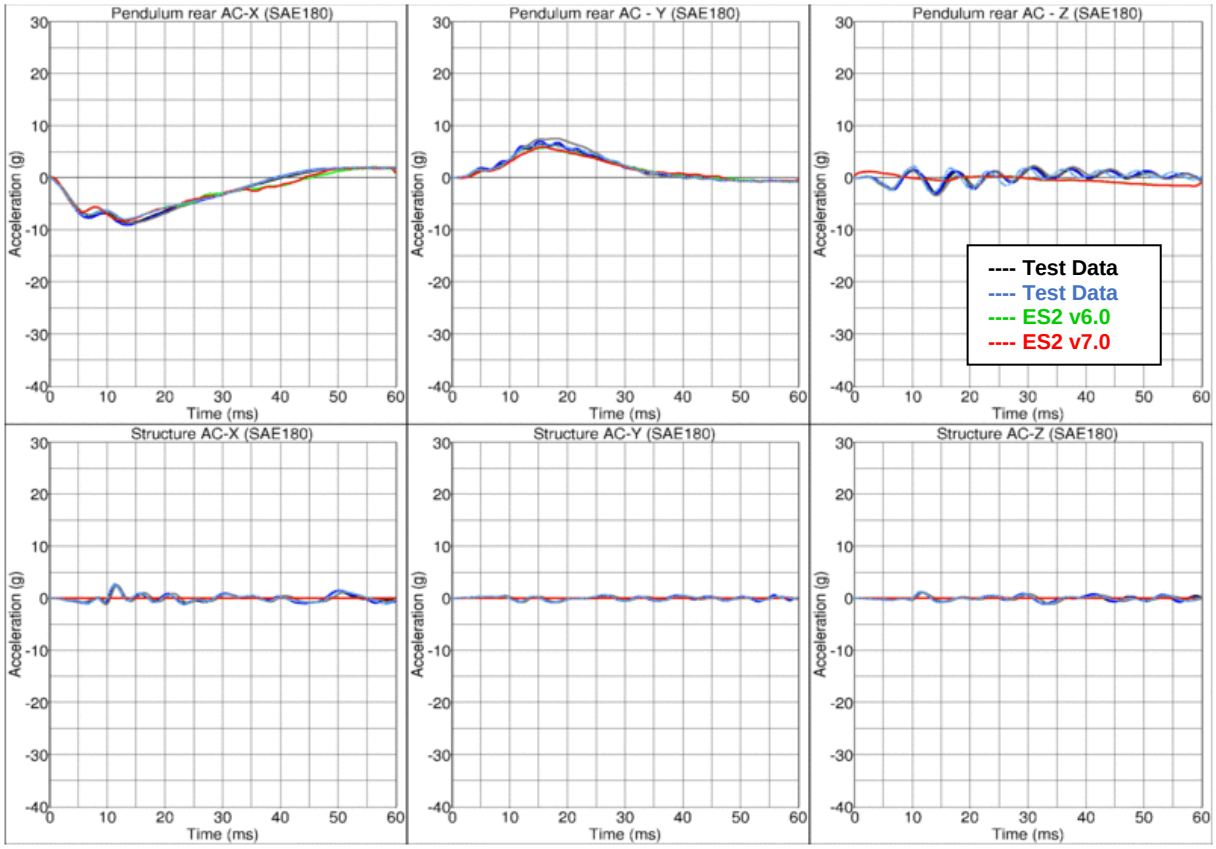
Results for Y-direction impact, low velocity, with clavicle strap (CBYMG)



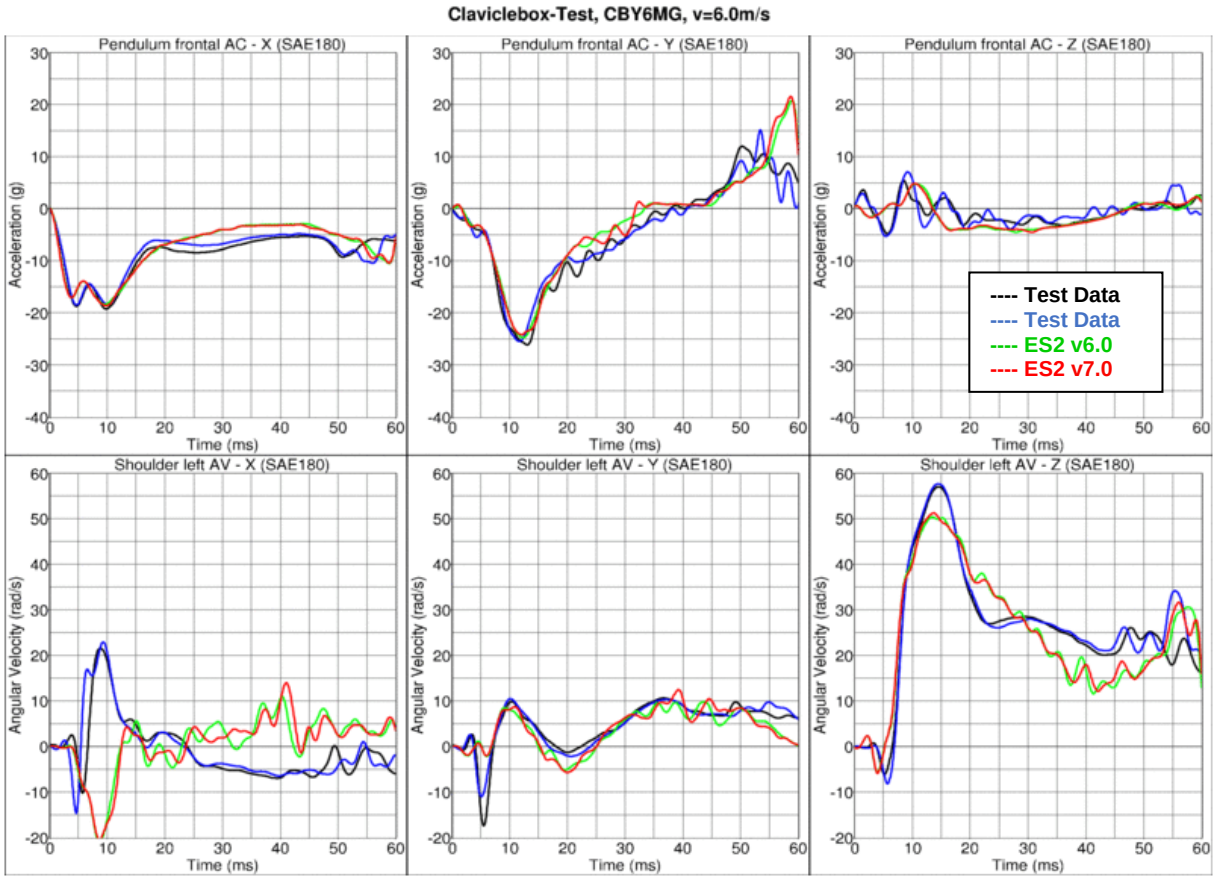
Claviclebox-Test, CBY3MG, v=3.0m/s

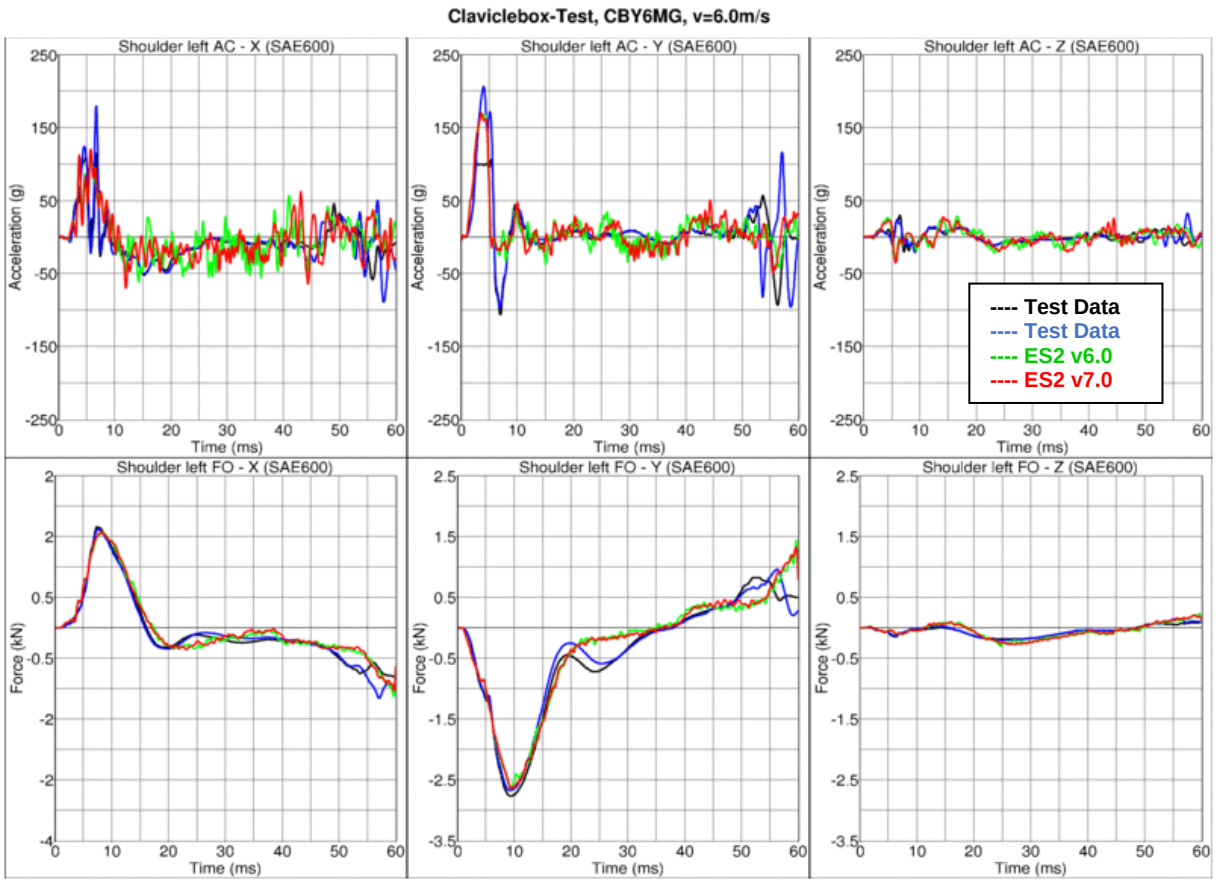


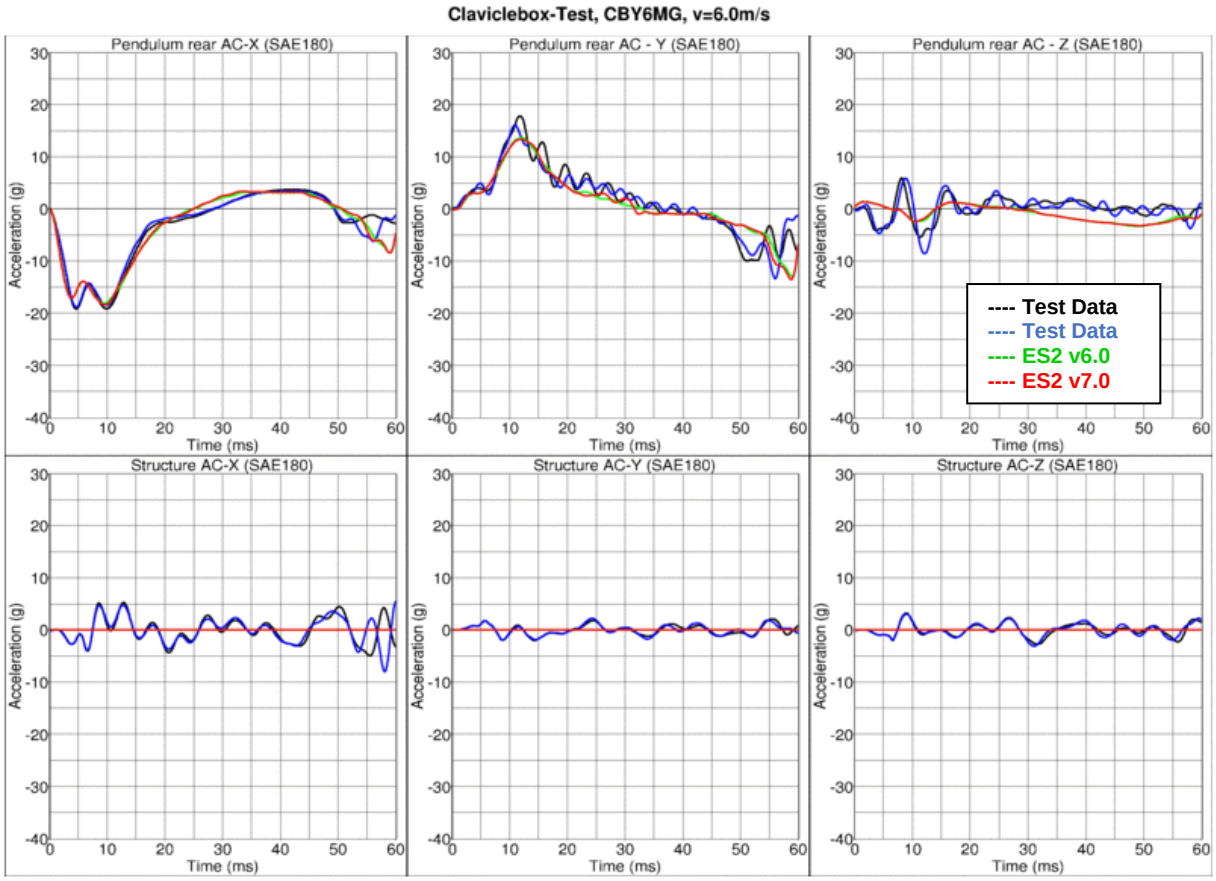
Claviclebox-Test, CBY3MG, v=3.0m/s



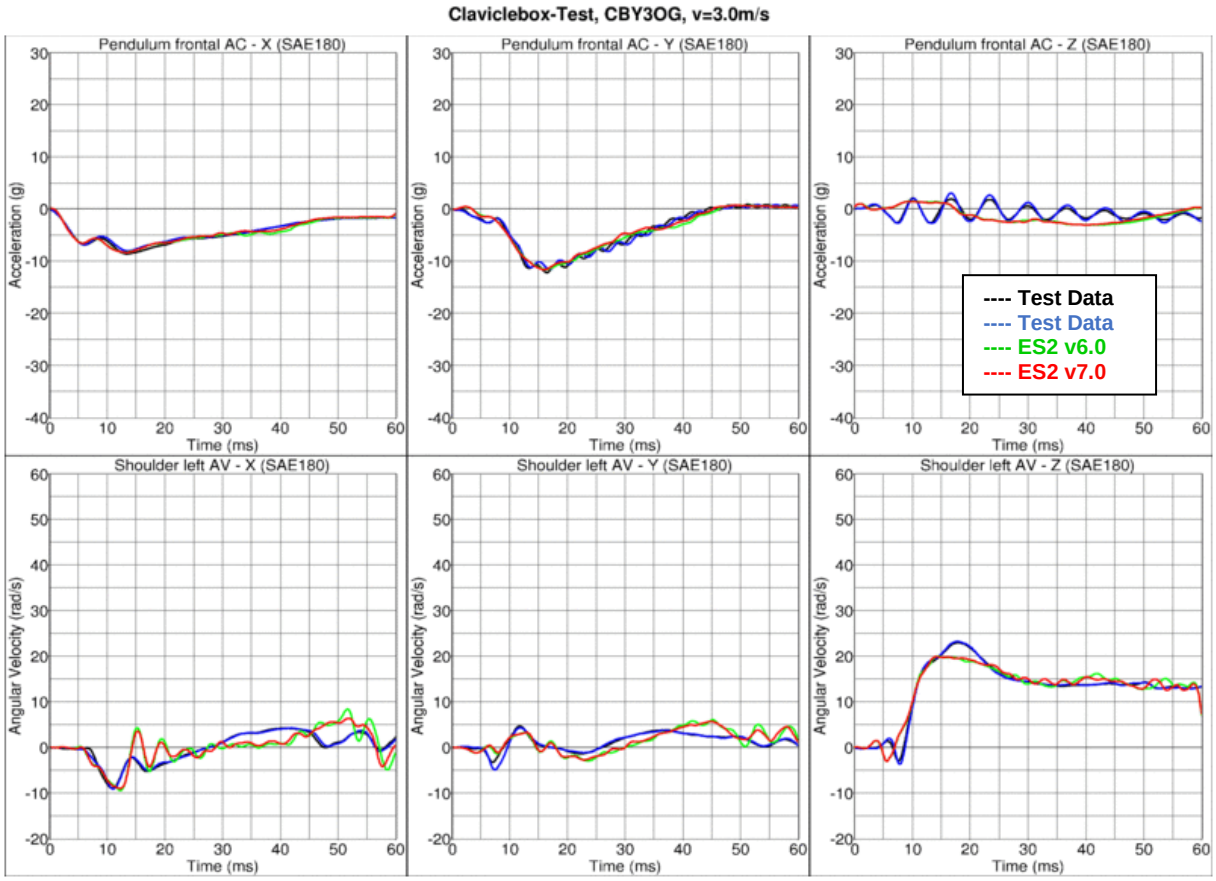
Results for Y-direction impact, high velocity, with clavicle strap (CBYMG)



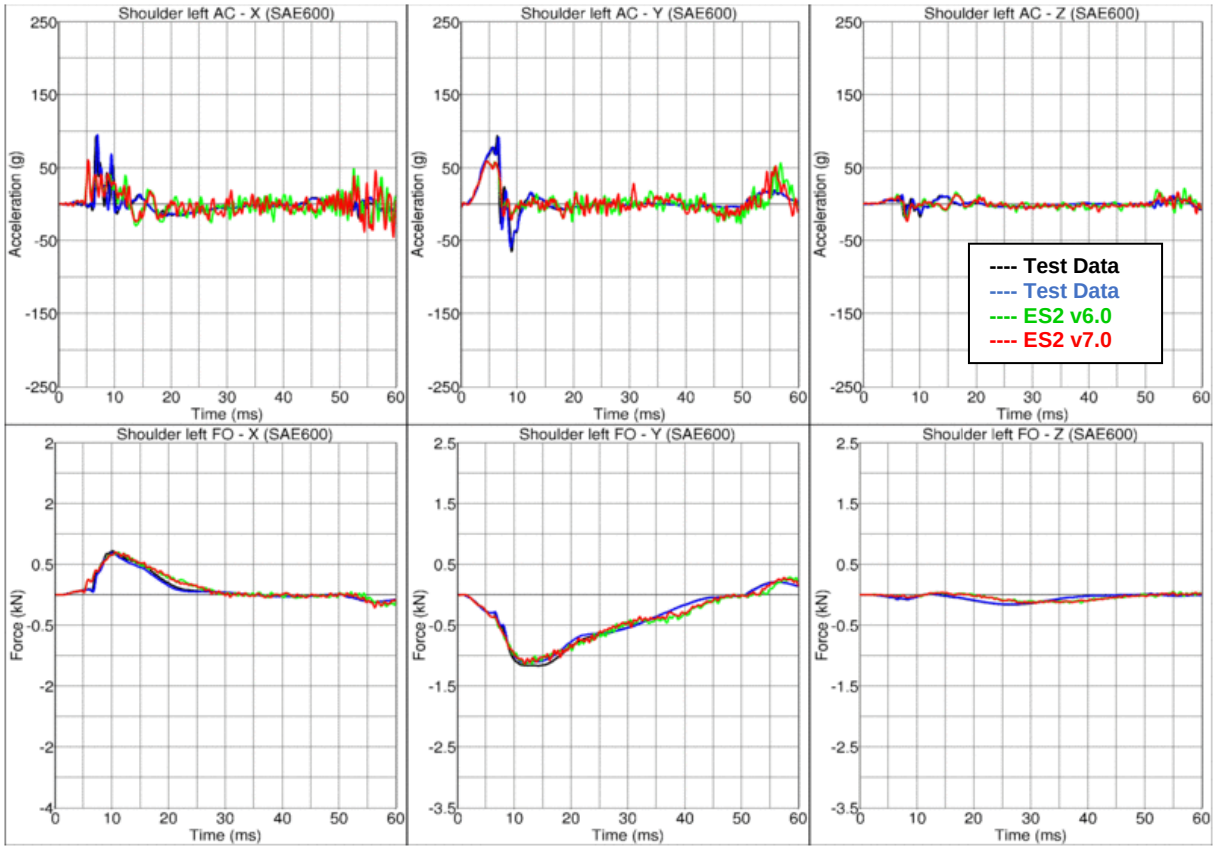




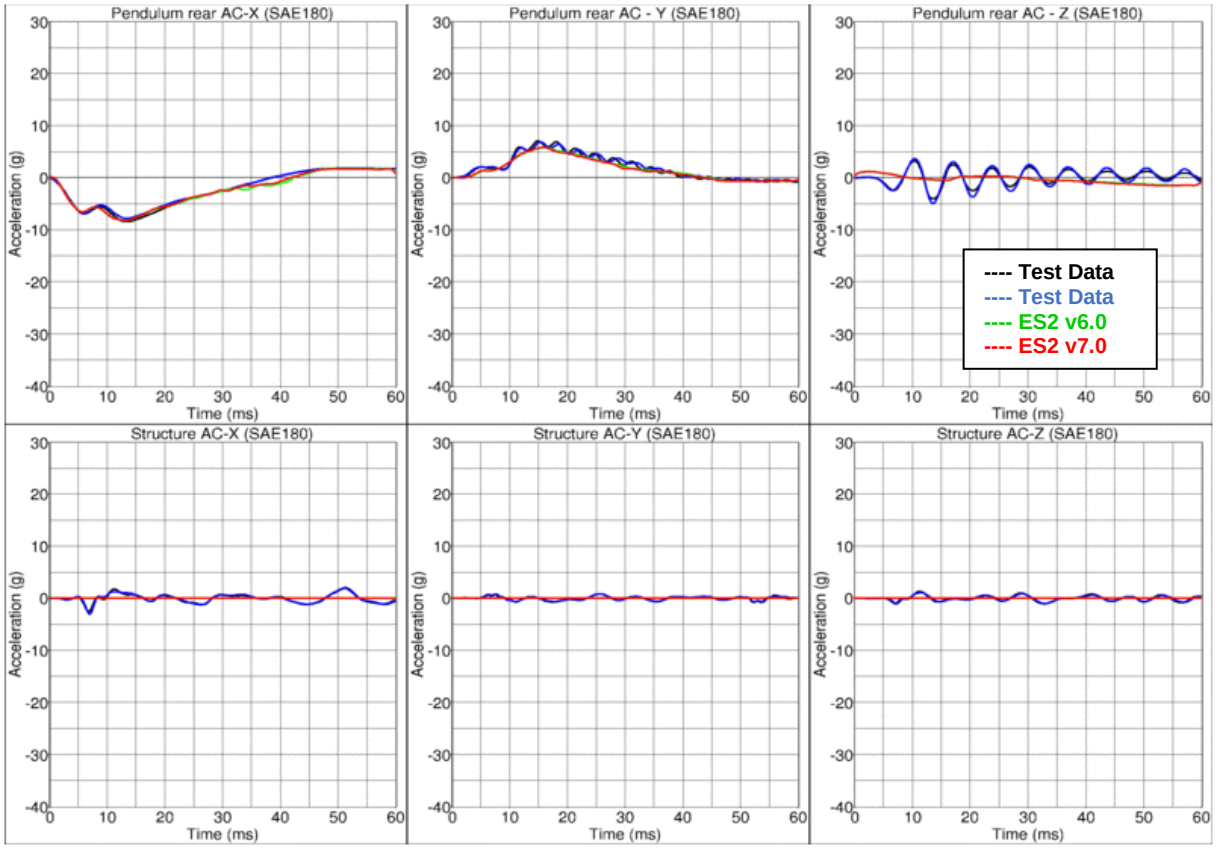
Results for Y-direction impact, low velocity, w/o clavicle strap (CBYOG)



Claviclebox-Test, CBY3OG, v=3.0m/s



Claviclebox-Test, CBY3OG, v=3.0m/s



11.1.4 Abdomen slab test

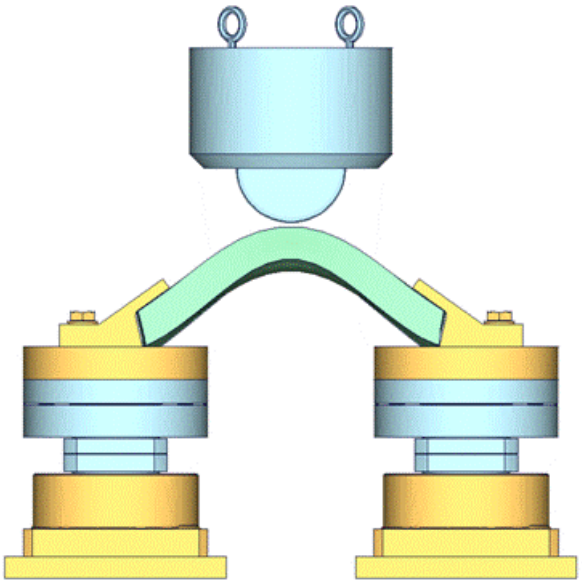
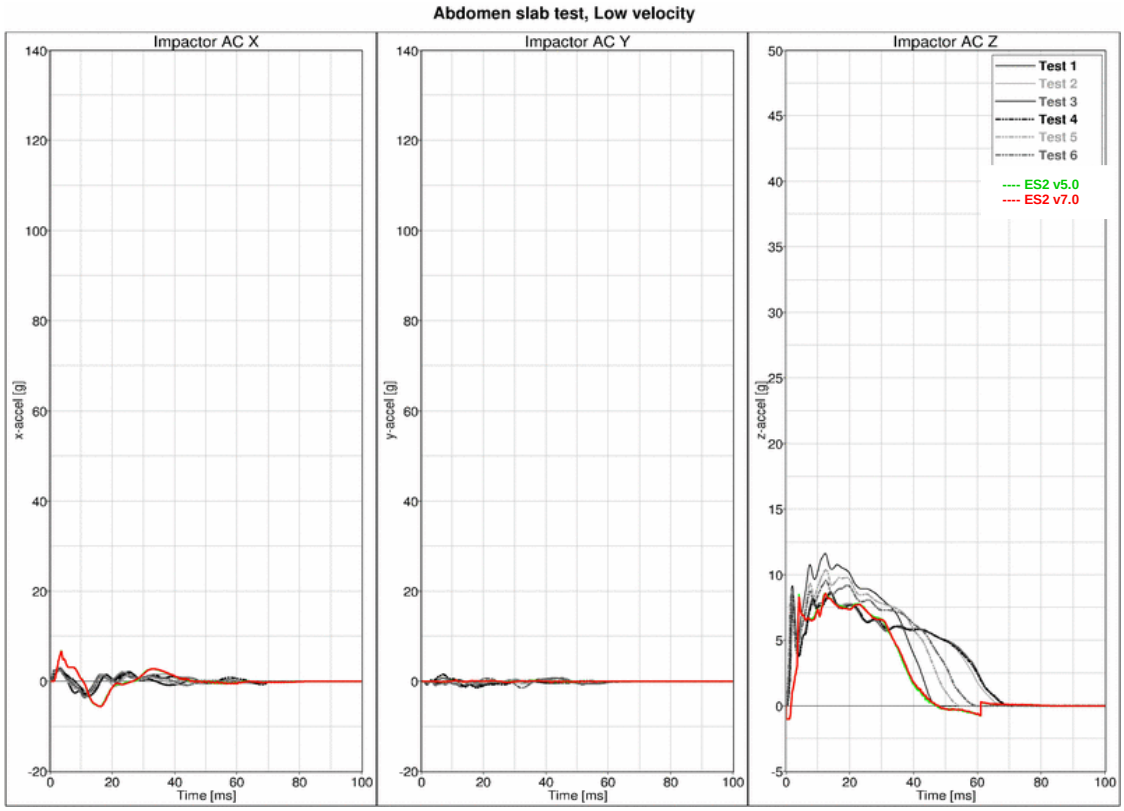
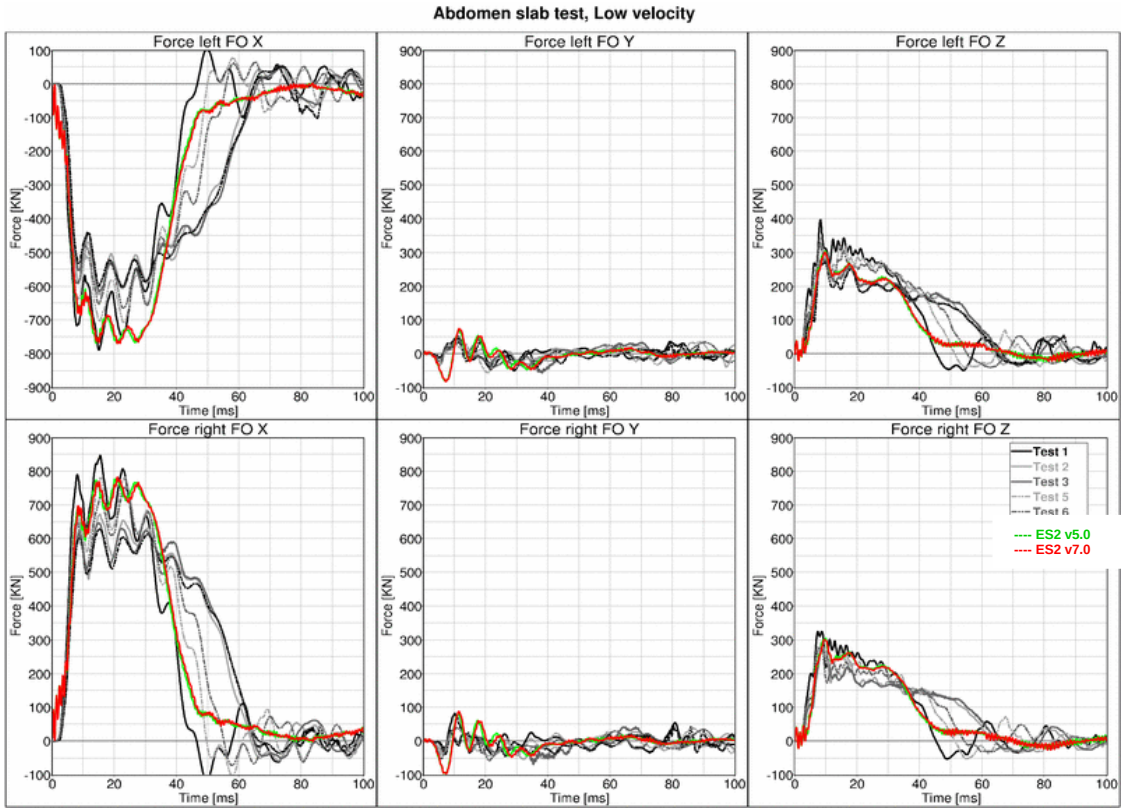


Figure 29: Test setup for Abdomen slab test

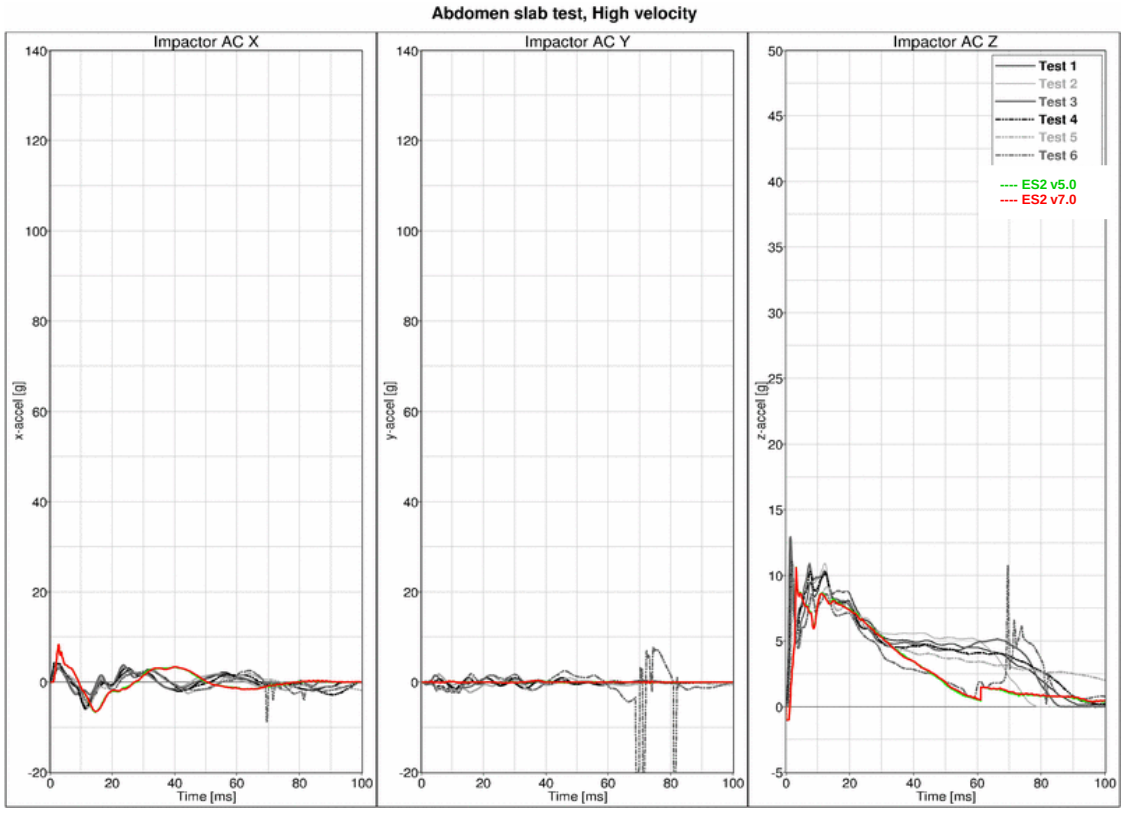
For the abdomen slab component test, the abdomen slab is held in a fixed position by two fixtures as shown in the figure above. The abdomen slab is impacted by a pendulum at 2 different velocities.
Between v6.0 and v7.0 are no changes in the slab. Due to this the results of the v7.0 are compared to a previous version of the slab which showed different results. Results of v6.0 and v7.0 are identical.

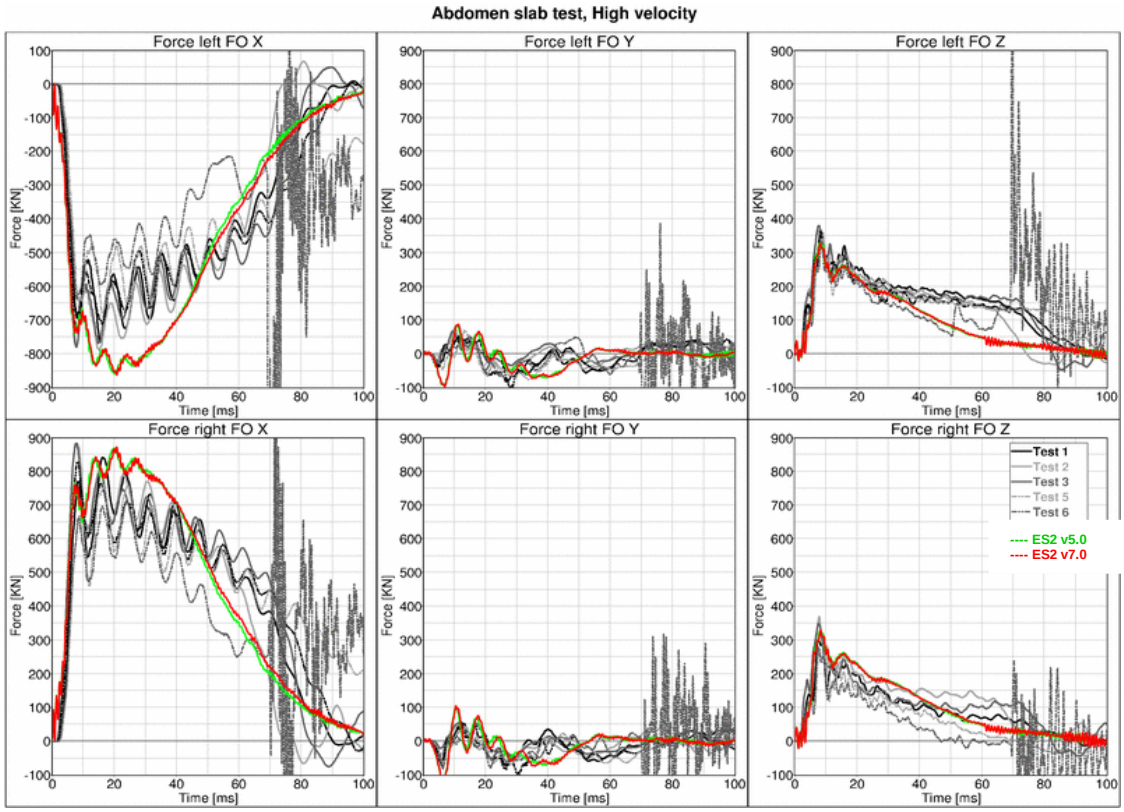
Results for low velocity impact





Results for high velocity impact





11.1.5 Abdomen test

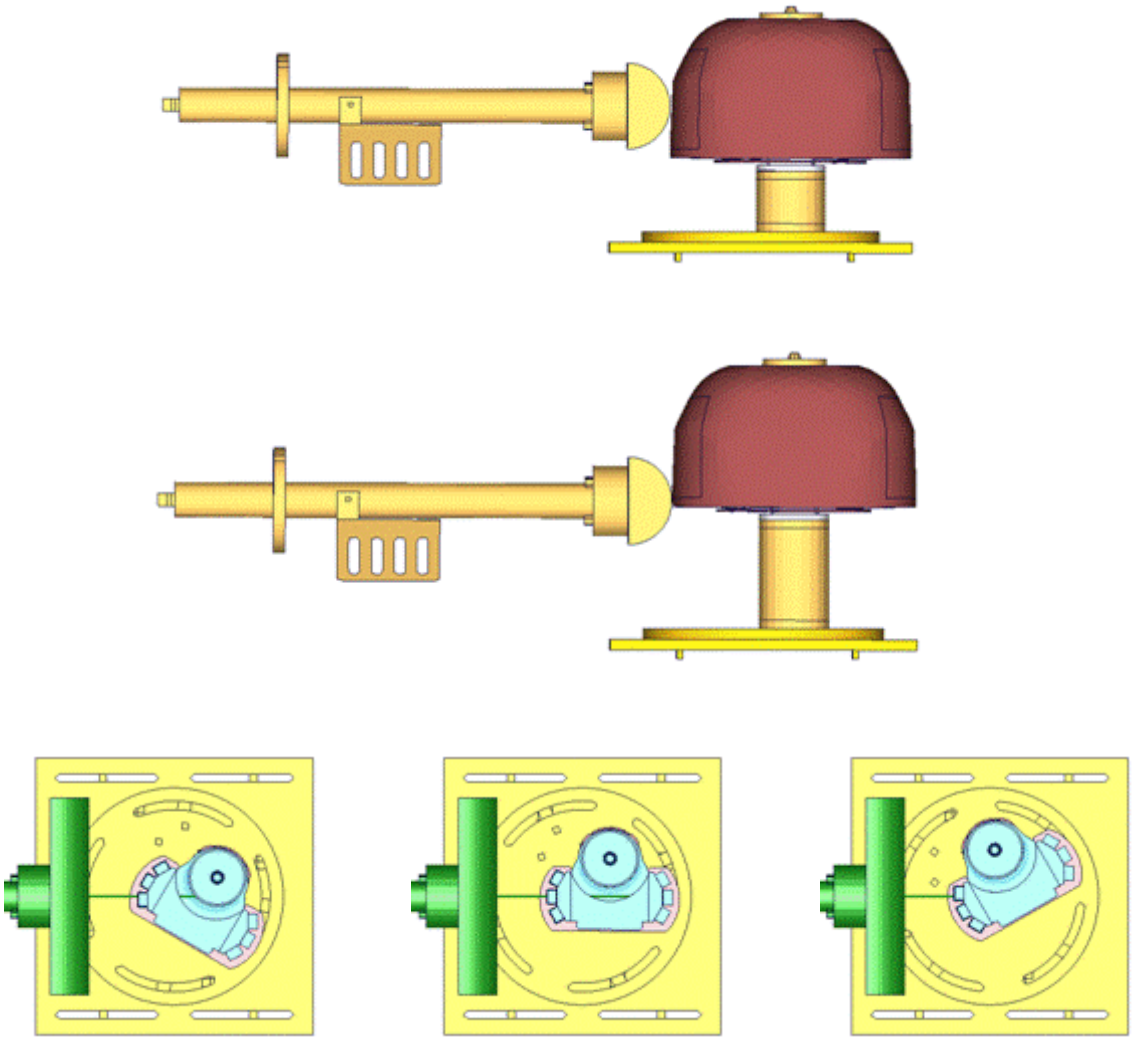
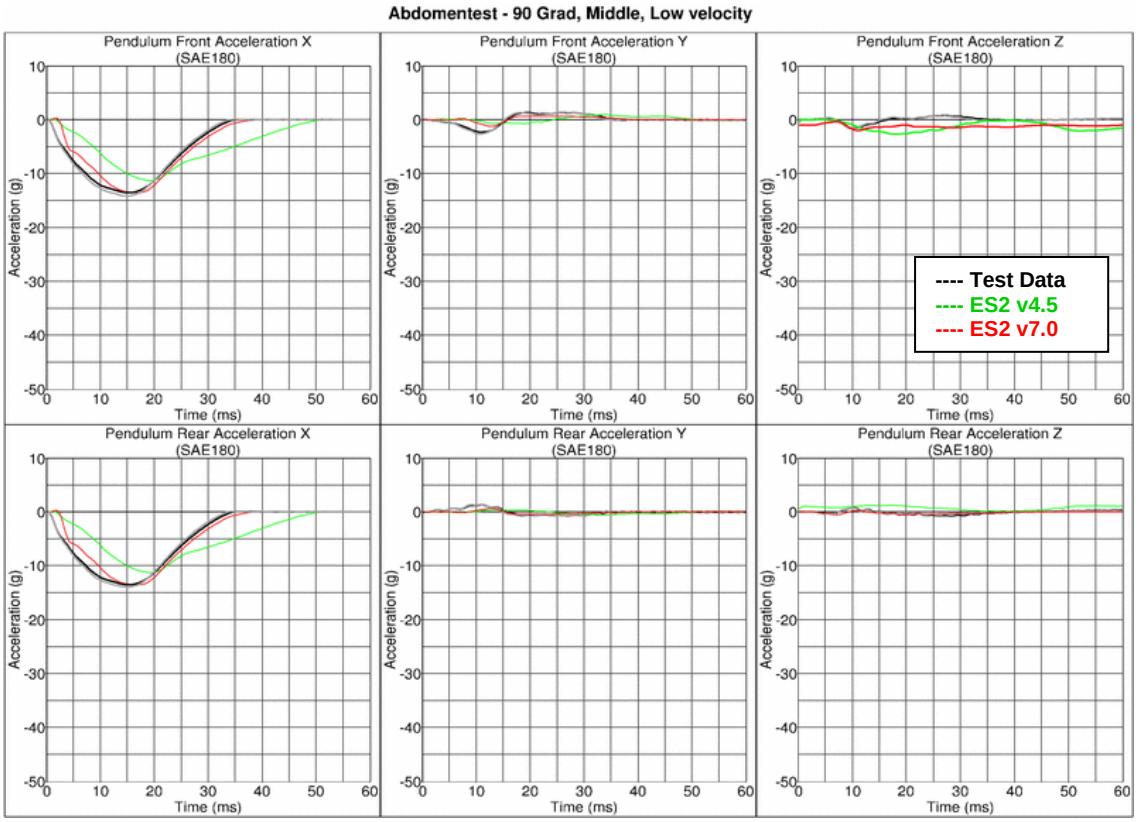
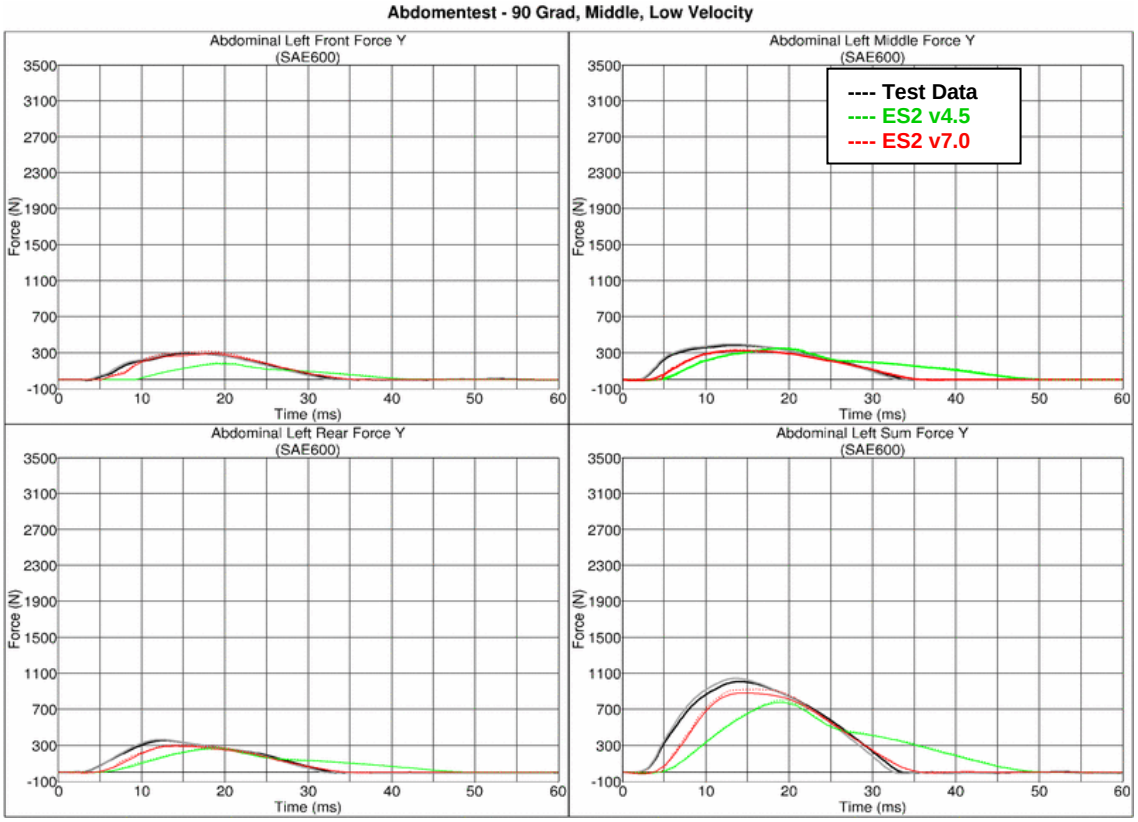


Figure 30: Test setup for Abdomen test

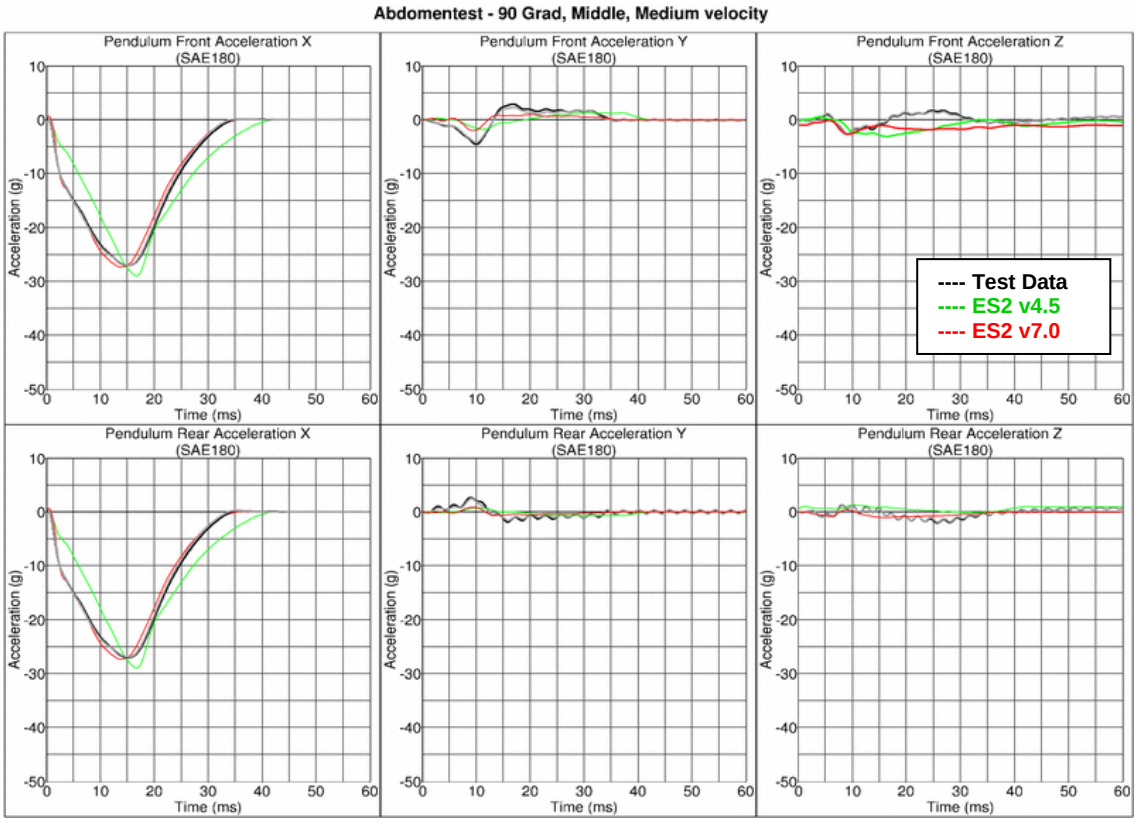
The test setup for the abdomen test is shown in the figure above. The Abdomen assembly is impacted by a pendulum at 2 different heights with 3 different velocities and 3 different abdomen assembly orientations each. The different abdomen assembly orientations are achieved by rotating the abdomen assembly by 30 degrees on either side of the adaptor axis.
Between v6.0 and v7.0 are no changes in the abdomen area. Due to this the results of the v7.0 are compared to a previous version of the abdomen which showed different results. Results of v6.0 and v7.0 are identical.

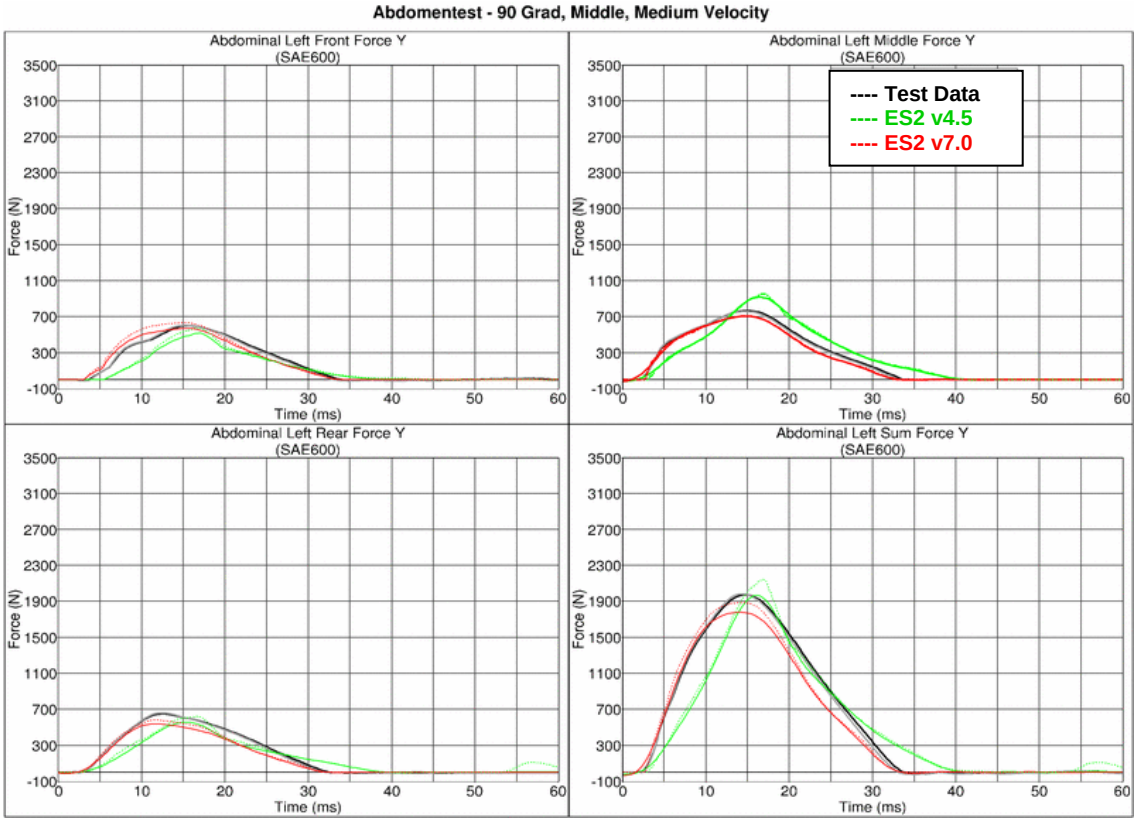
Results for 90° orientation, middle impact, low velocity



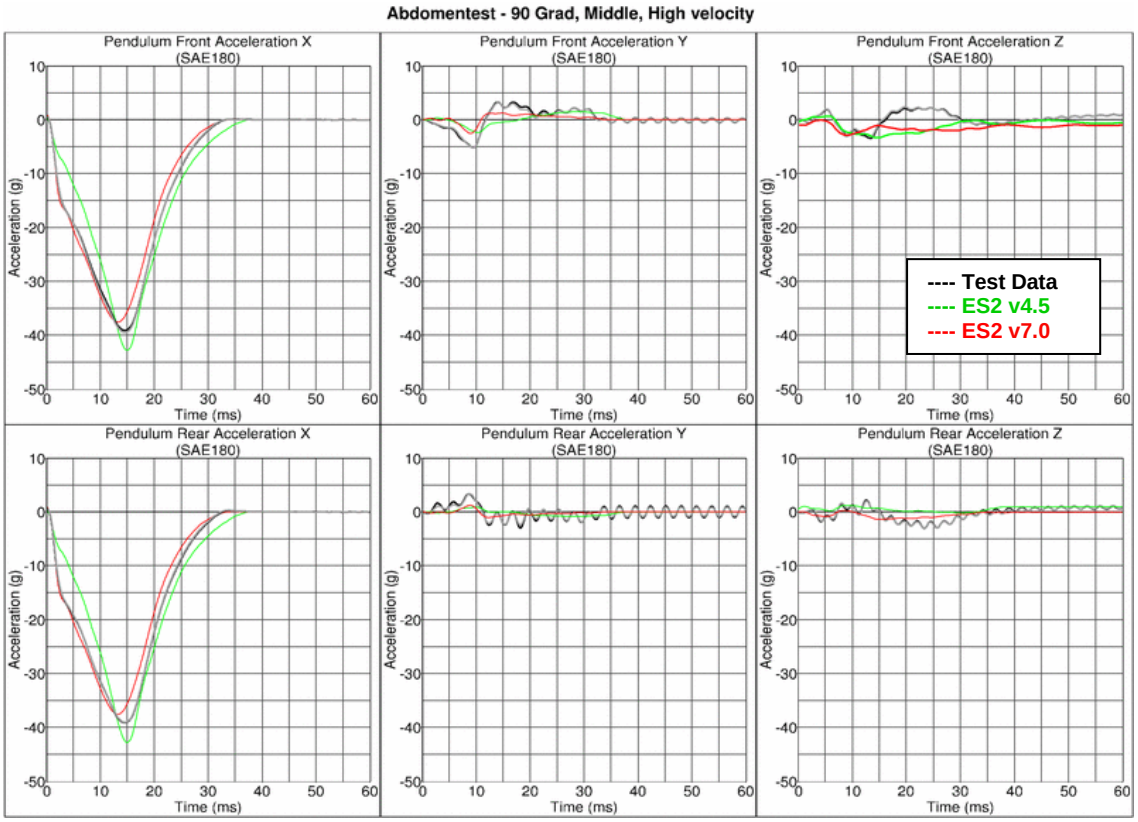


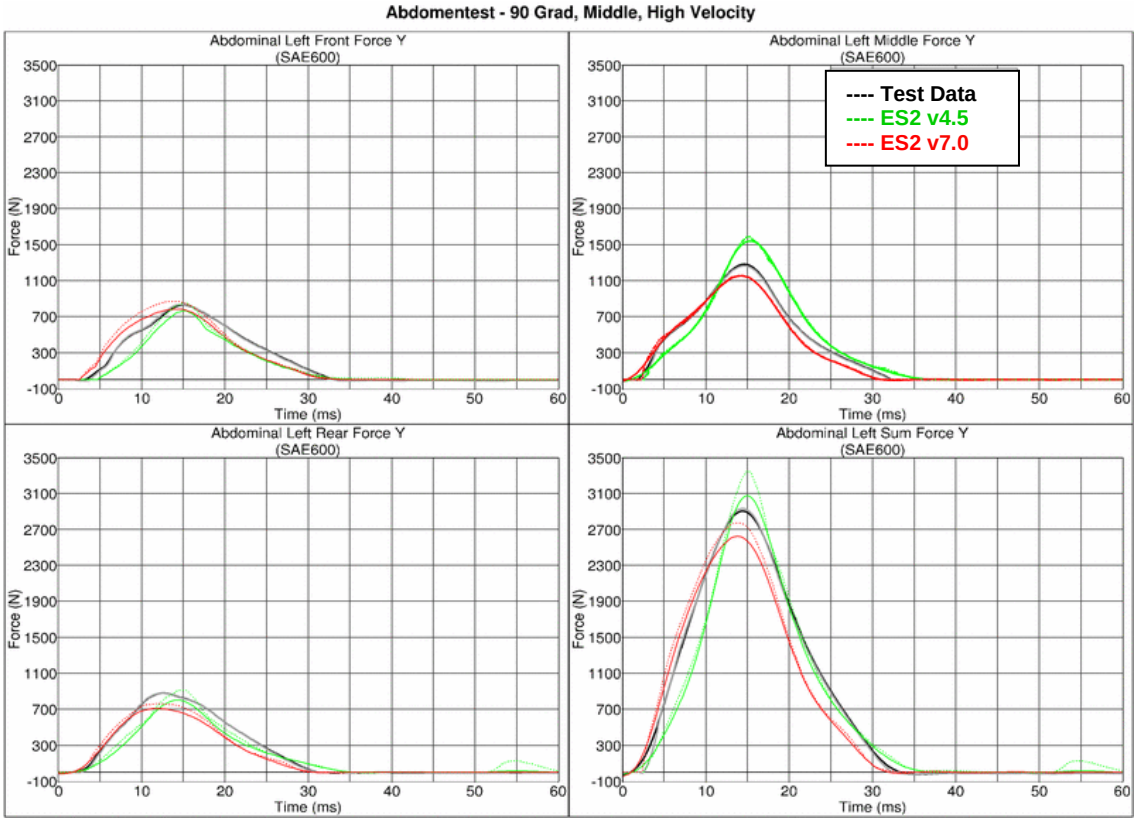
Results for 90° orientation, middle impact, medium velocity



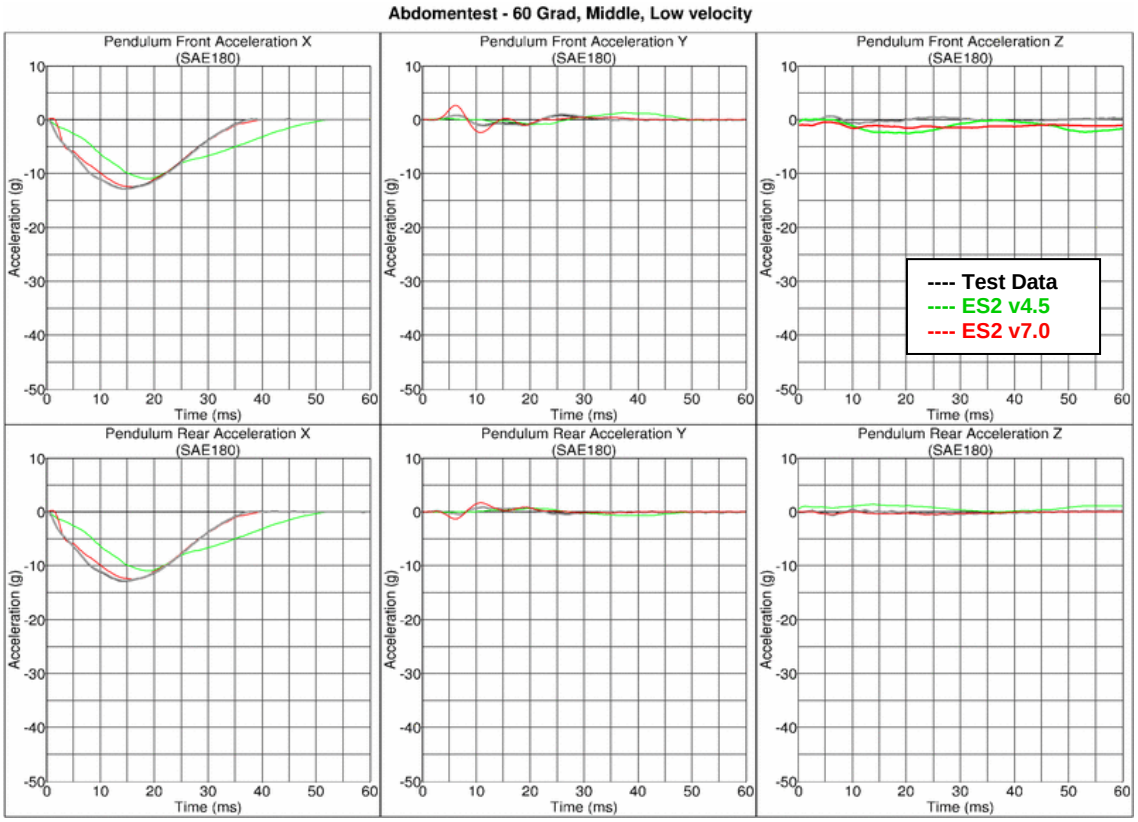


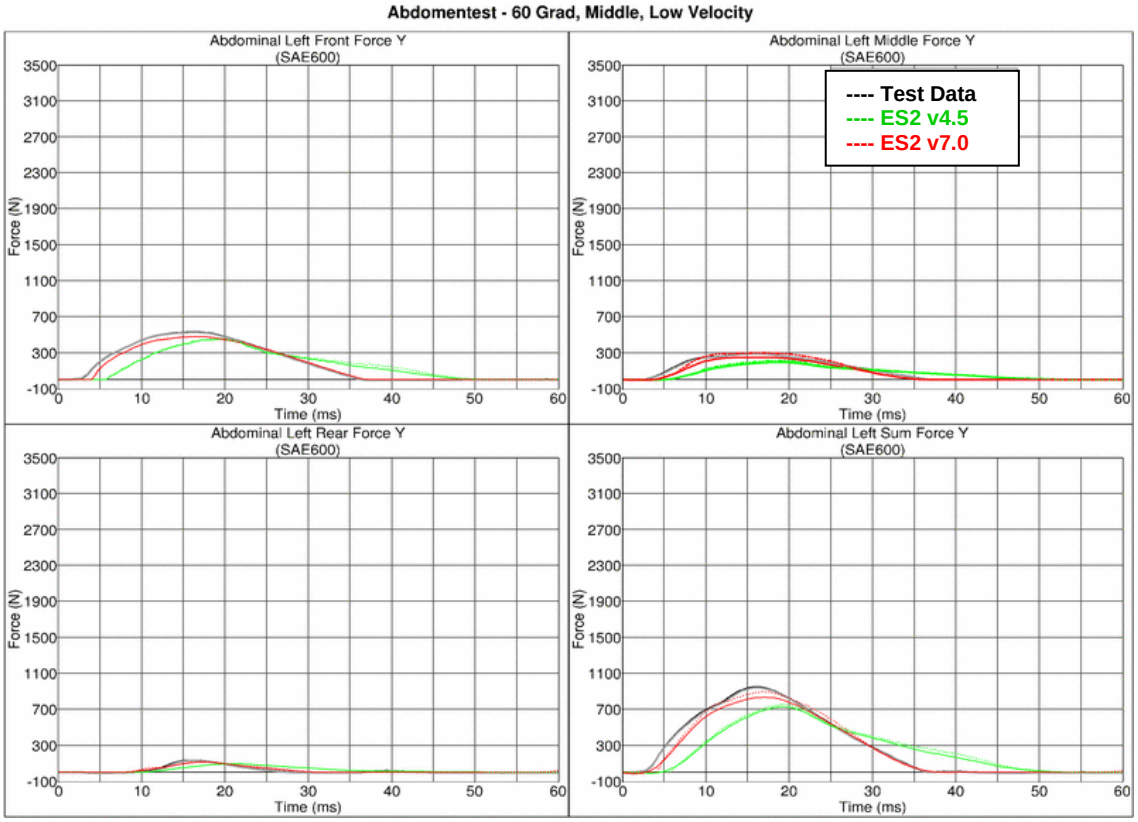
Results for 90° orientation, middle impact, high velocity



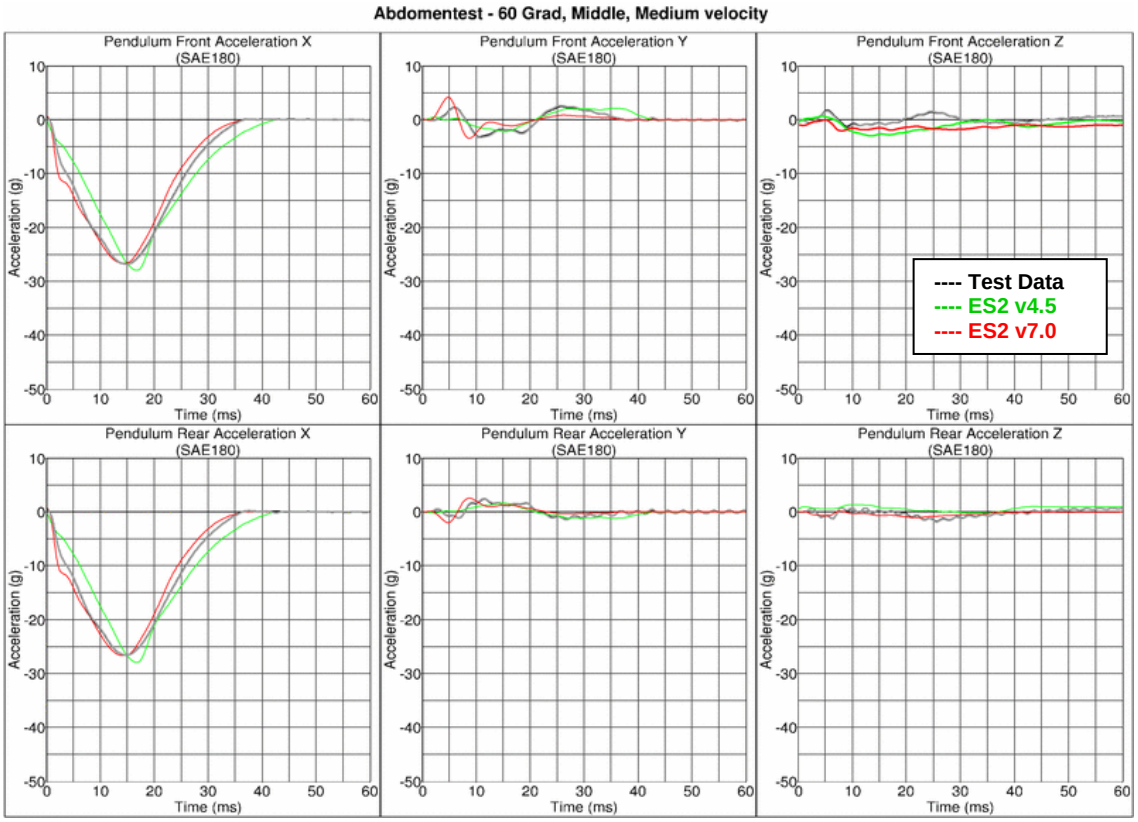


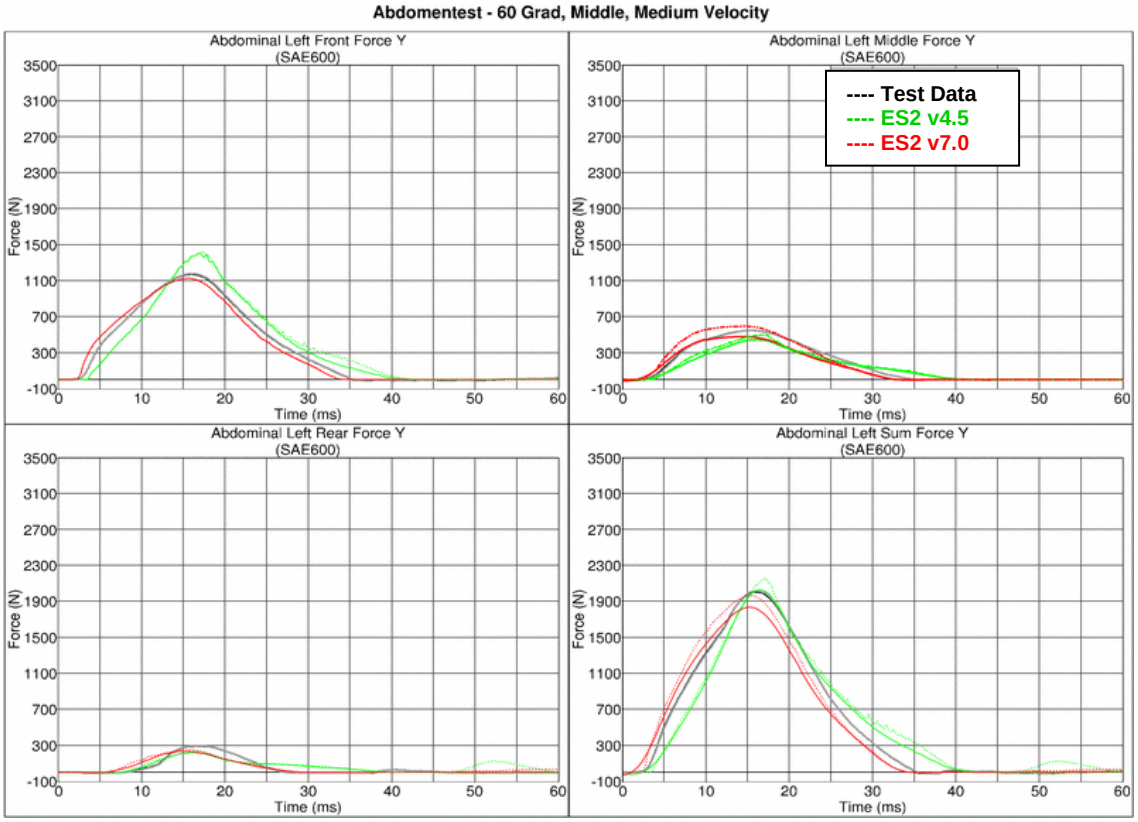
Results for 60° orientation, middle impact, low velocity



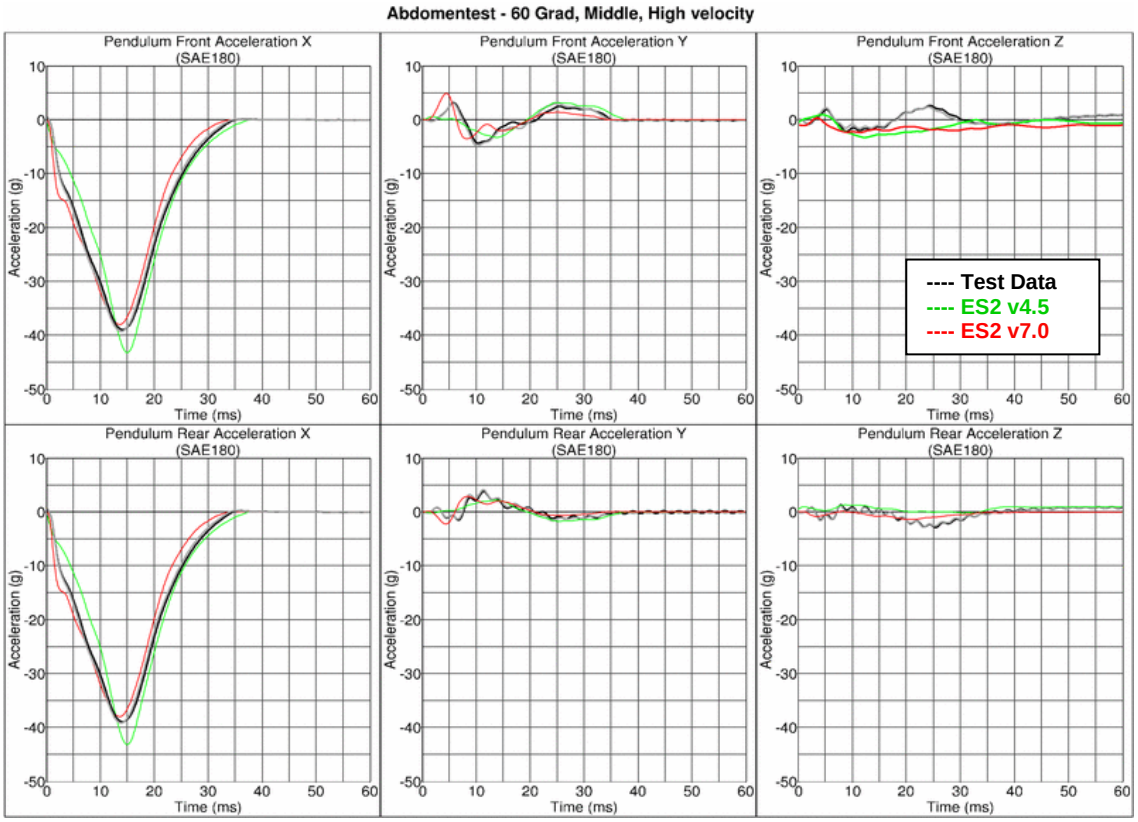


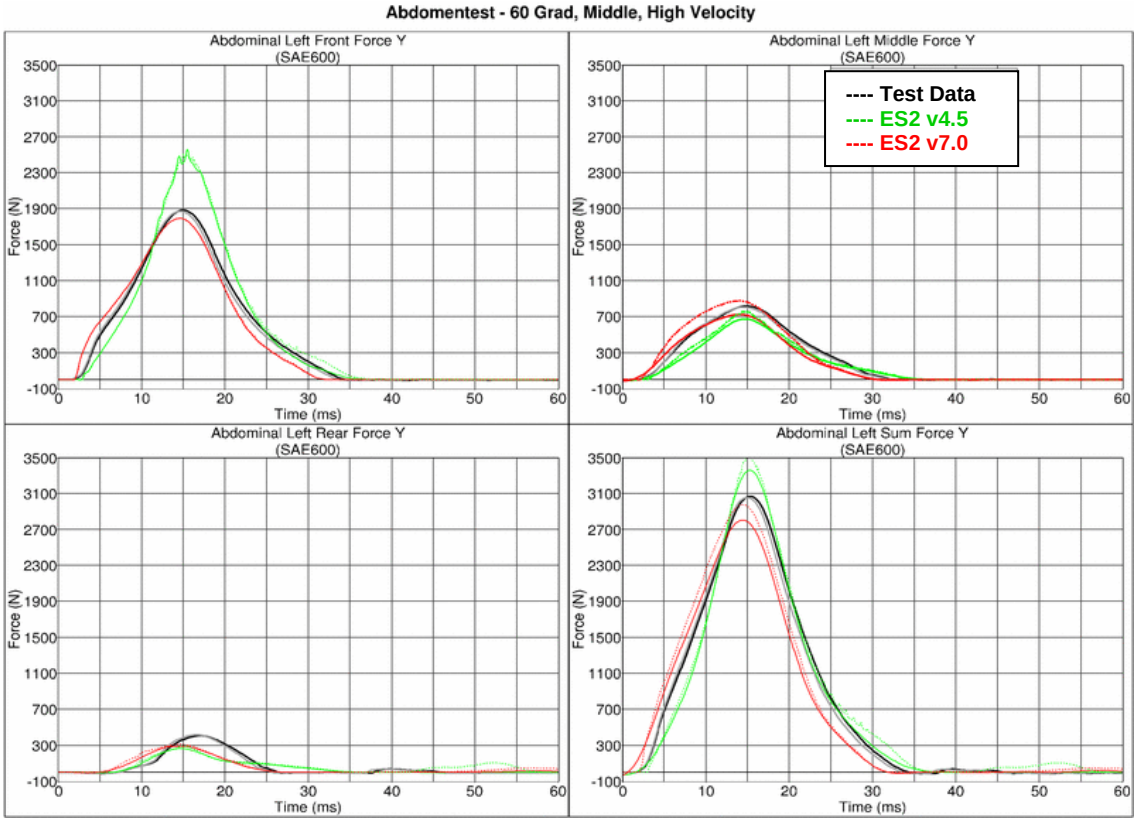
Results for 60° orientation, middle impact, medium velocity



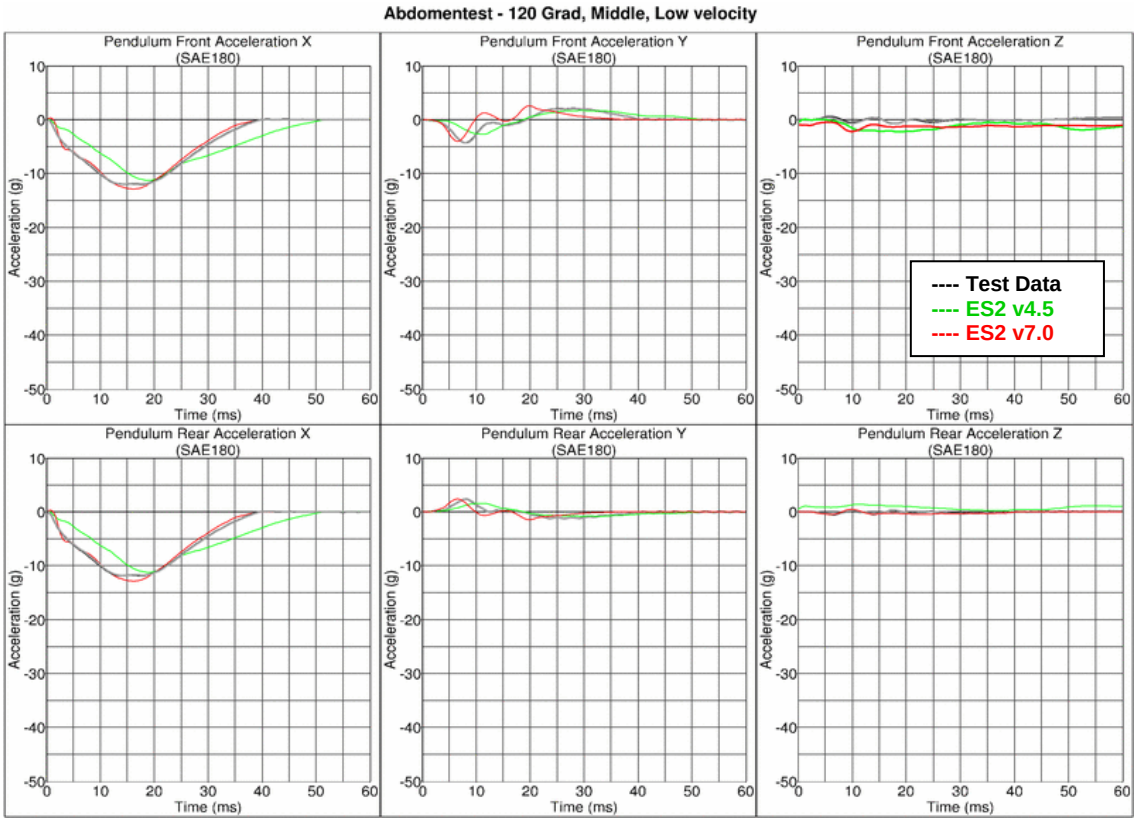


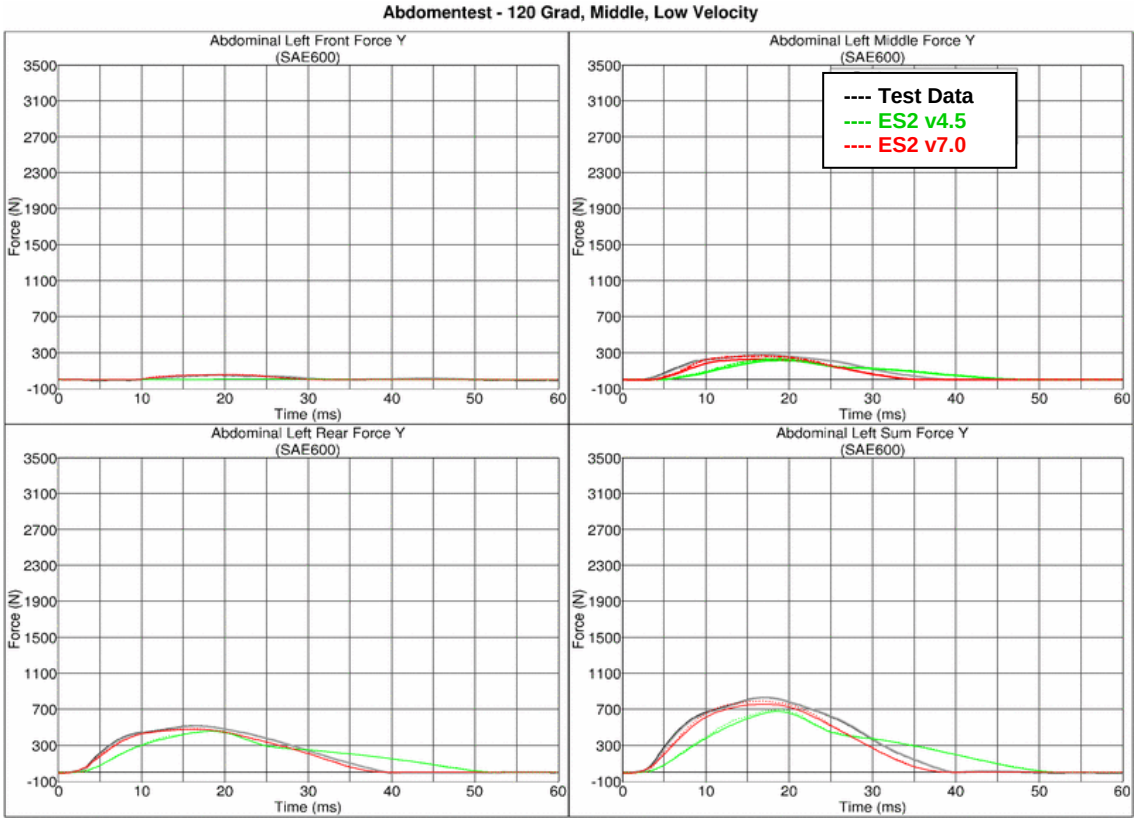
Results for 60° orientation, middle impact, high velocity



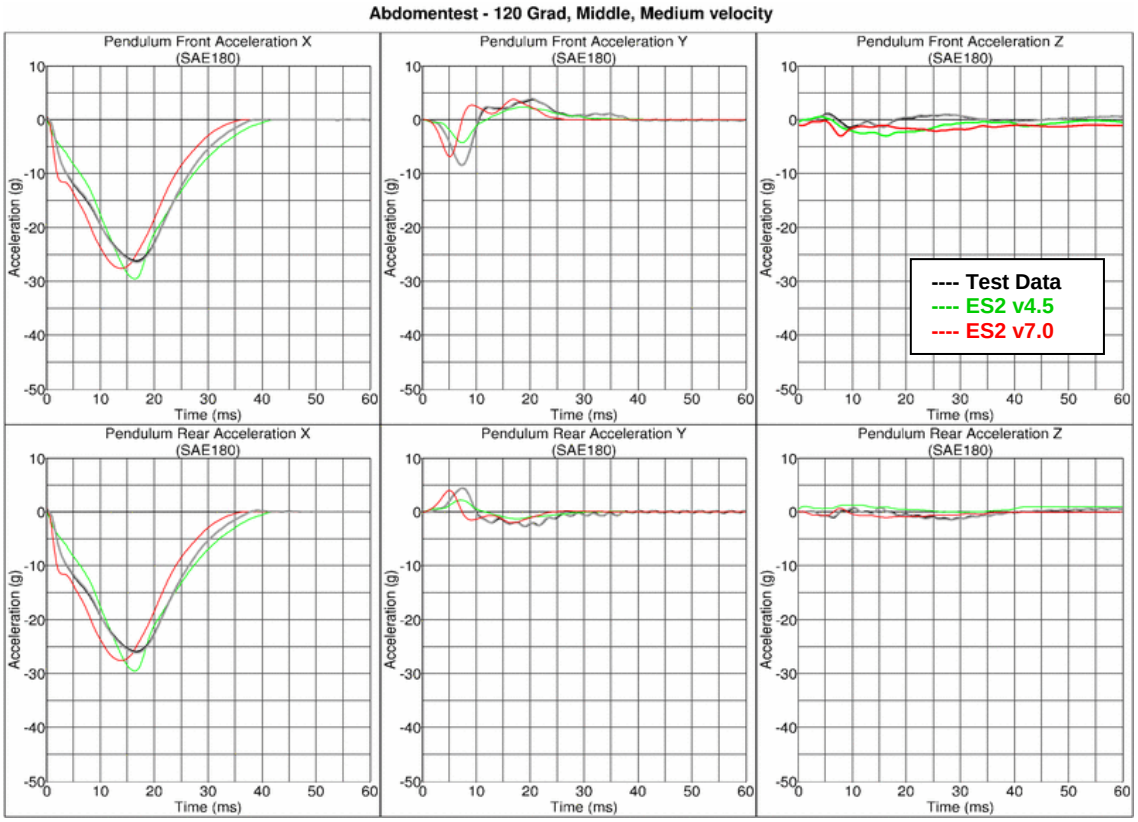


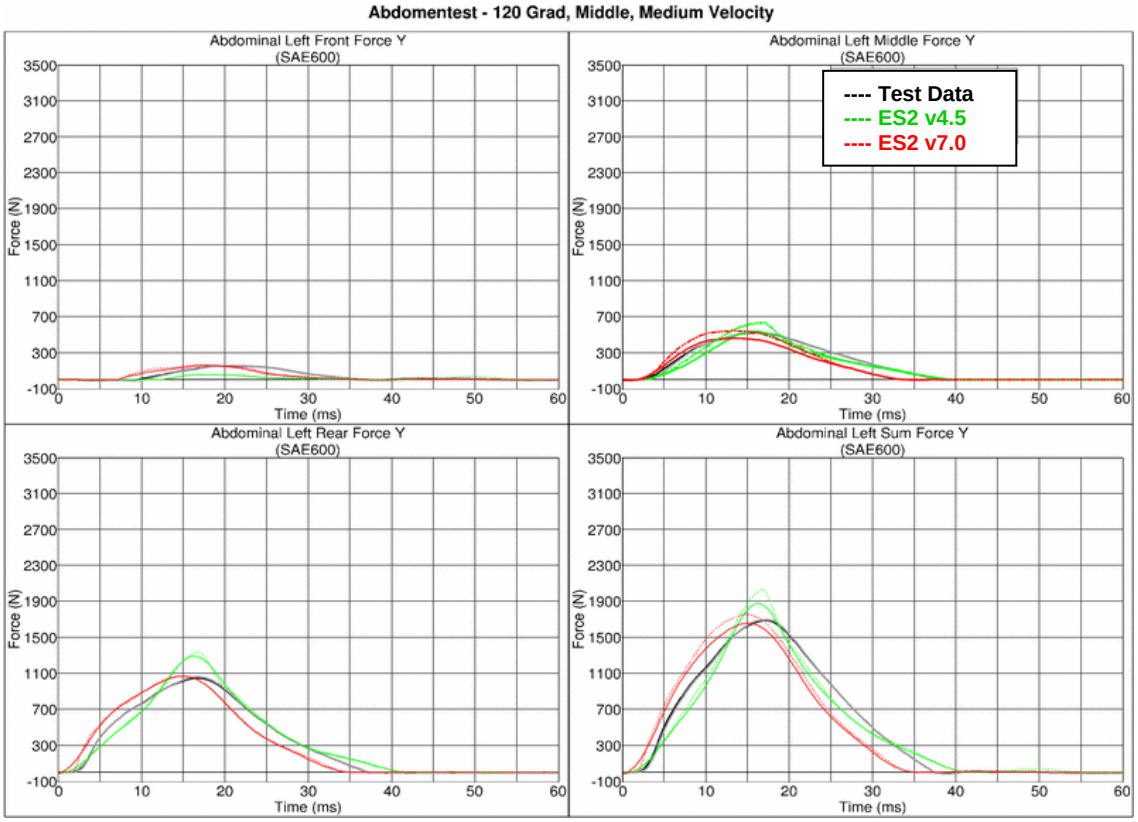
Results for 120° orientation, middle impact, low velocity



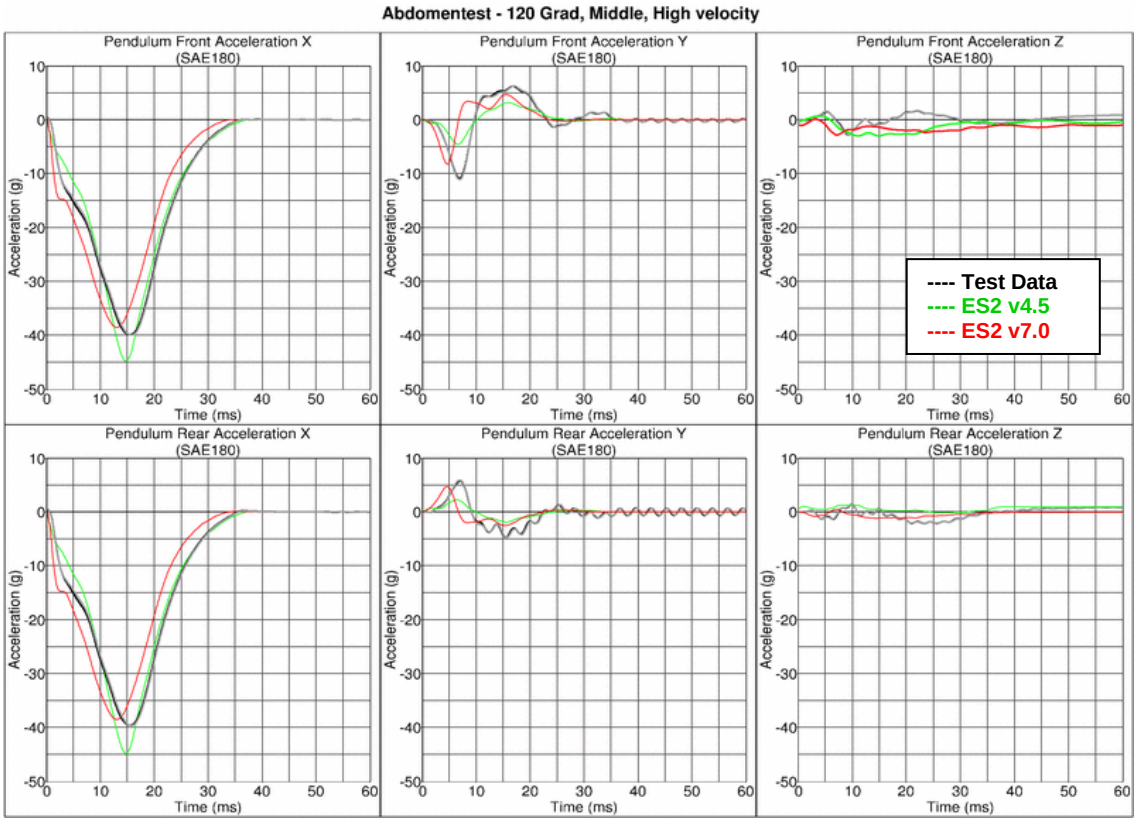


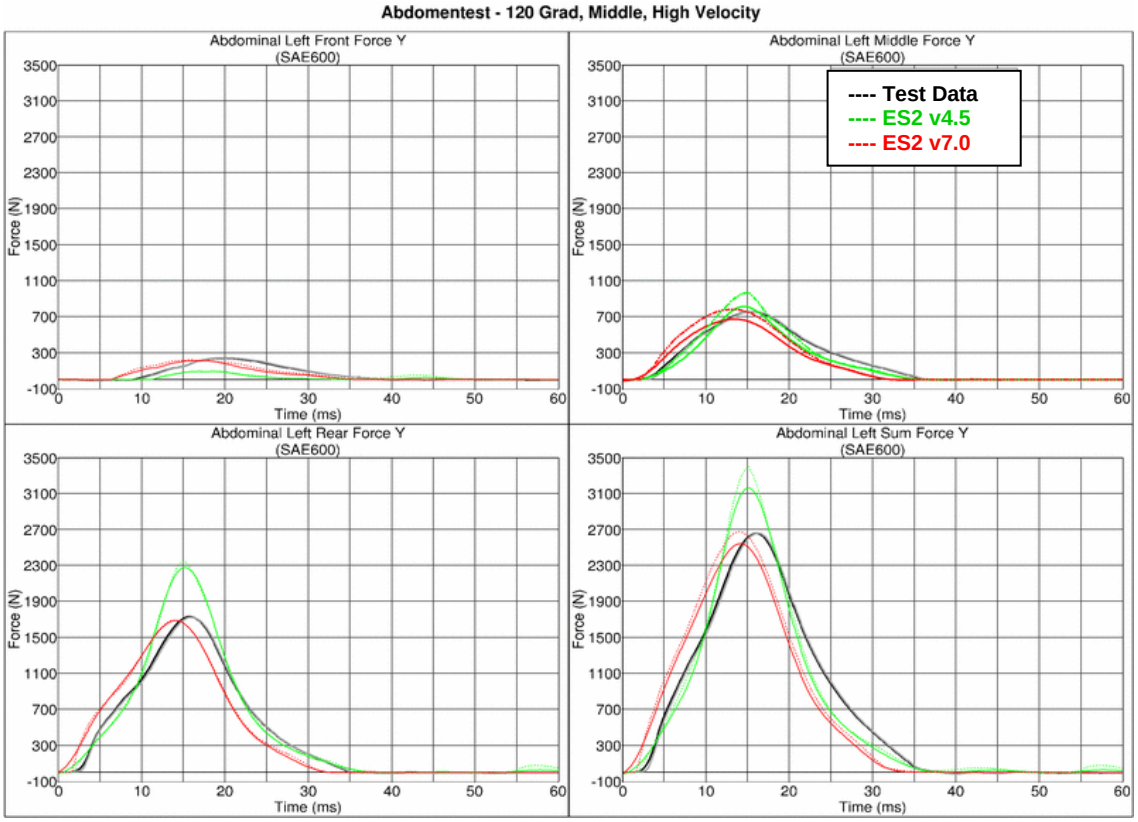
Results for 120° orientation, middle impact, medium velocity



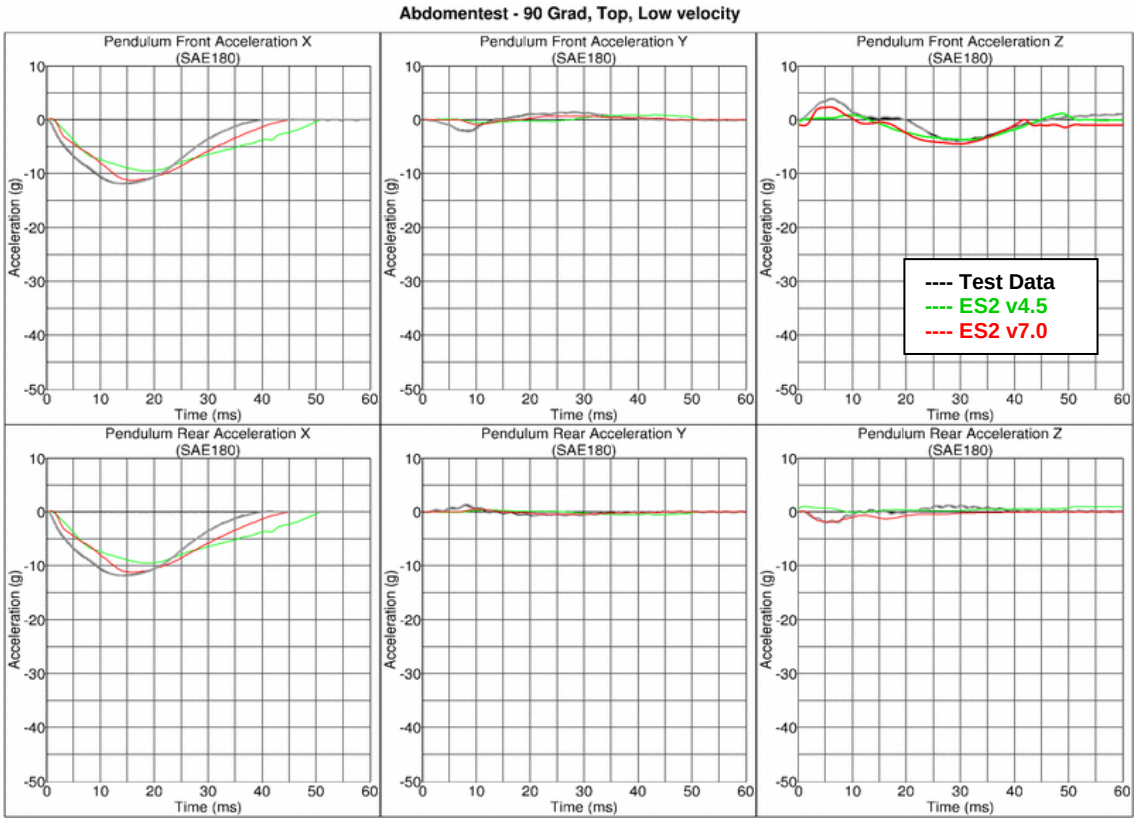


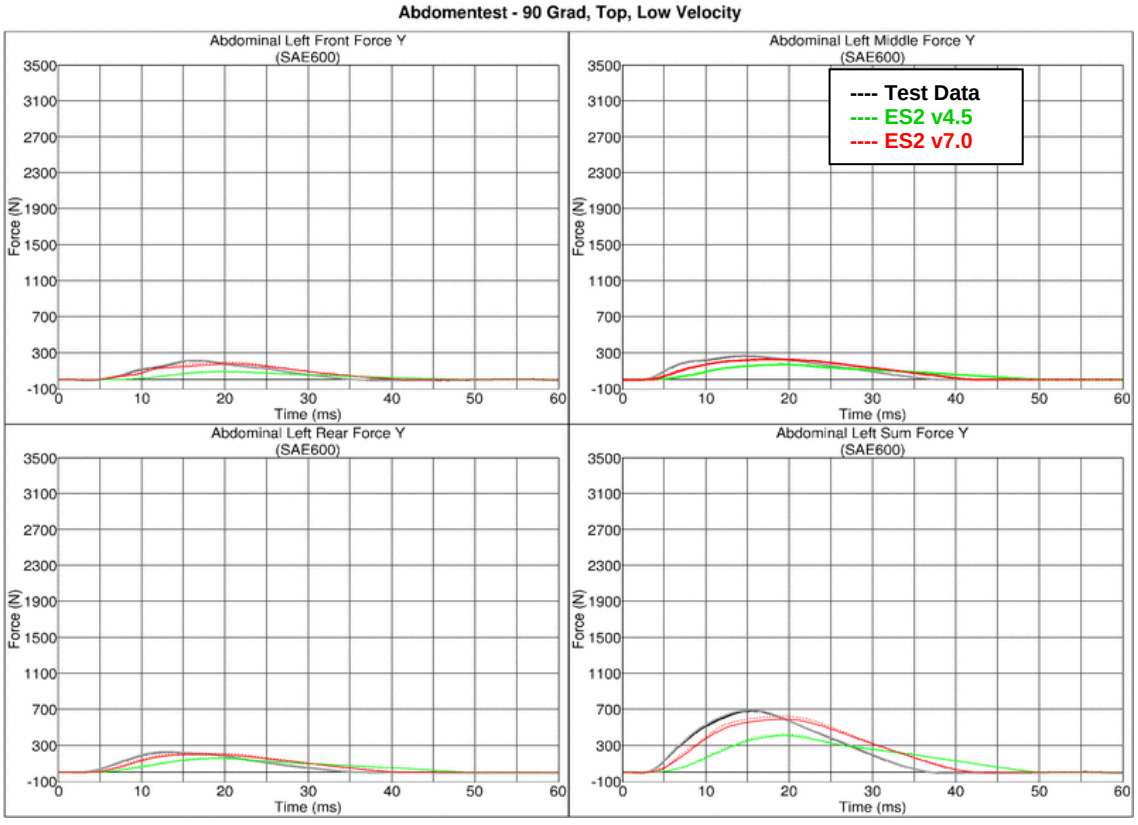
Results for 120° orientation, middle impact, high velocity



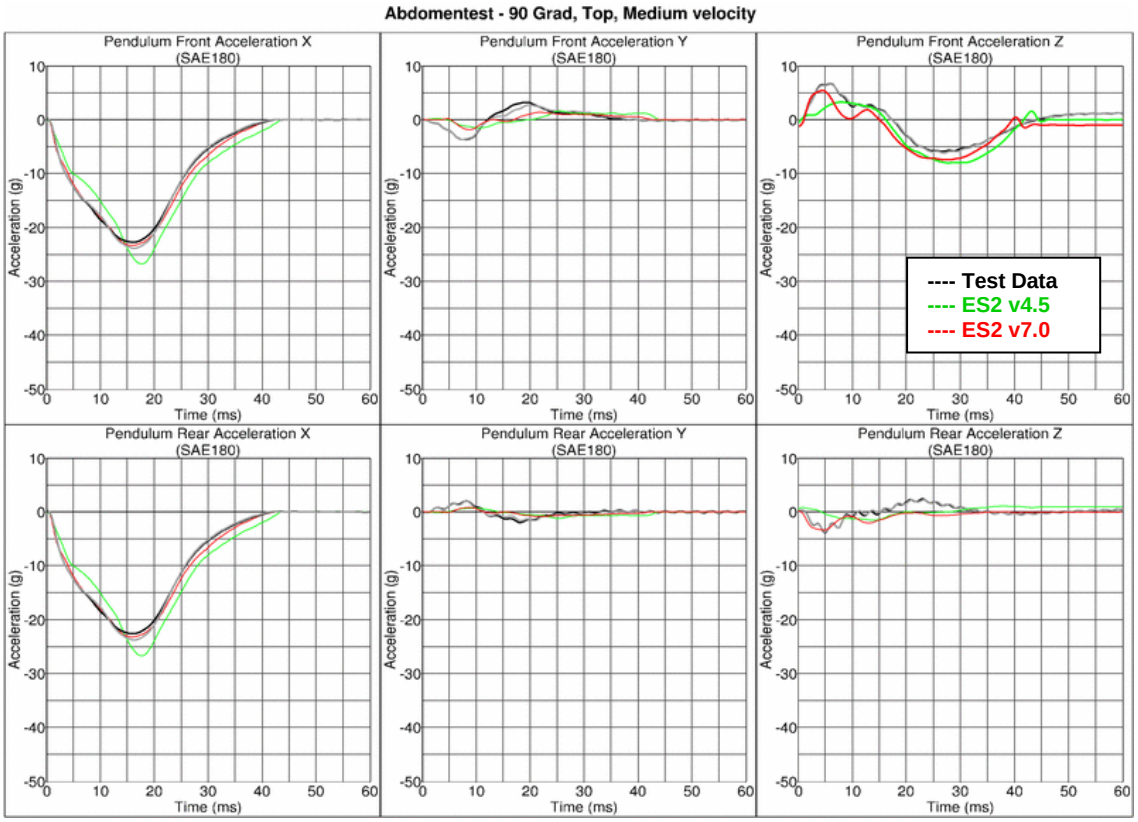


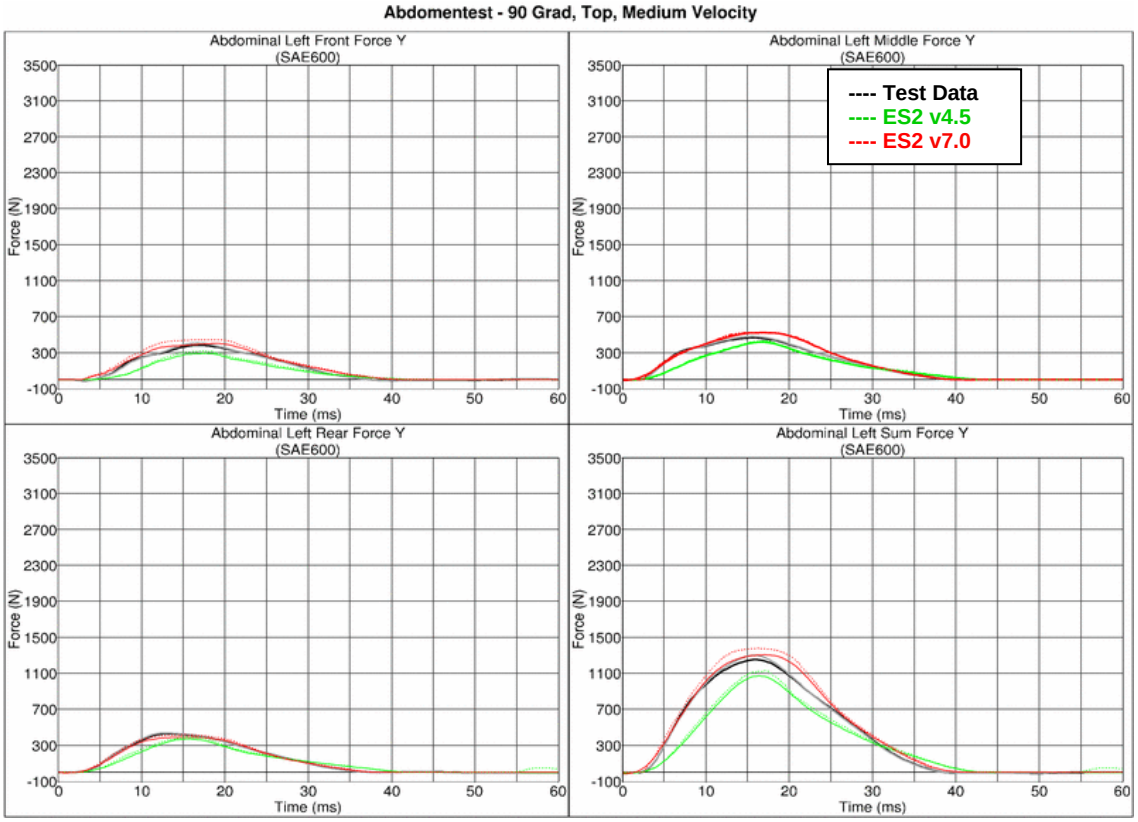
Results for 90° orientation, top impact, low velocity



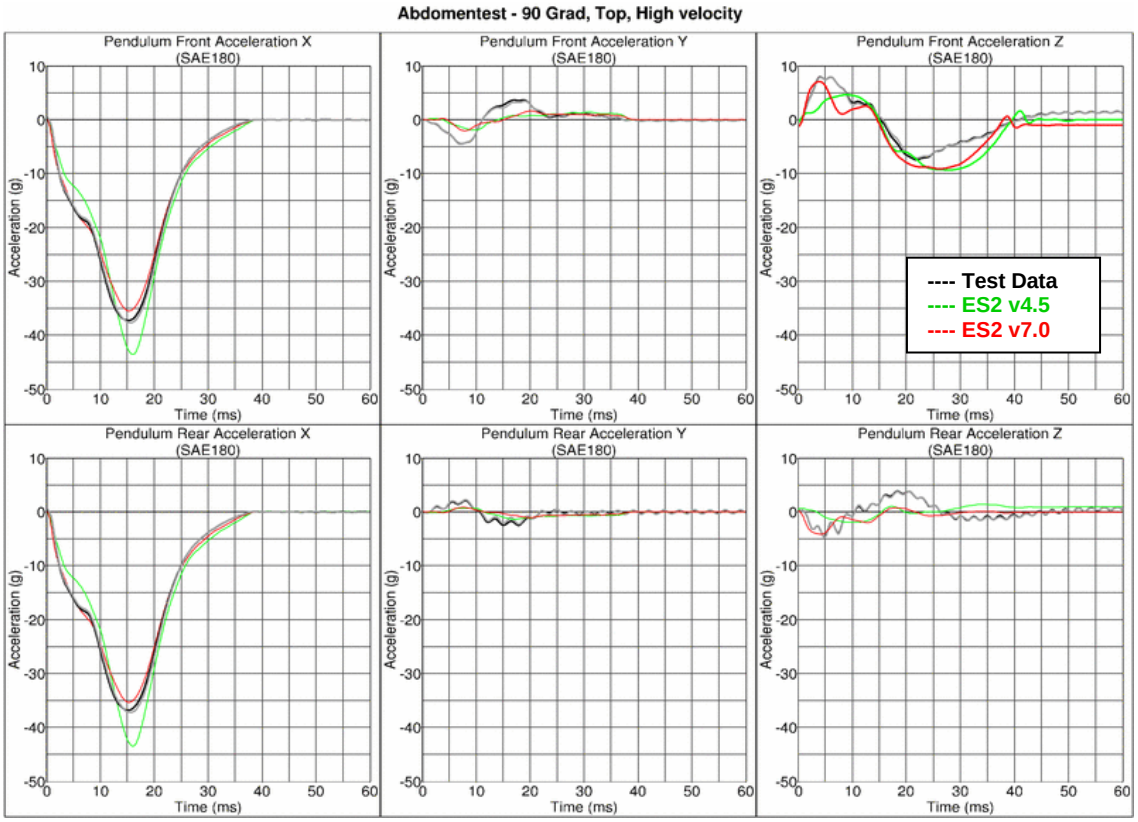


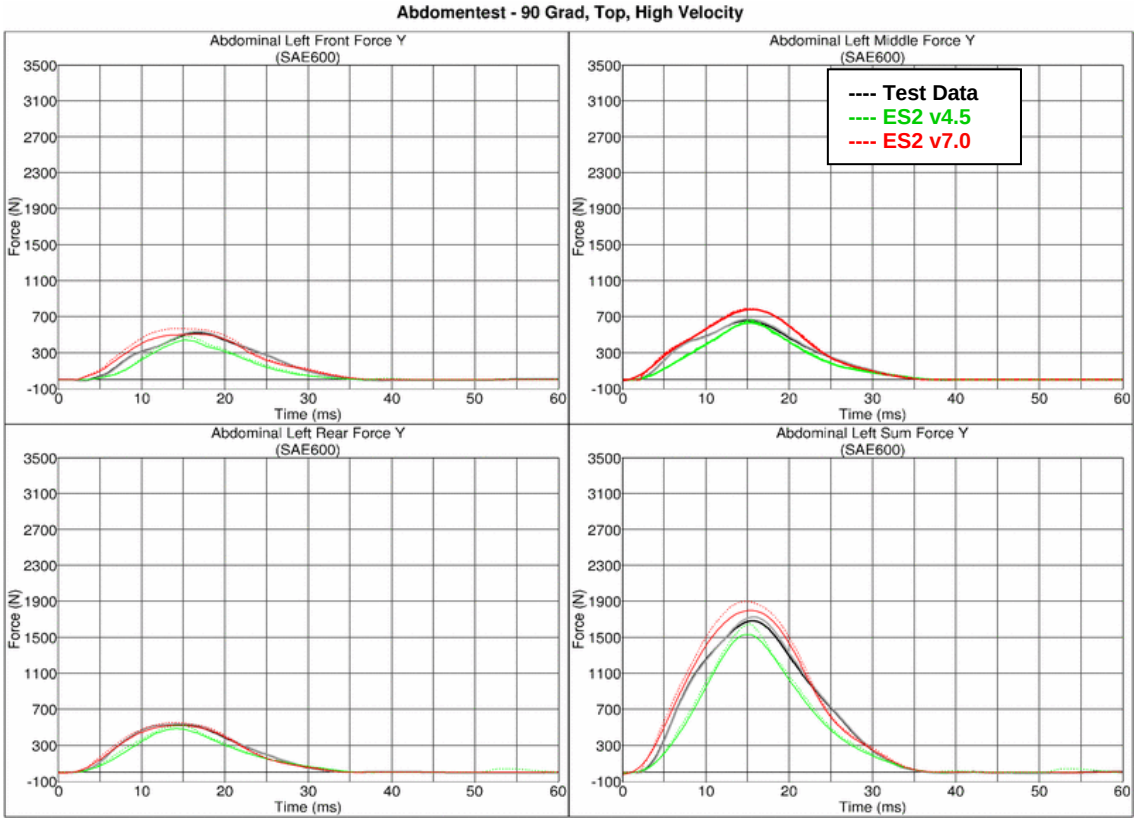
Results for 90° orientation, top impact, medium velocity



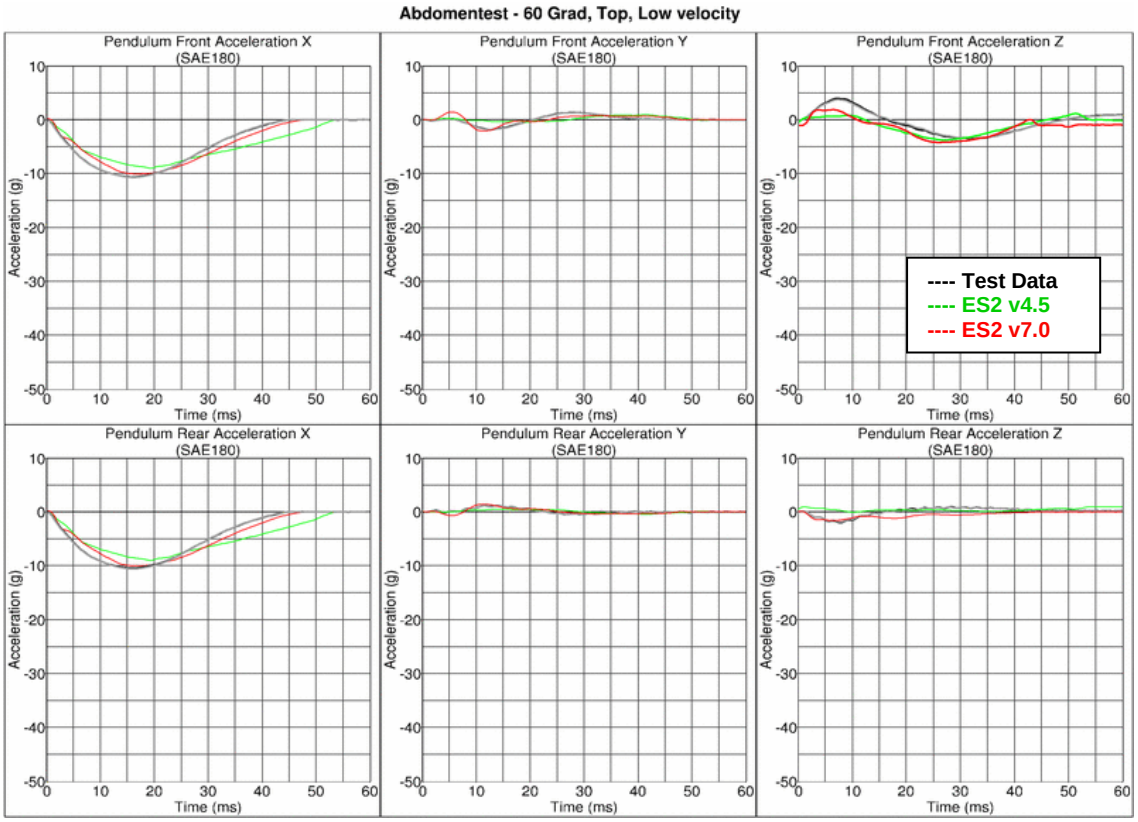


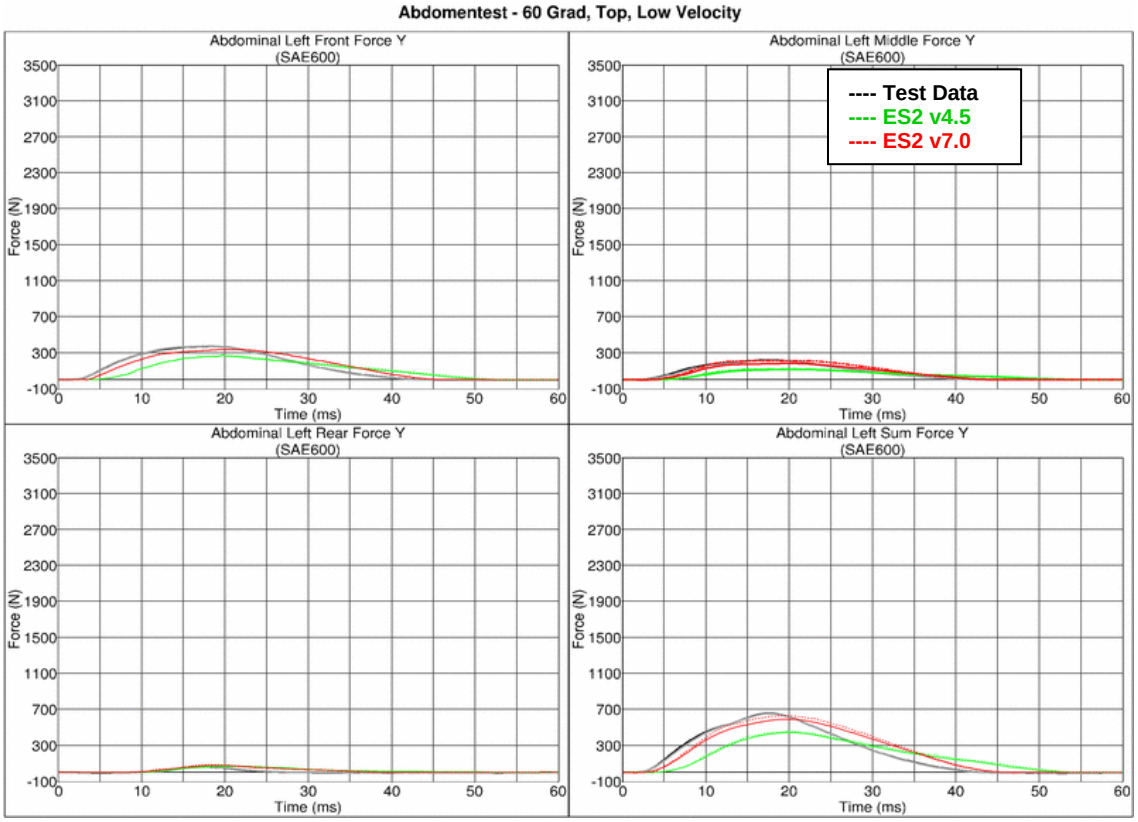
Results for 90° orientation, top impact, high velocity



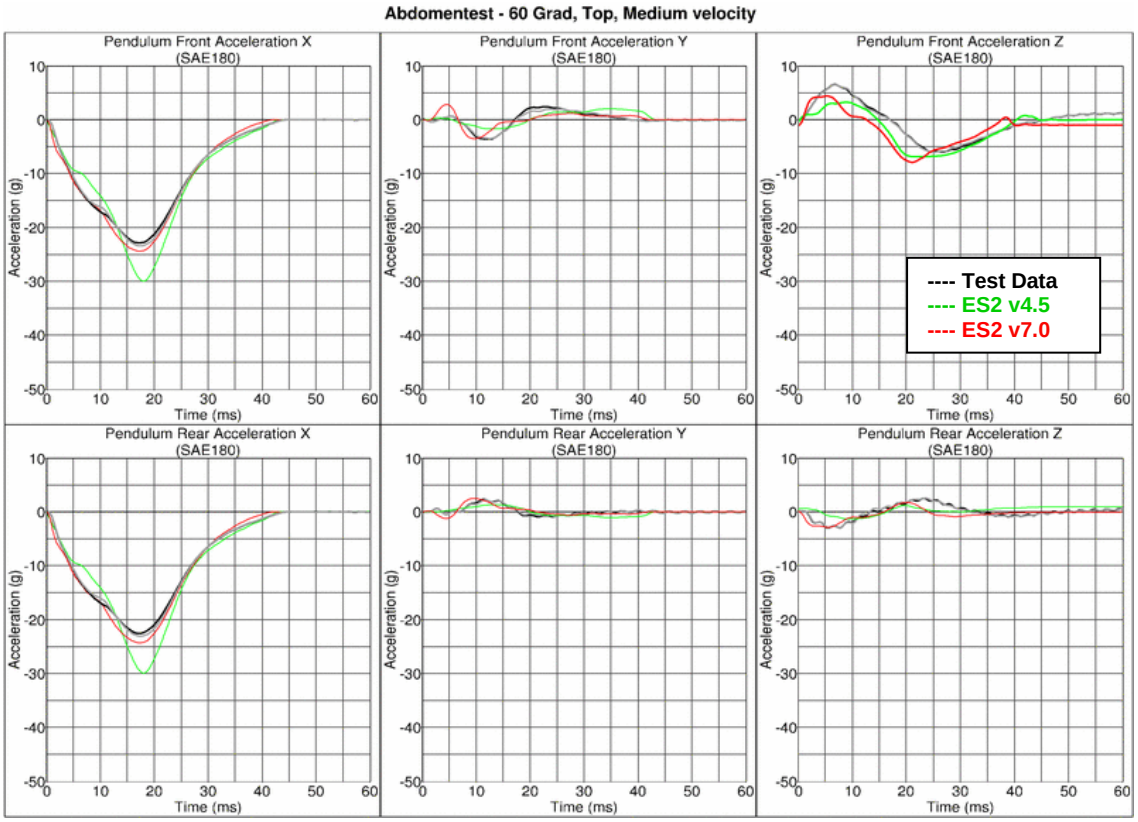


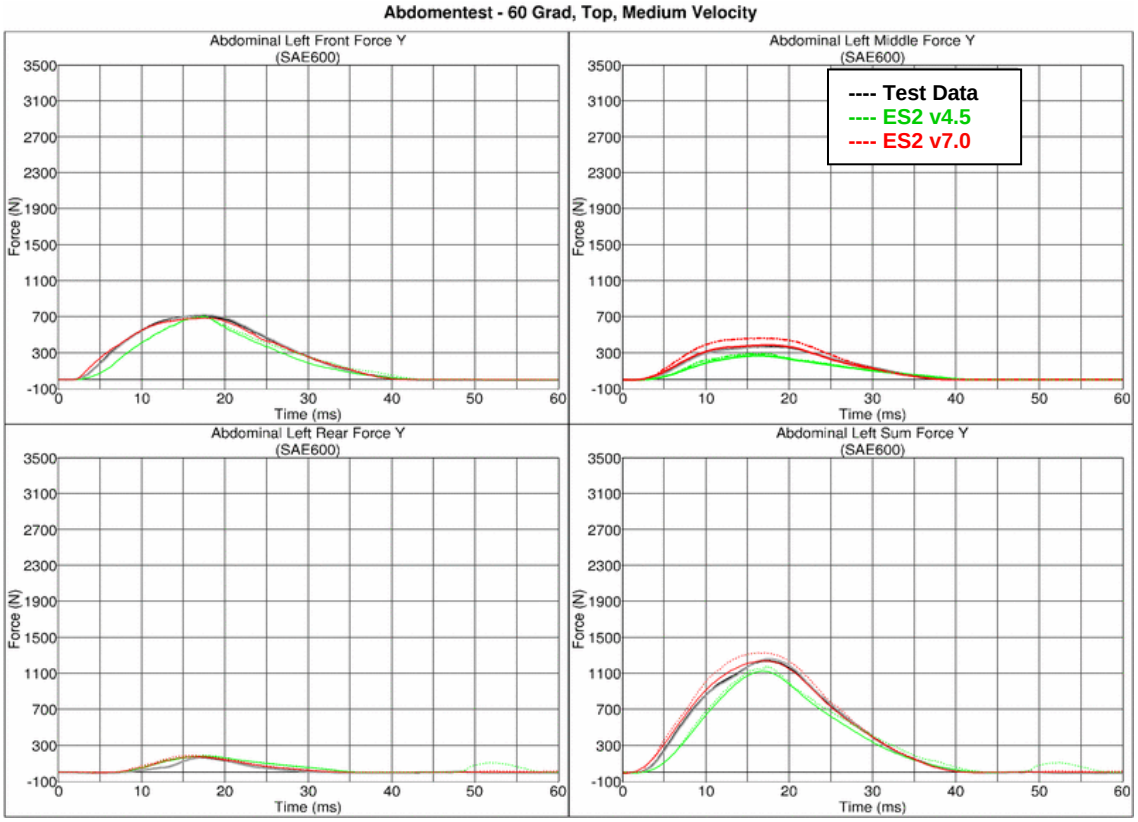
Results for 60° orientation, top impact, low velocity



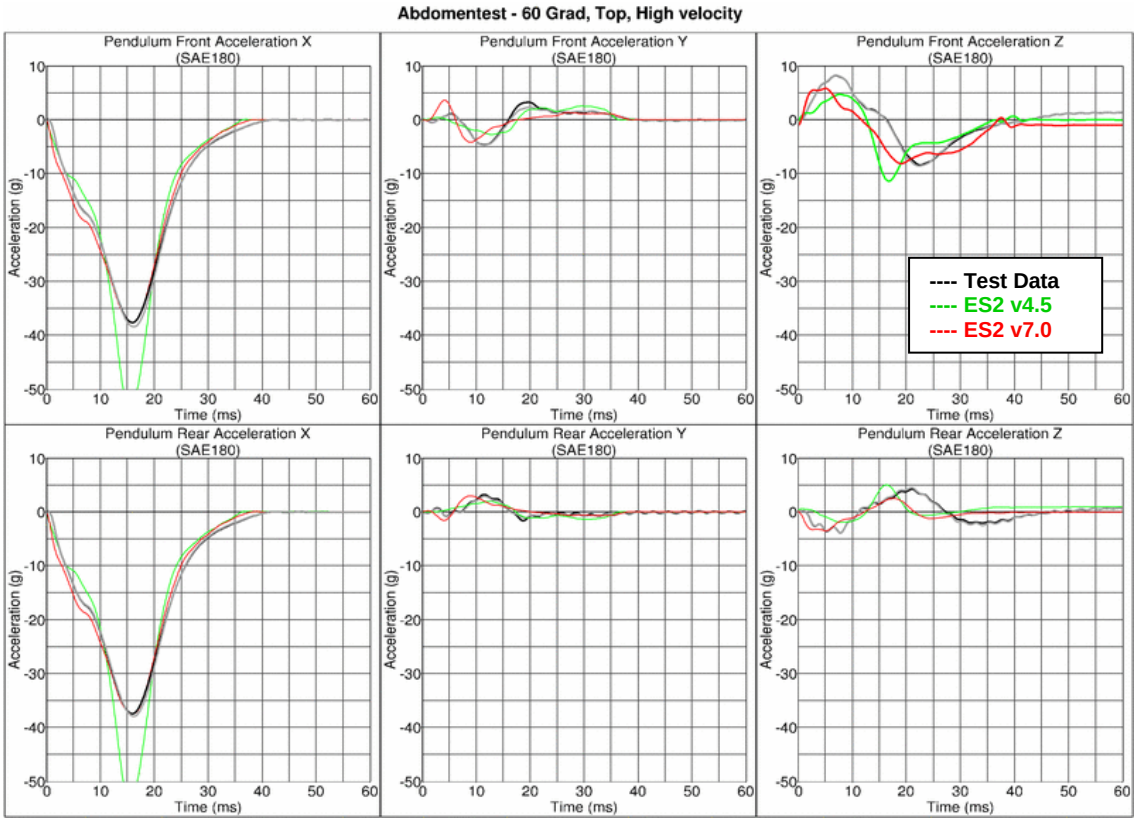


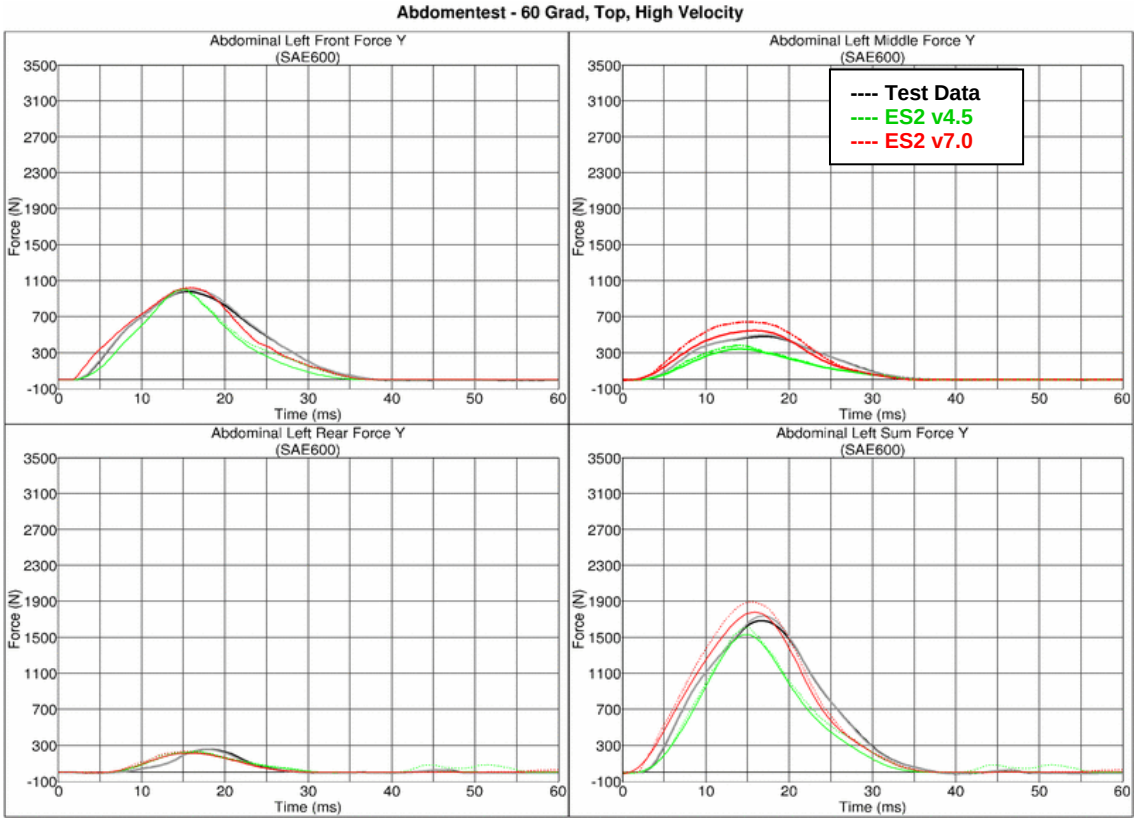
Results for 60° orientation, top impact, medium velocity



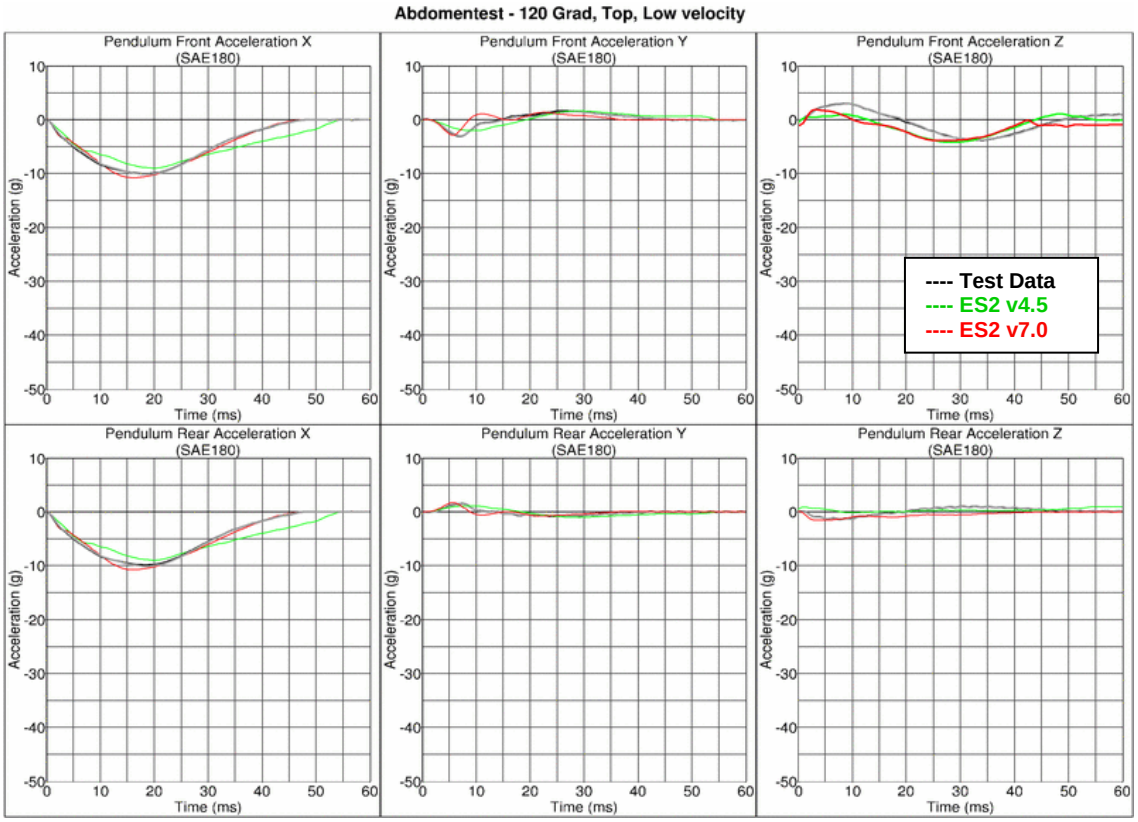


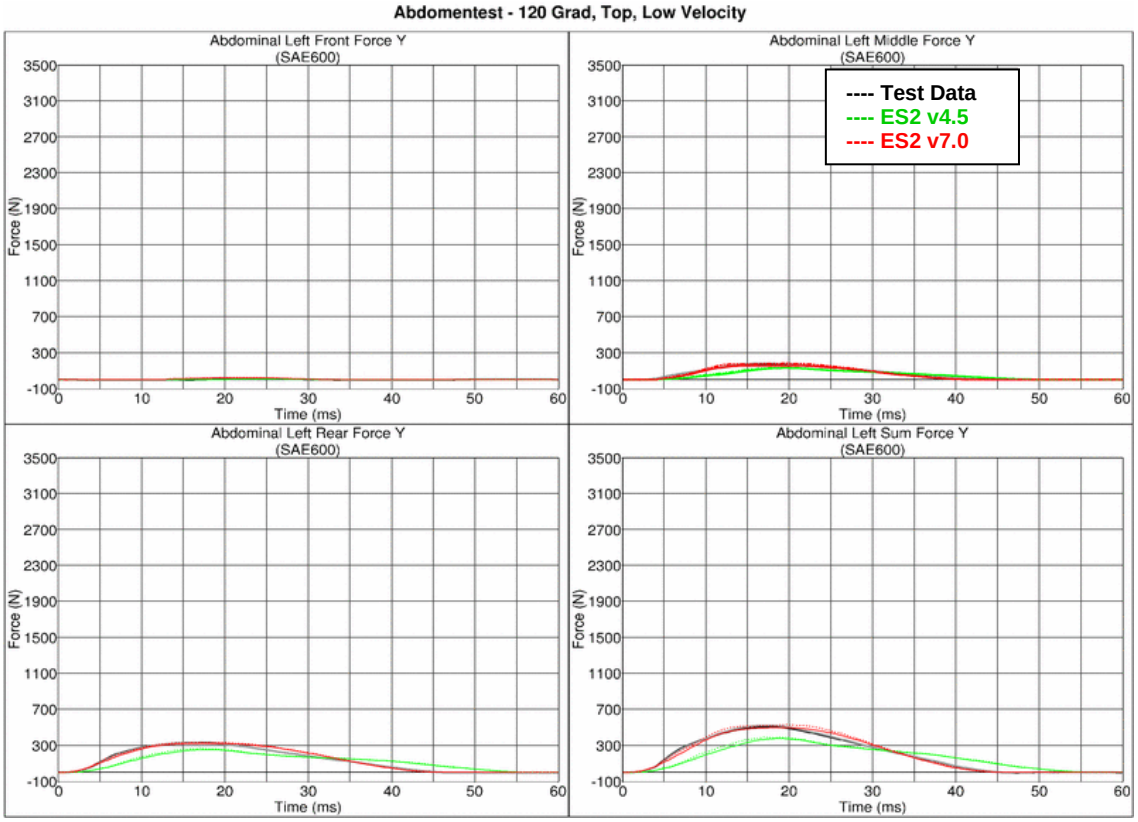
Results for 60° orientation, top impact, high velocity



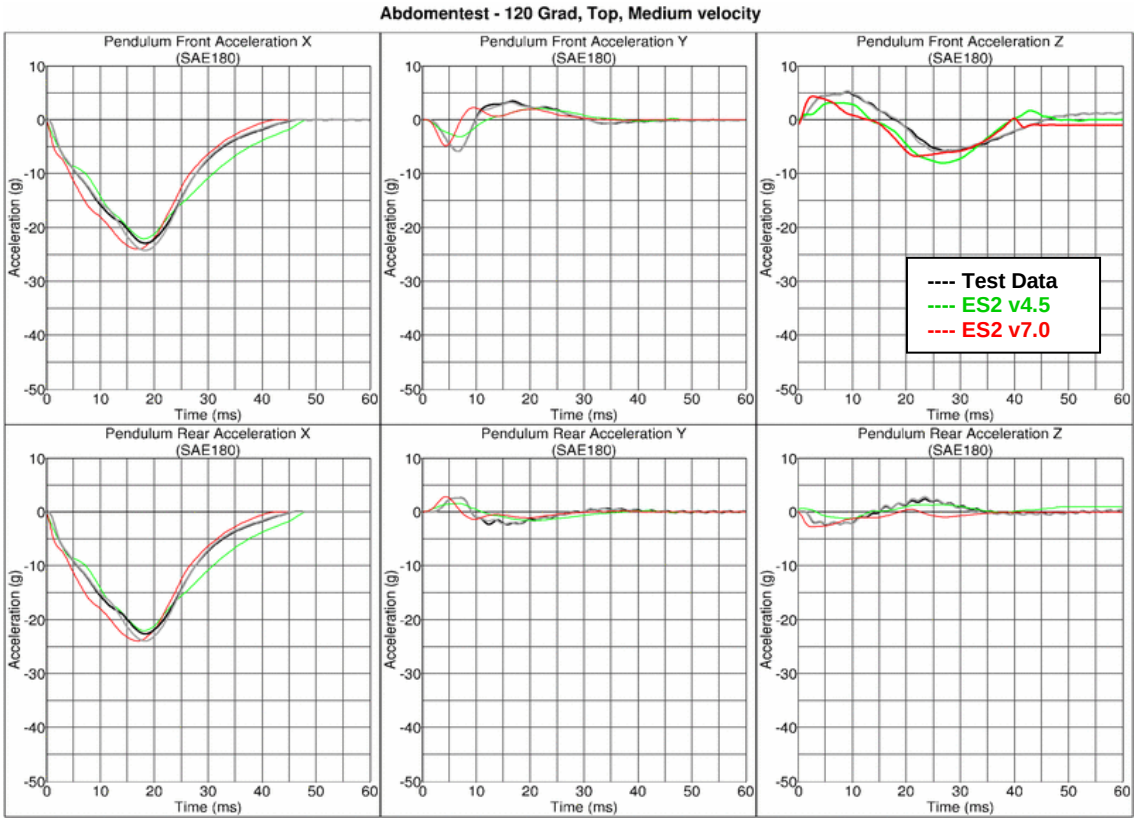


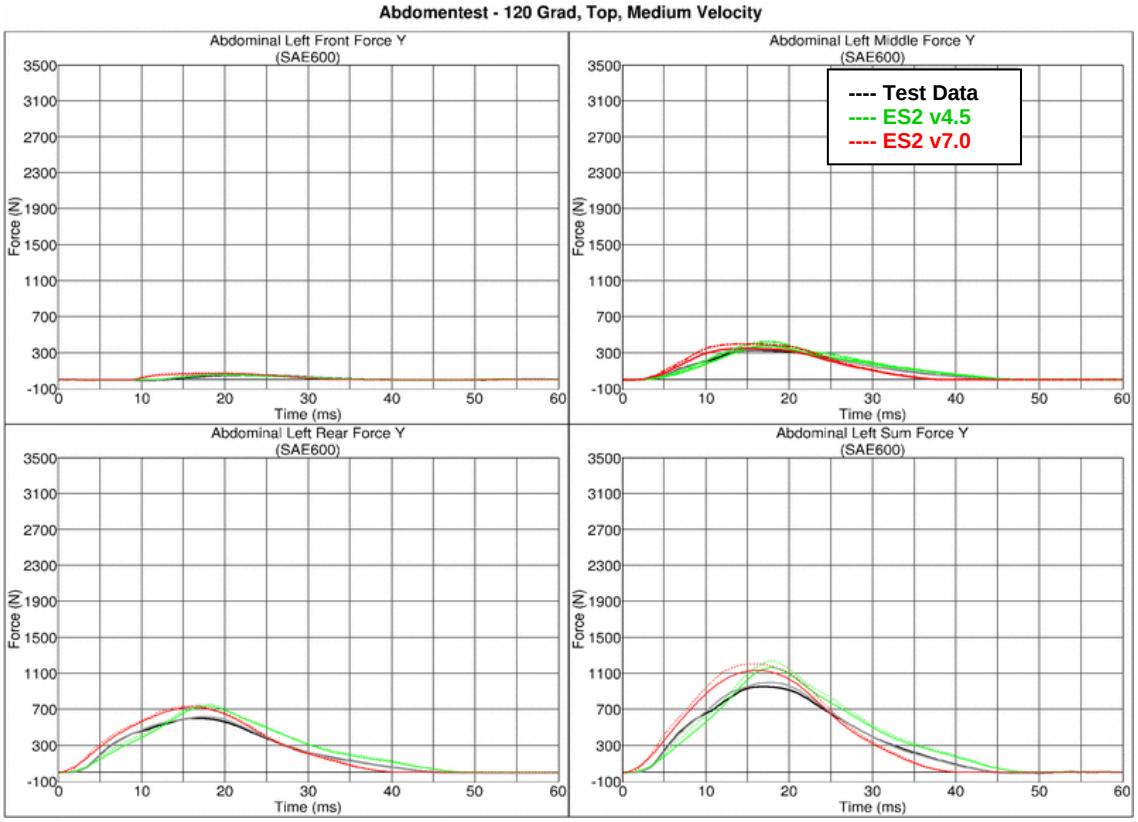
Results for 120° orientation, top impact, low velocity



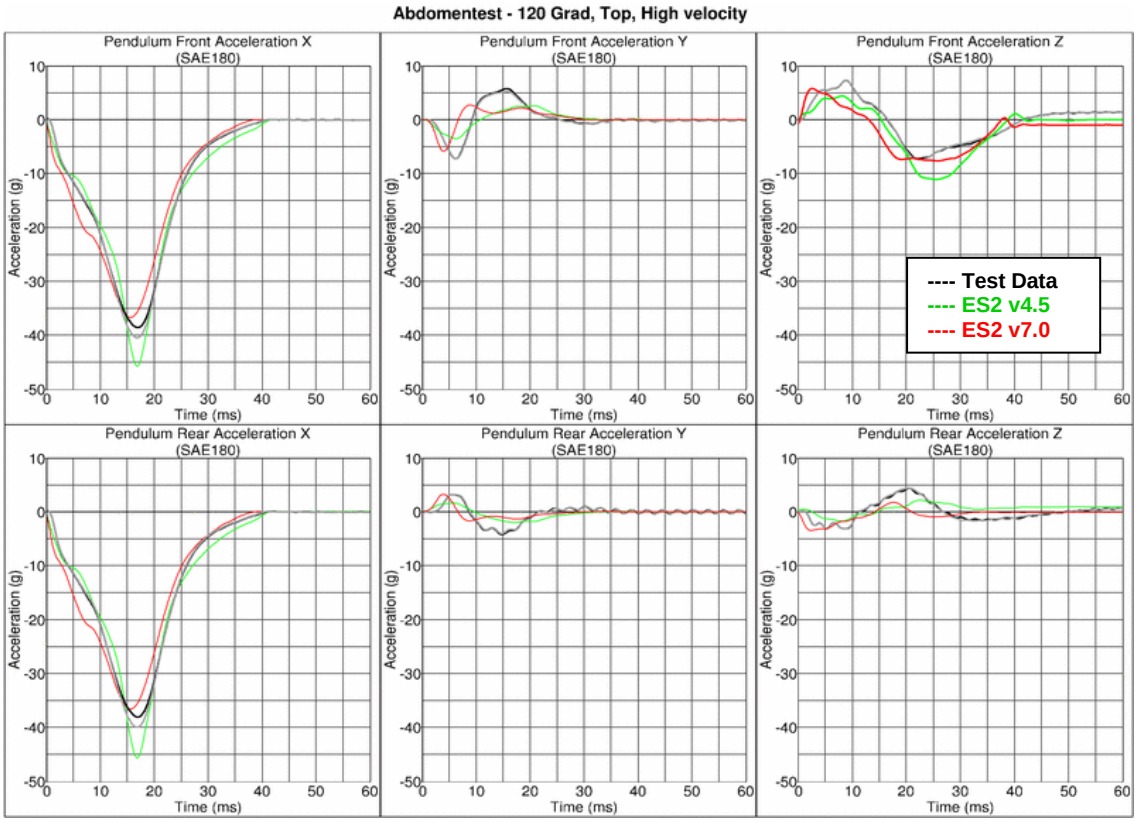


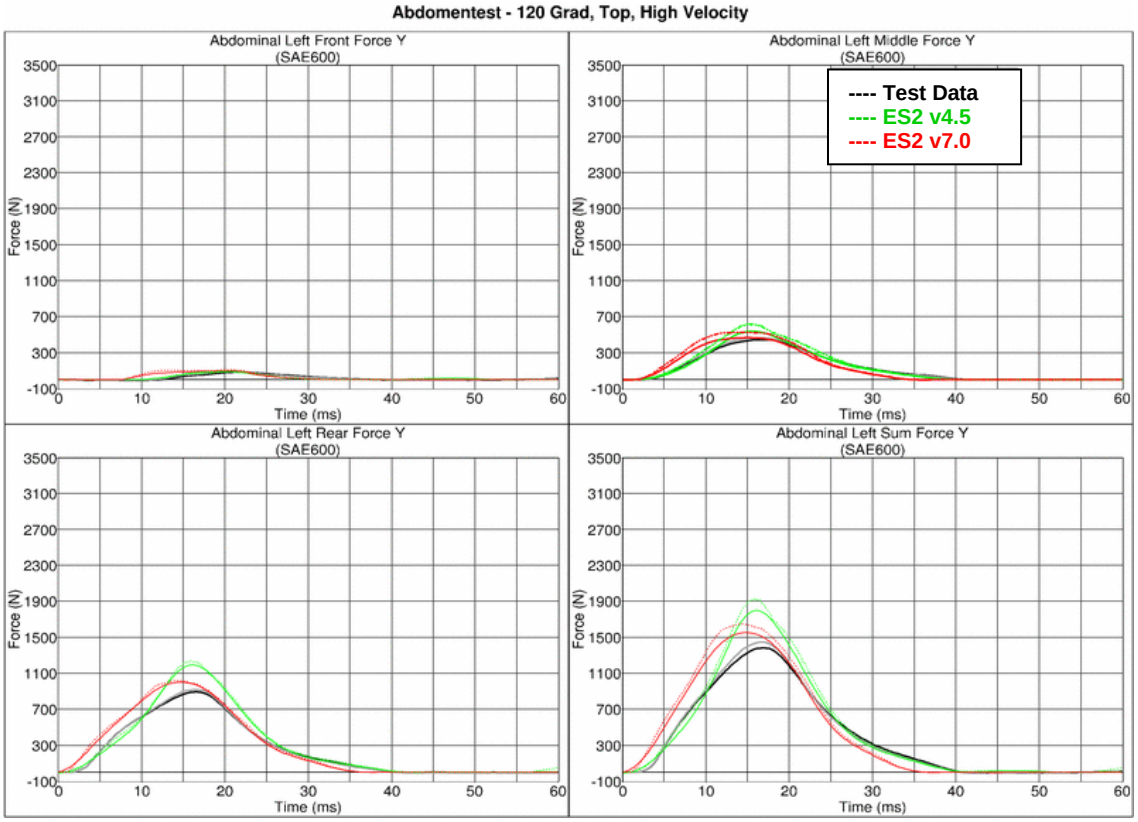
Results for 120° orientation, top impact, medium velocity





Results for 120° orientation, top impact, high velocity





11.1.6 Lumbar spine test

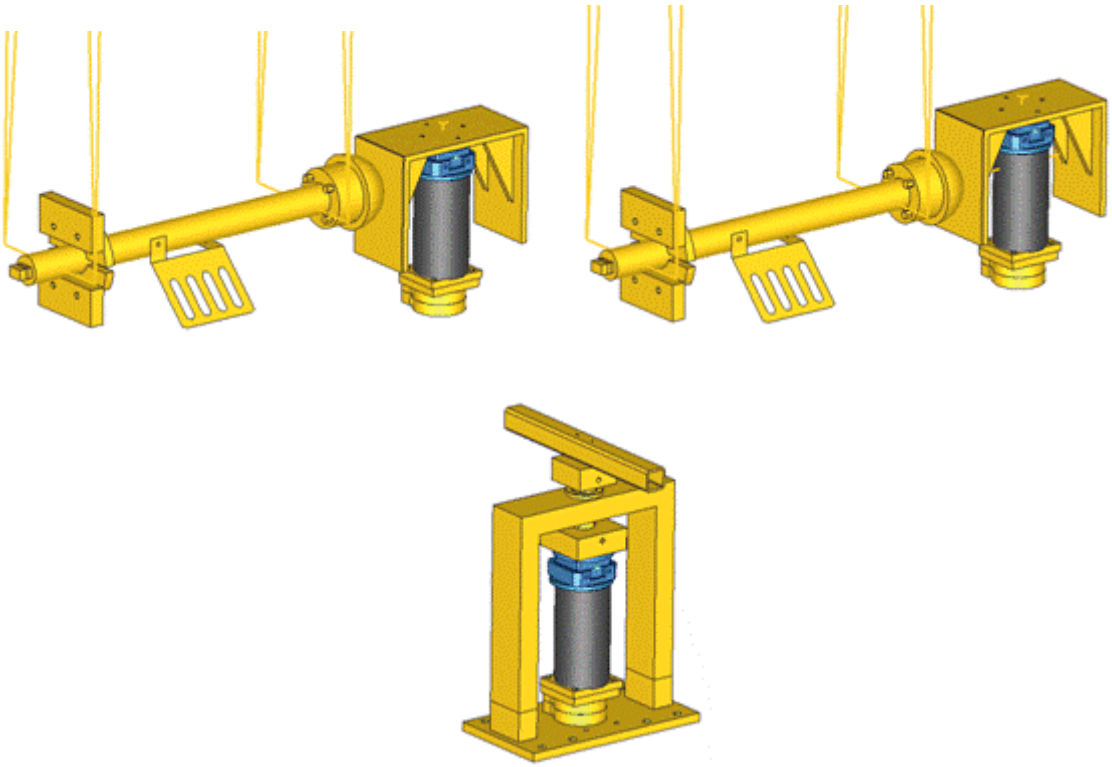
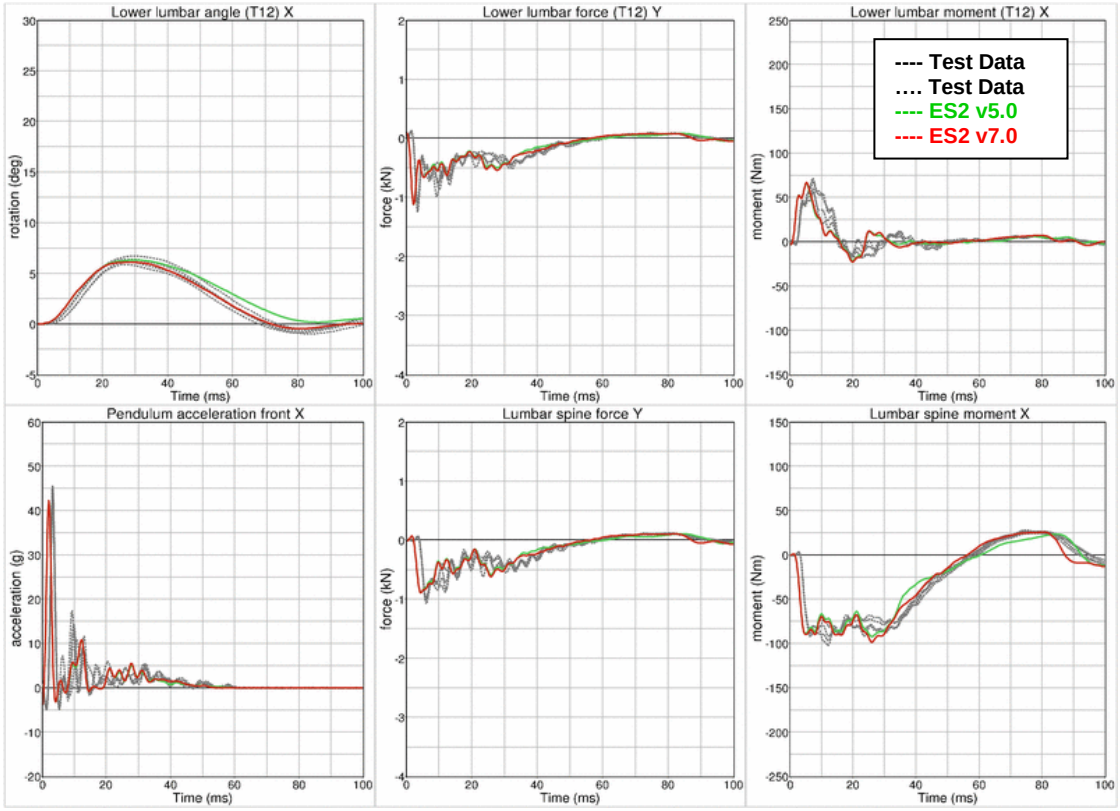
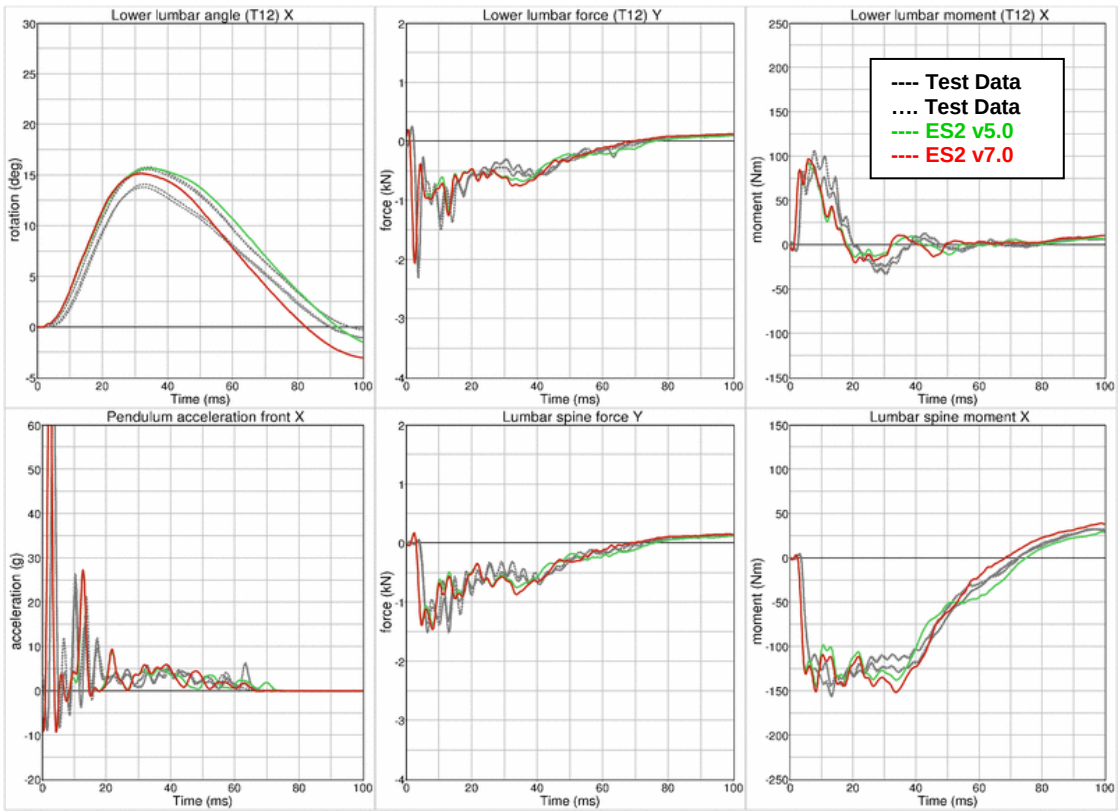


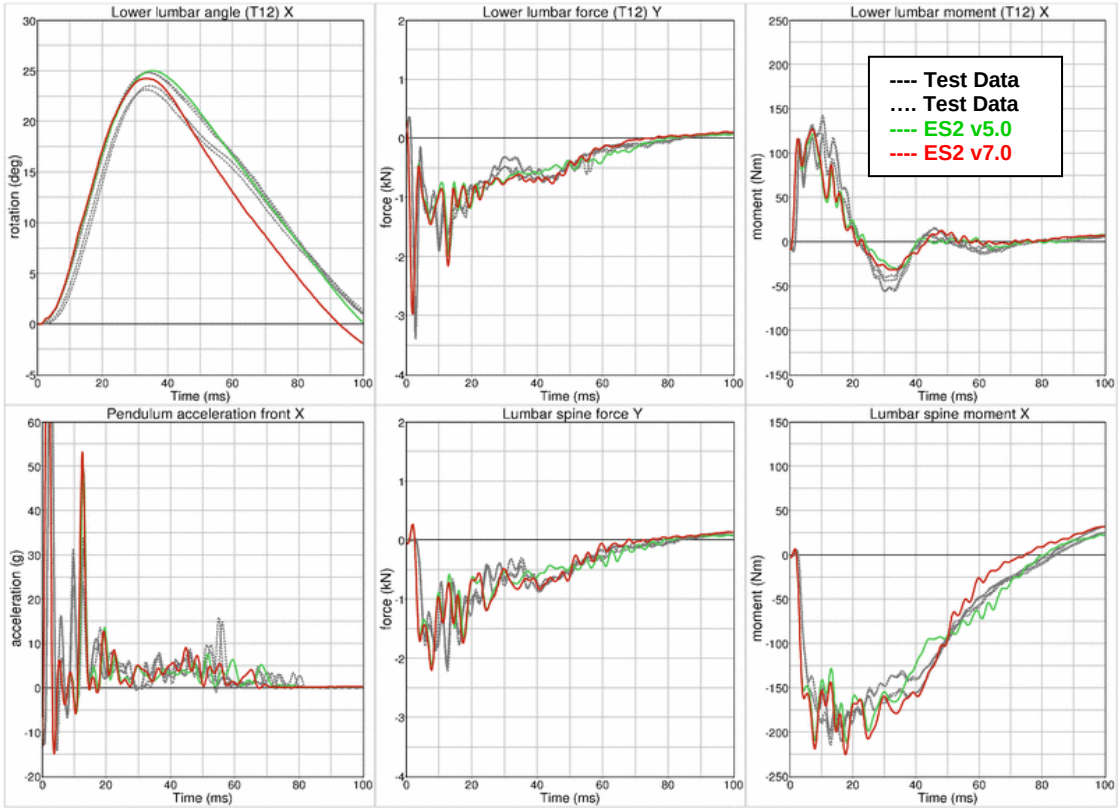
Figure 31: Setups for bending, shear and torsion tests on lumbar spine

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.
Between v6.0 and v7.0 are no changes in the lumbar spine. Due to this the results of the v7.0 are compared to a previous version of the lumber spine which showed different results. Results of v6.0 and v7.0 are identical.

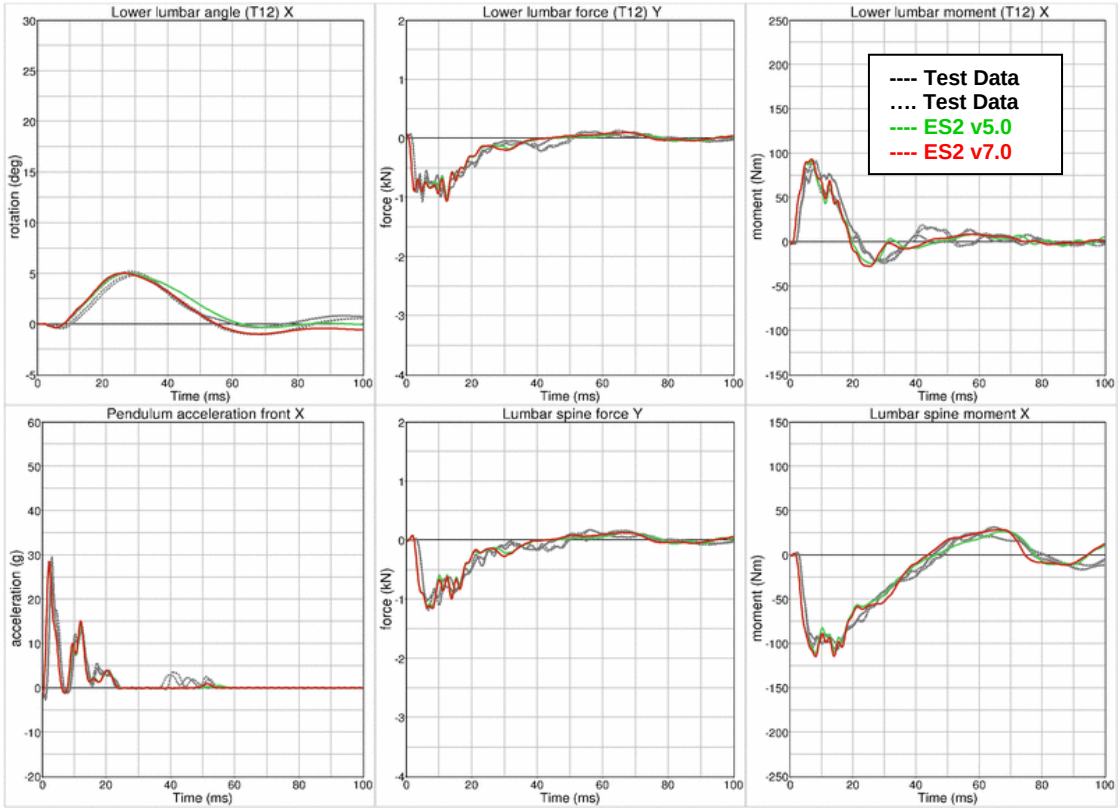
Results for Bending

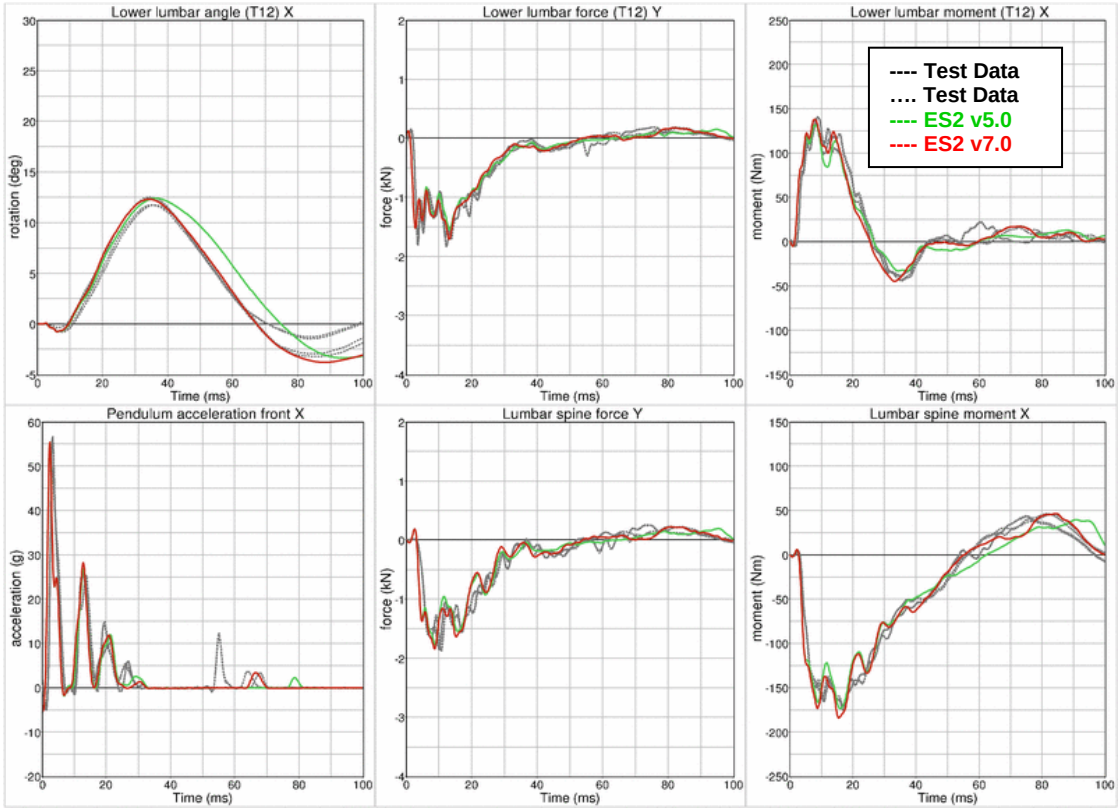


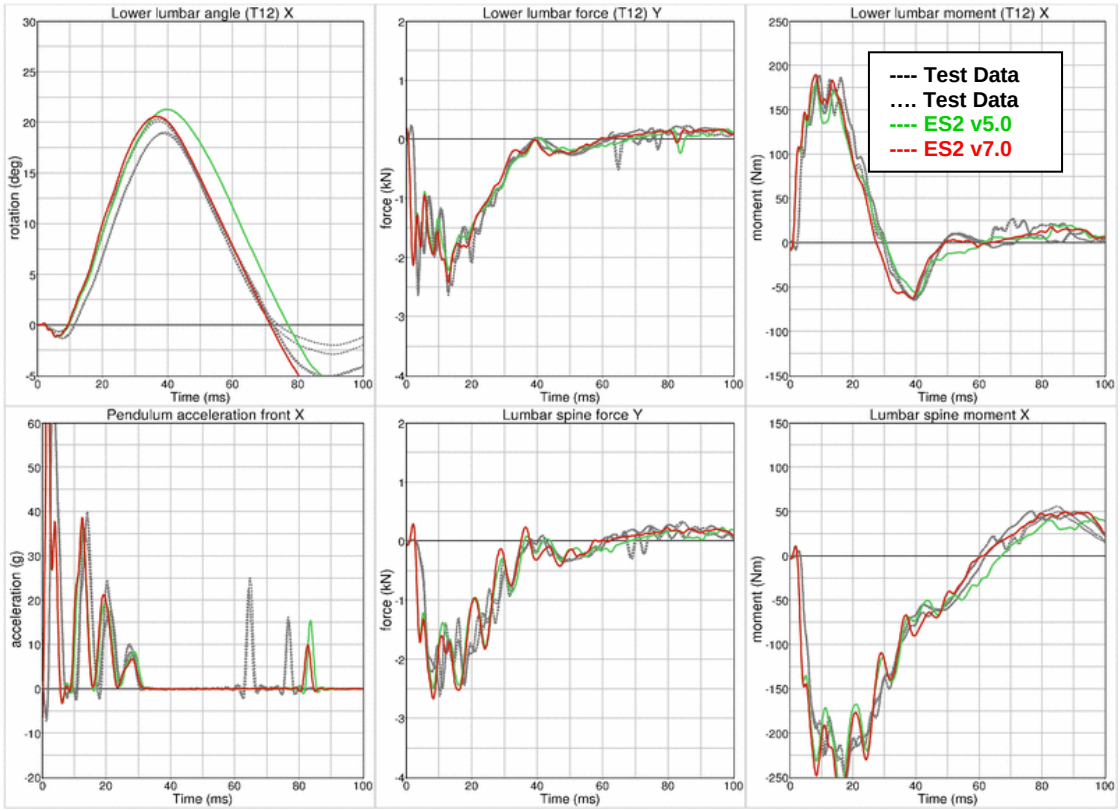




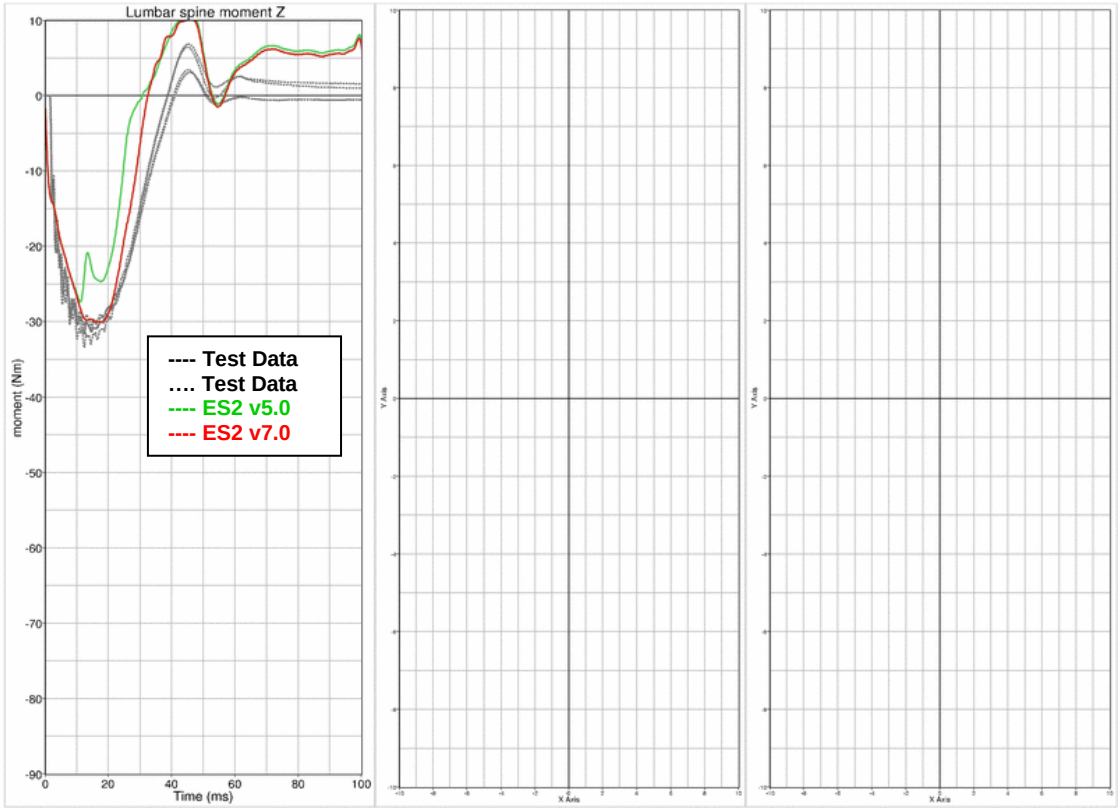
Results for Shear

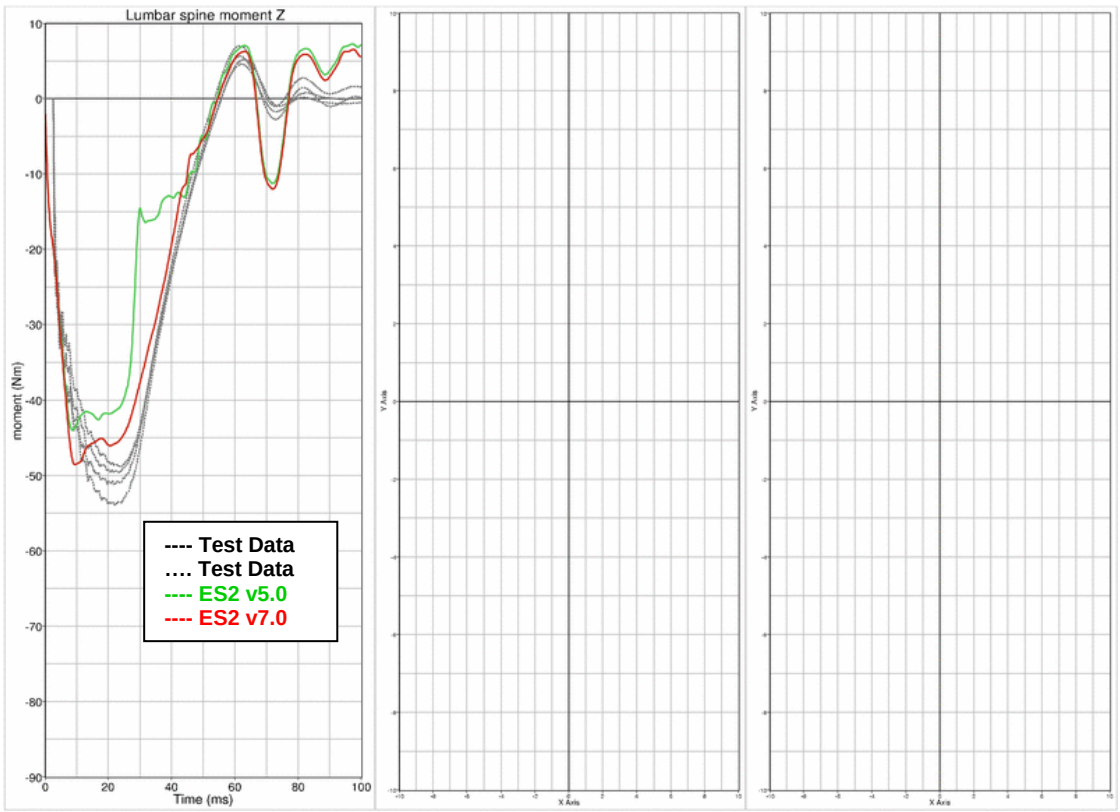



Lower lumbar angle (T12) X
rotation (deg)
Time (ms)
Lower lumbar force (T12) Y
force (kN)
Time (ms)
Lower lumbar moment (T12) X
moment (Nm)
Time (ms)
---- Test Data
.... Test Data
---- ES2 v5.0
---- ES2 v7.0
Pendulum acceleration front X
acceleration (g)
Time (ms)
Lumbar spine force Y
force (kN)
Time (ms)
Lumbar spine moment X
moment (Nm)
Time (ms)


Lower lumbar angle (T12) X
rotation (deg)
Time (ms)
Lower lumbar force (T12) Y
force (kN)
Time (ms)
Lower lumbar moment (T12) X
moment (Nm)
Time (ms)
---- Test Data
.... Test Data
---- ES2 v5.0
---- ES2 v7.0
Pendulum acceleration front X
acceleration (g)
Time (ms)
Lumbar spine force Y
force (kN)
Time (ms)
Lumbar spine moment X
moment (Nm)
Time (ms)

Results for Torsion






Lumbar spine moment Z
moment (Nm)
Time (ms)
---- Test Data
.... Test Data
---- ES2 v5.0
---- ES2 v7.0

11.1.7 Iliac wing test

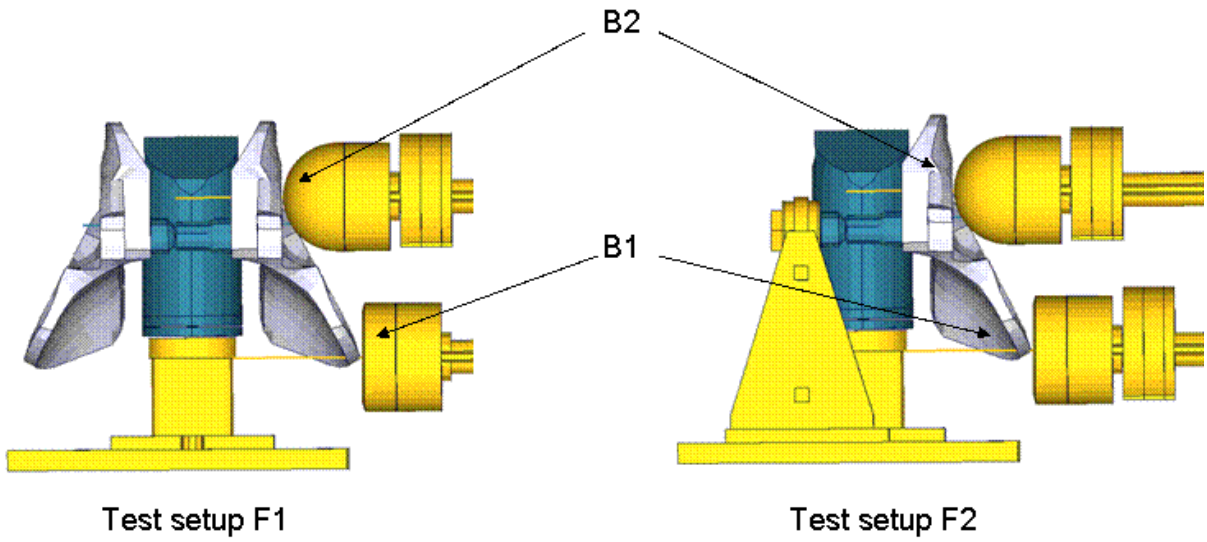
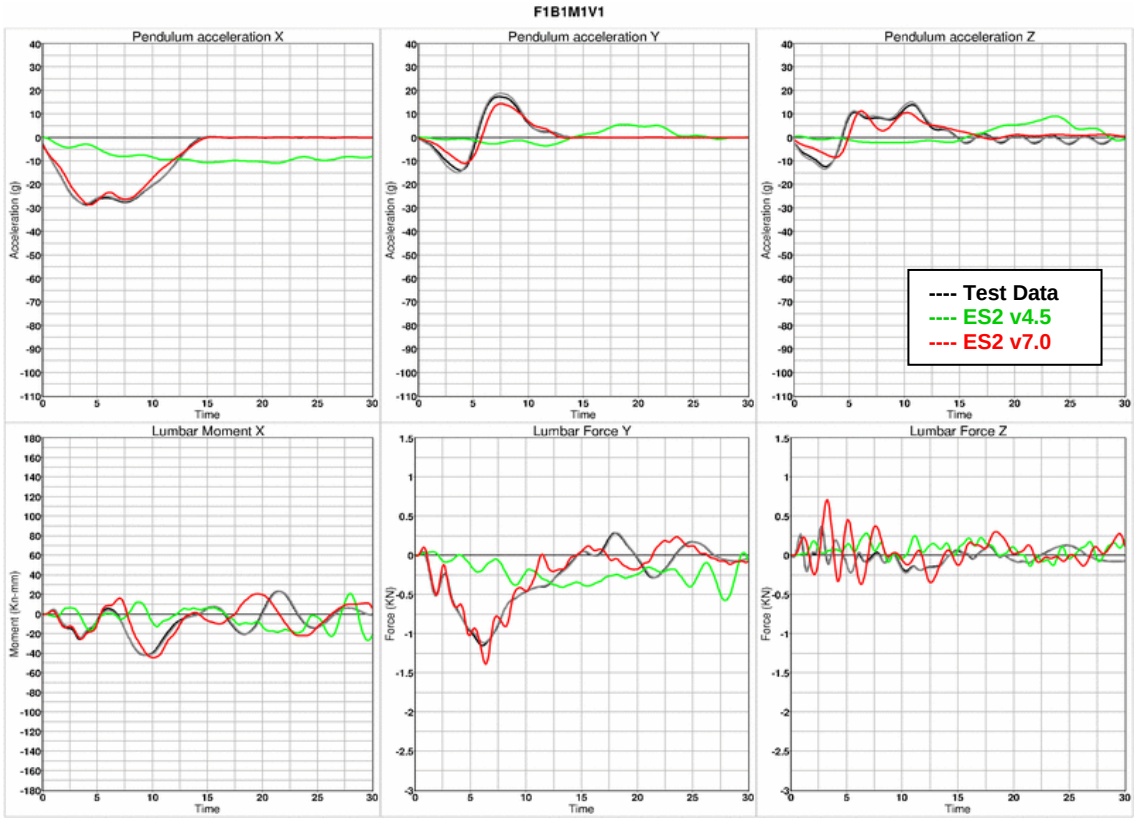
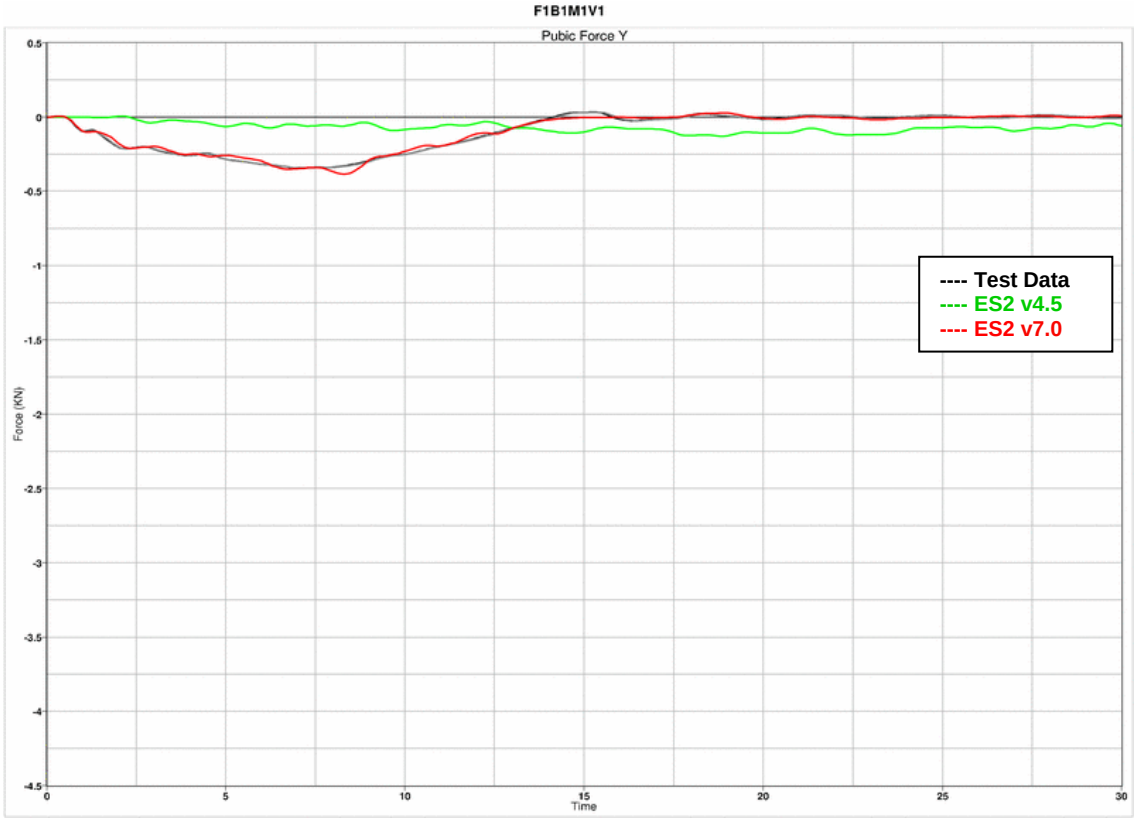


Figure 32: Test setup for Iliac wing test

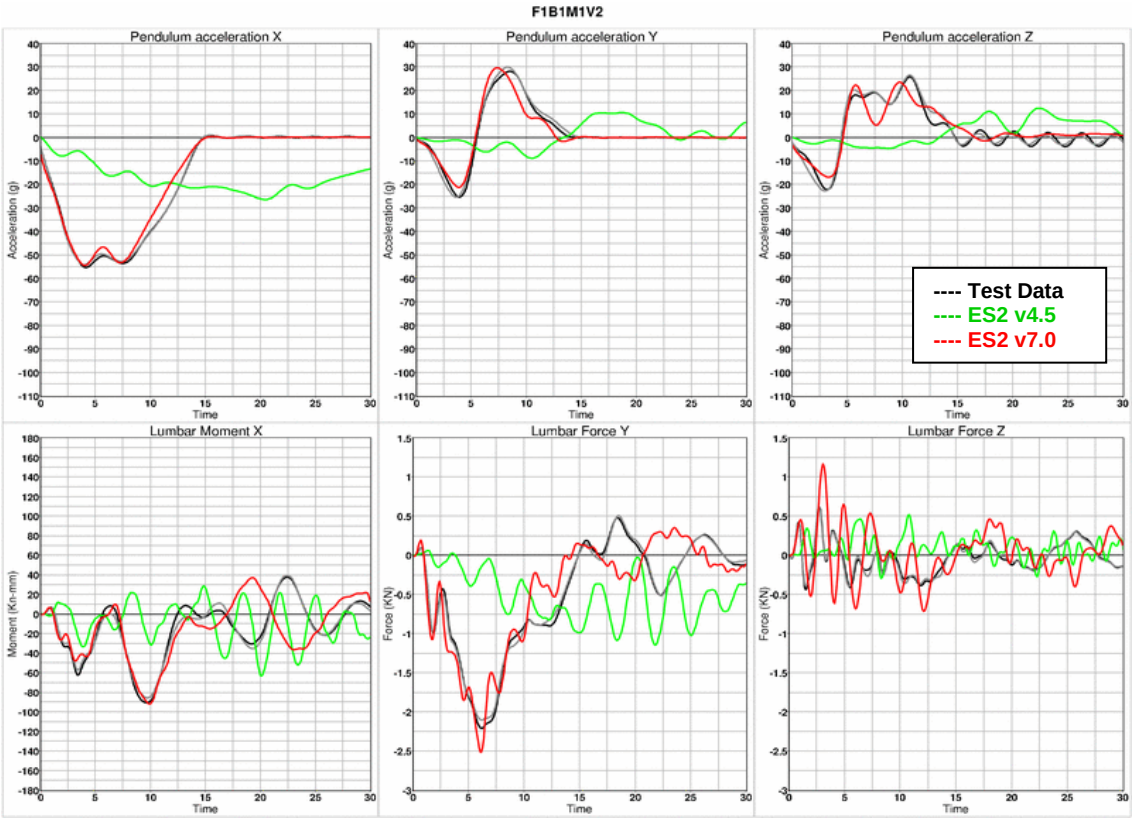
The Iliac wing assembly is mounted on a test block as shown in the figure above. The Iliac wings are impacted by a hemispherical-headed pendulum and a cylindrical-headed pendulum at 2 different points as indicated in the figure. The pendulum masses are varied for different configurations and the test is carried out at 2 velocities.
Between v6.0 and v7.0 are no changes in the iliac area. Due to this the results of the v7.0 are compared to a previous version of the iliac which showed different results. Results of v6.0 and v7.0 are identical.

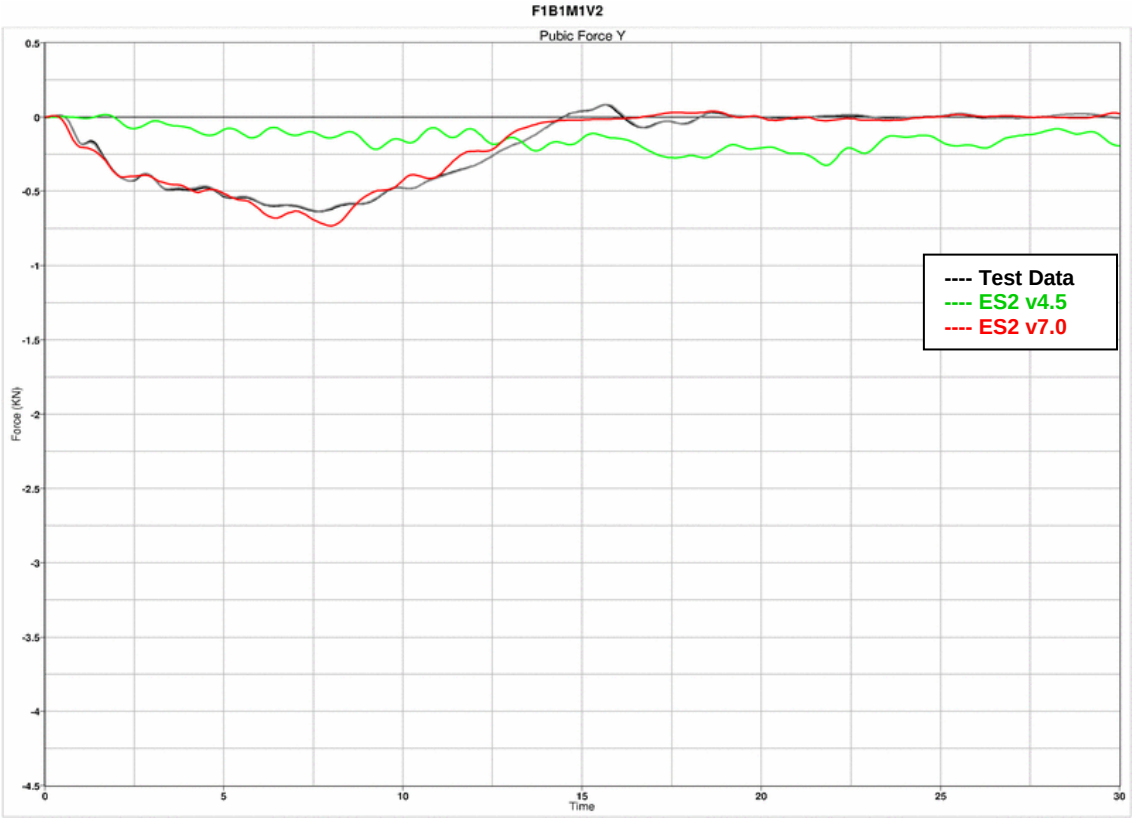
Results for configuration F1B1M1 , low velocity



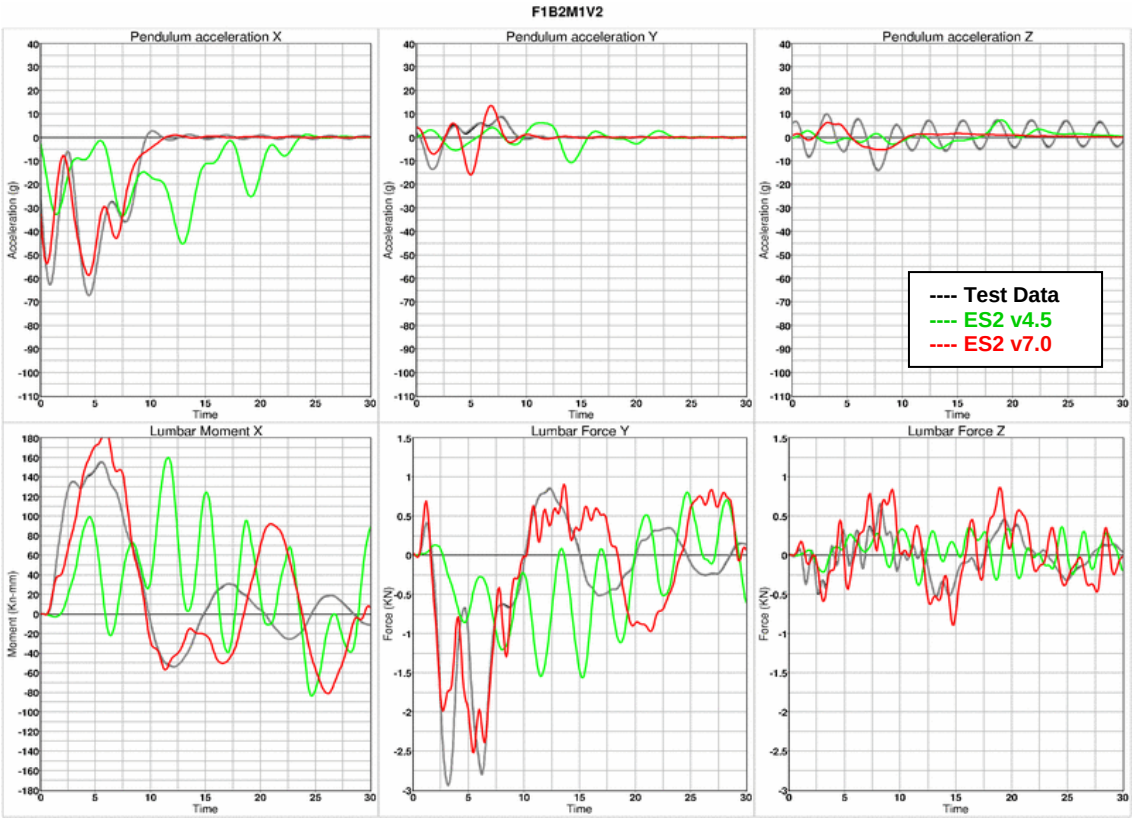


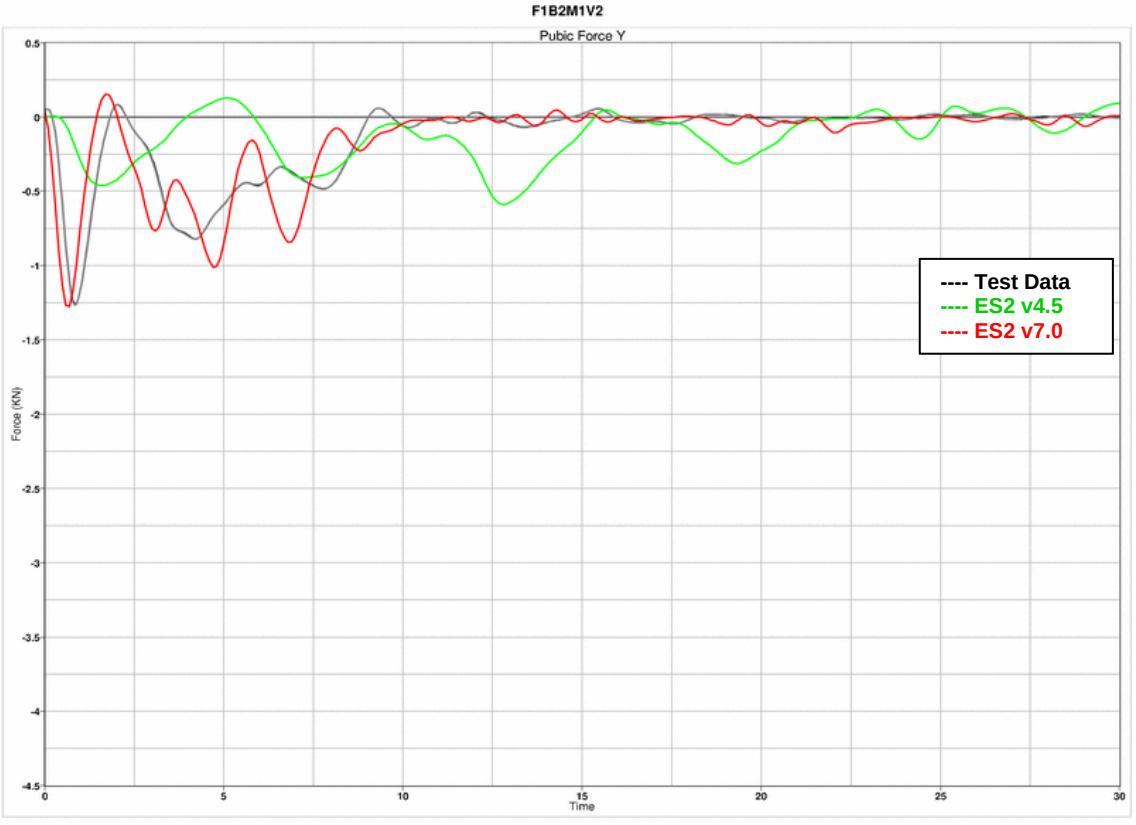
Results for configuration F1B1M1 , high velocity



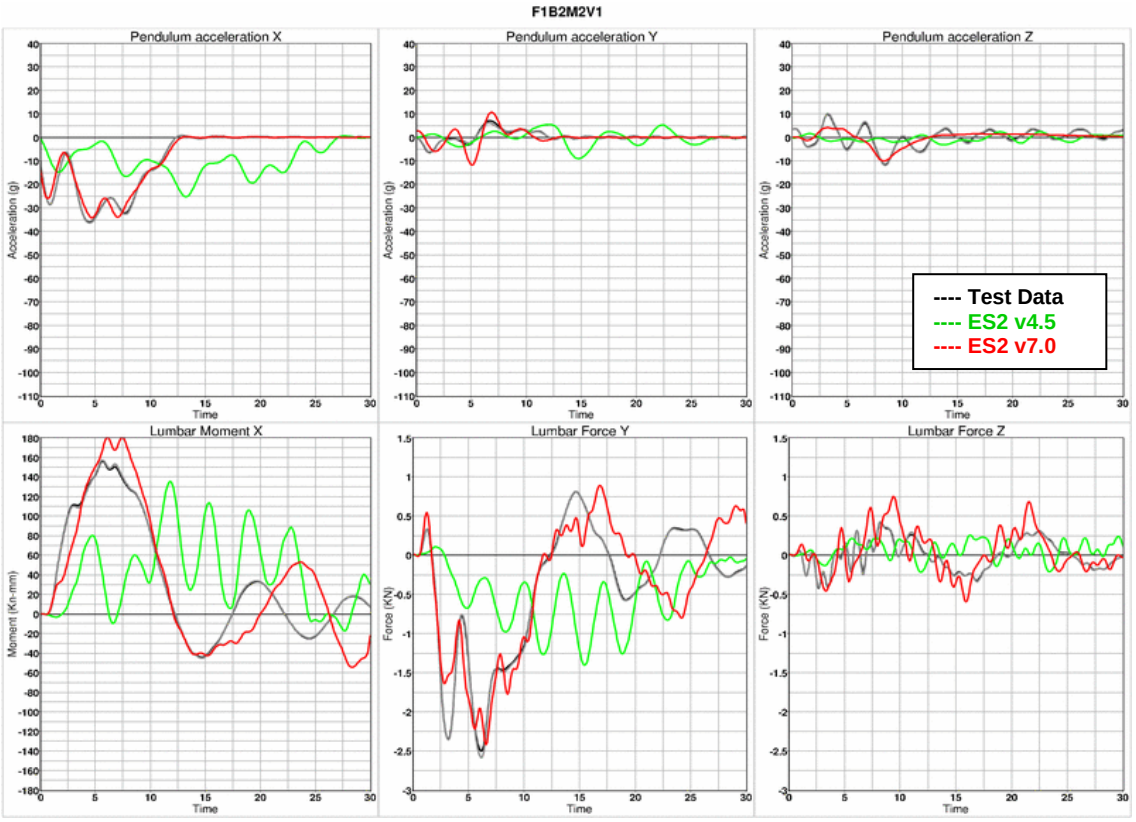


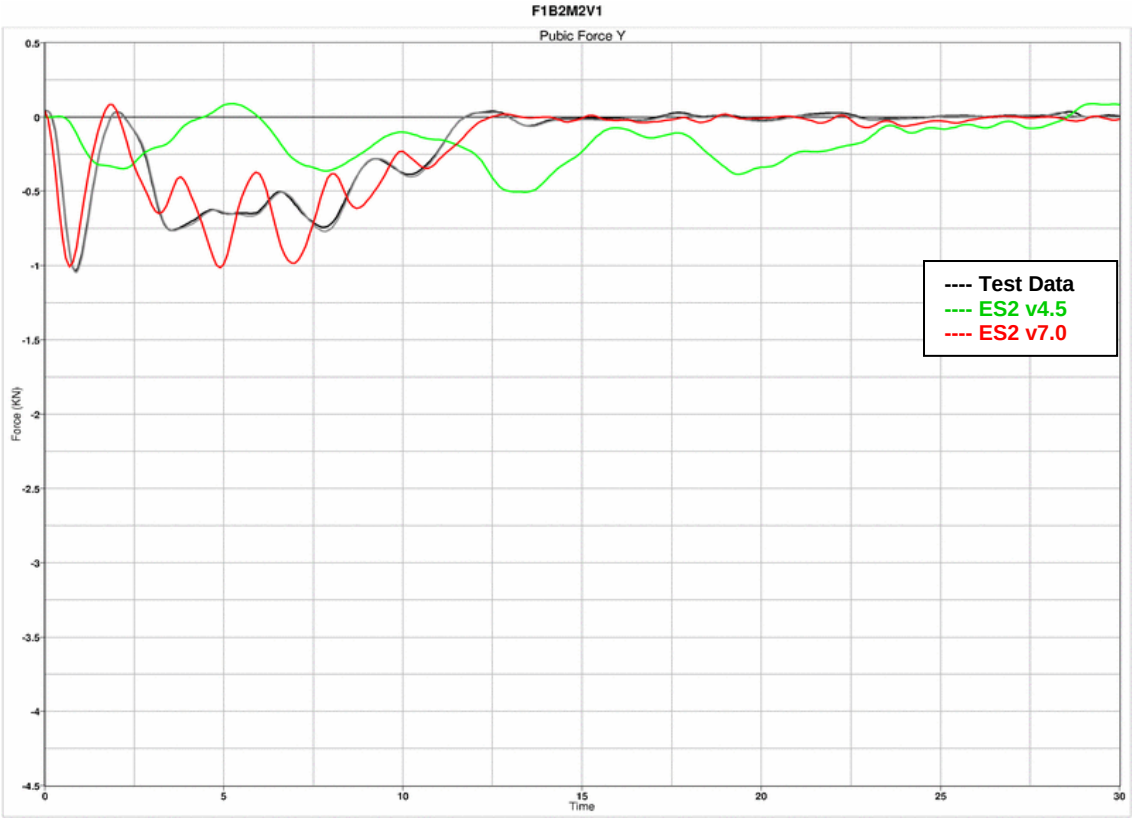
Results for configuration F1B2M1 , high velocity



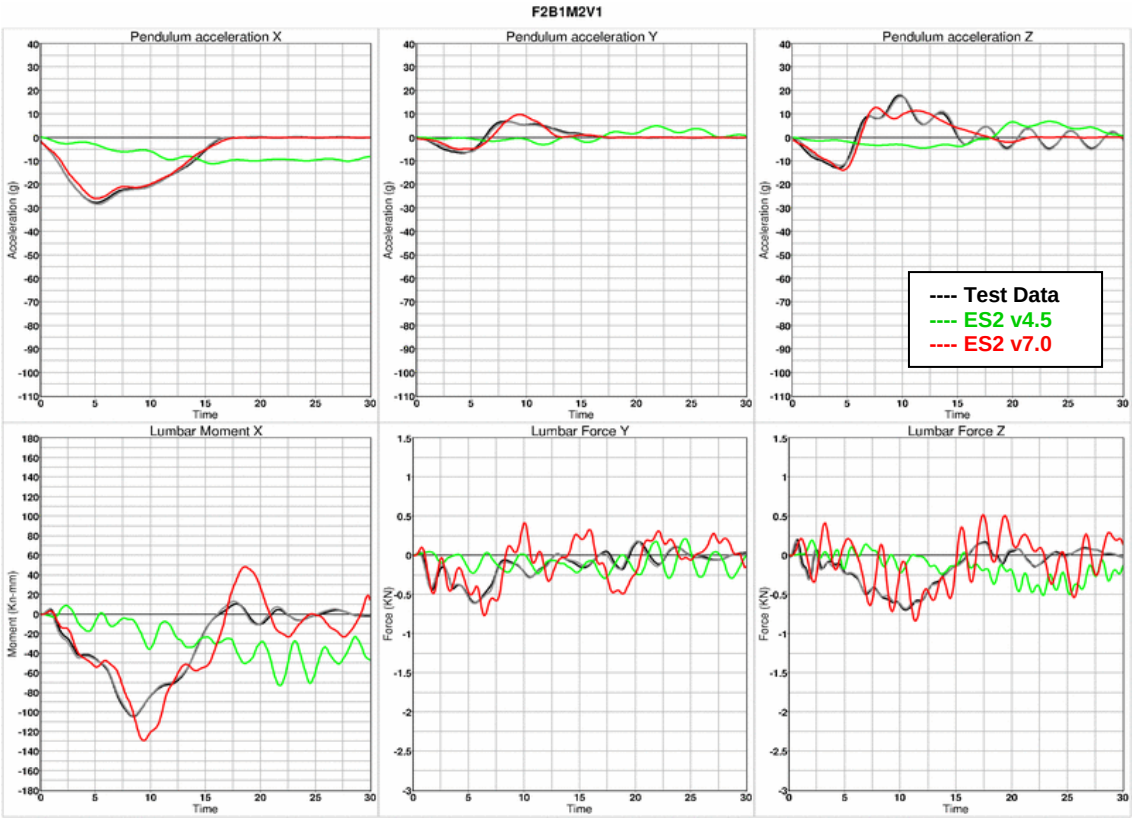


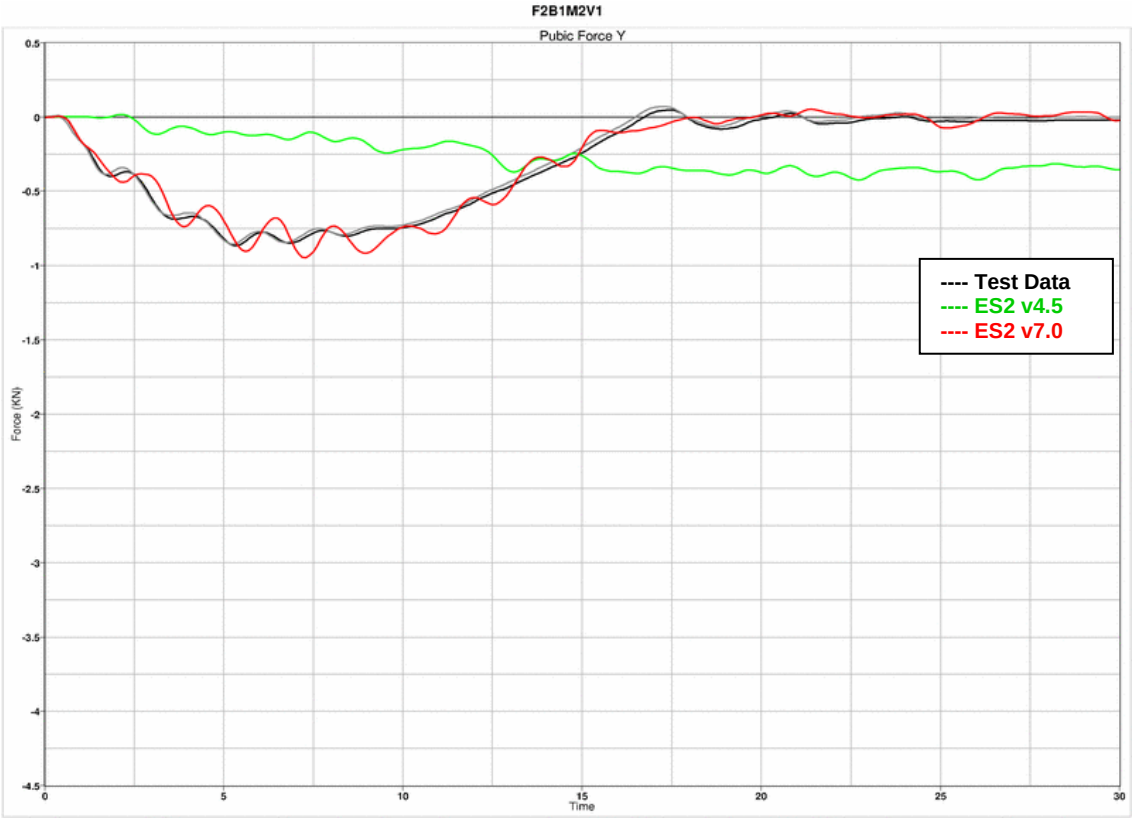
Results for configuration F1B2M2 , low velocity



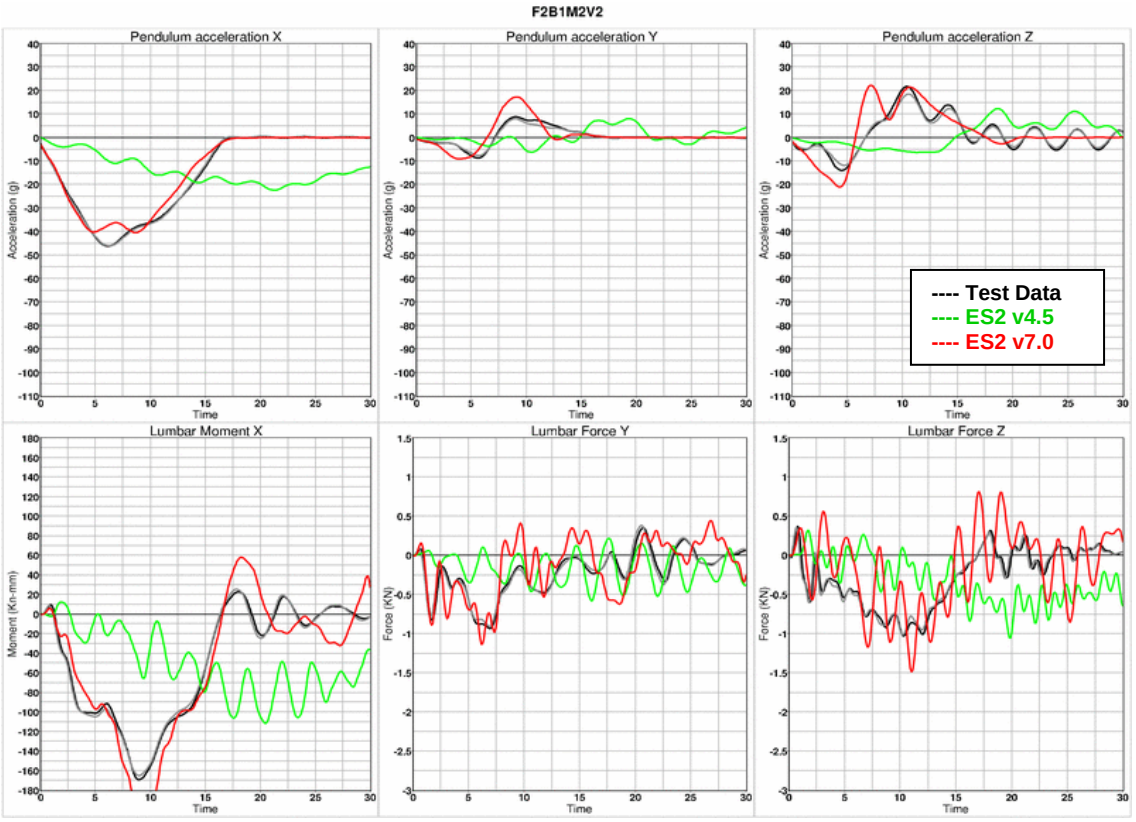


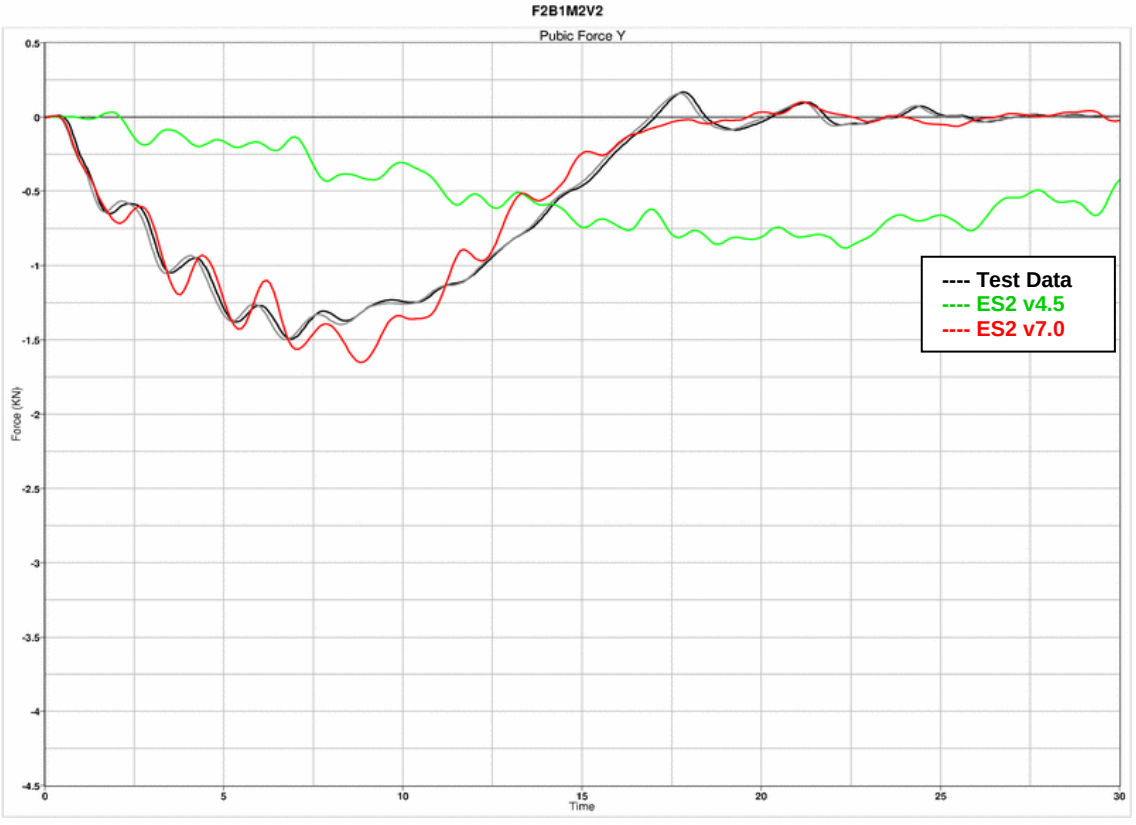
Results for configuration F2B1M2 , low velocity



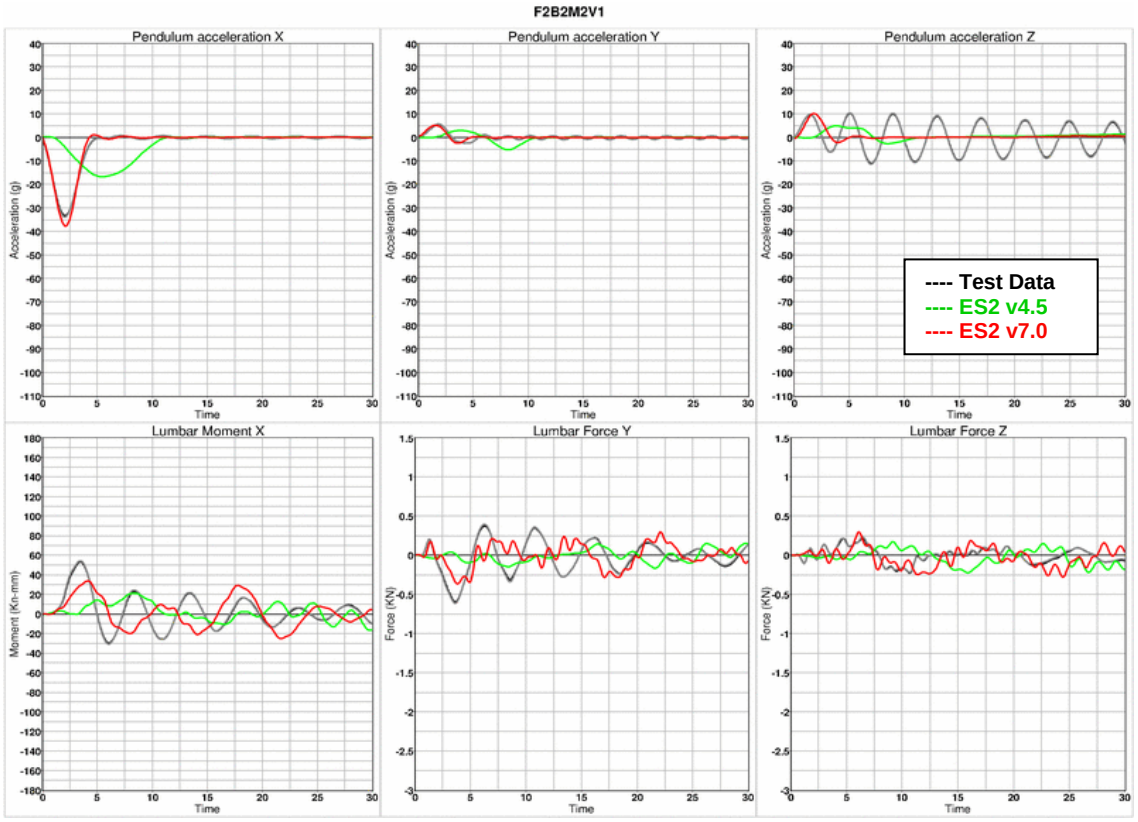


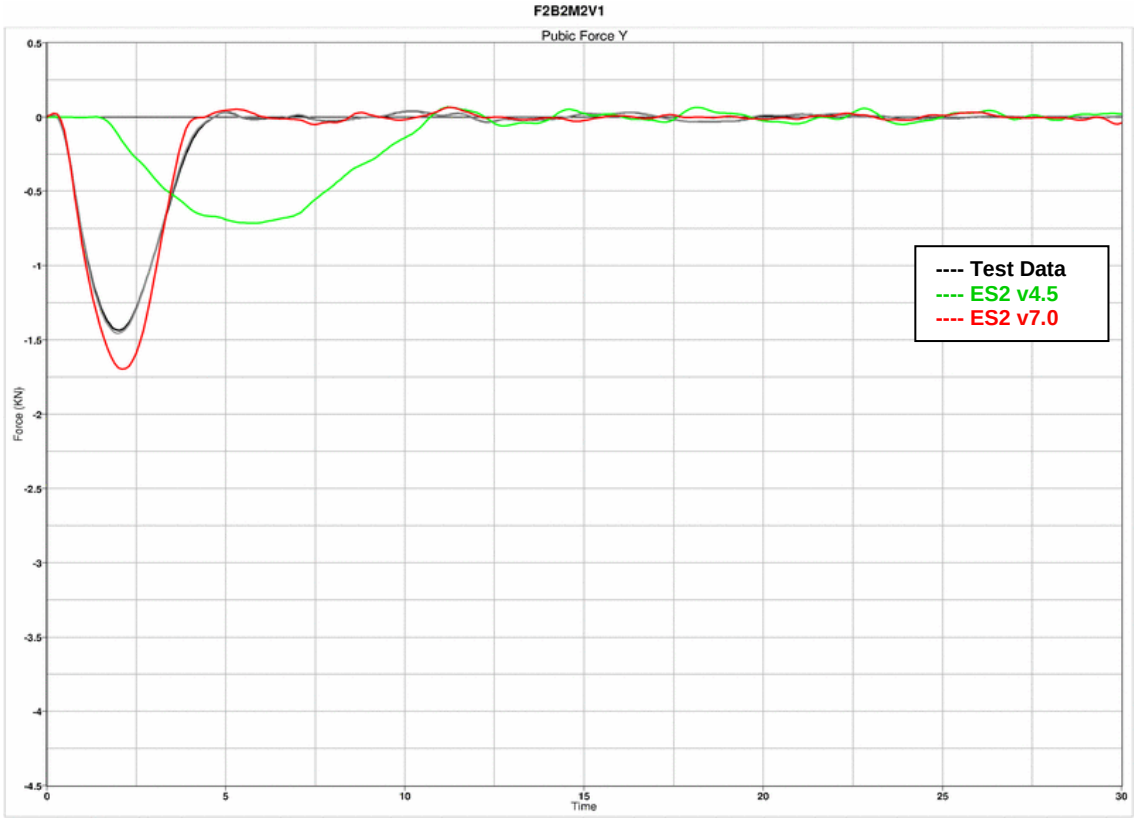
Results for configuration F2B1M2 , high velocity



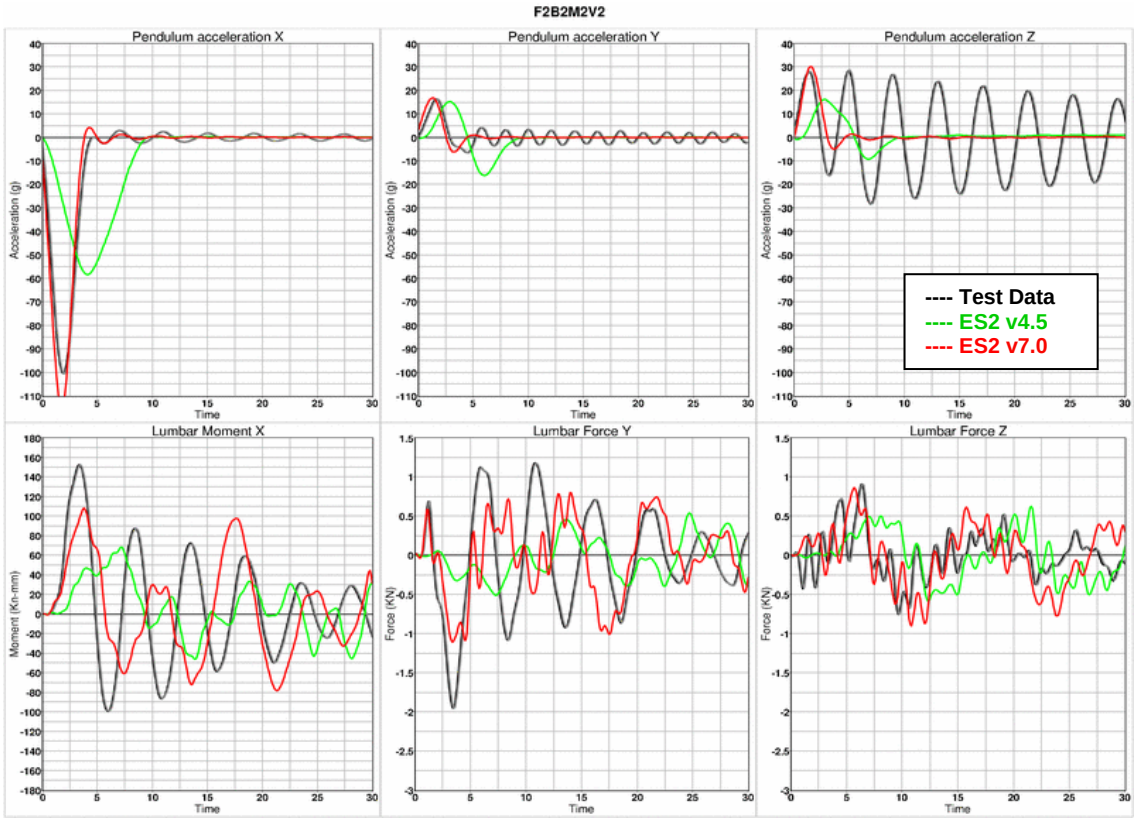


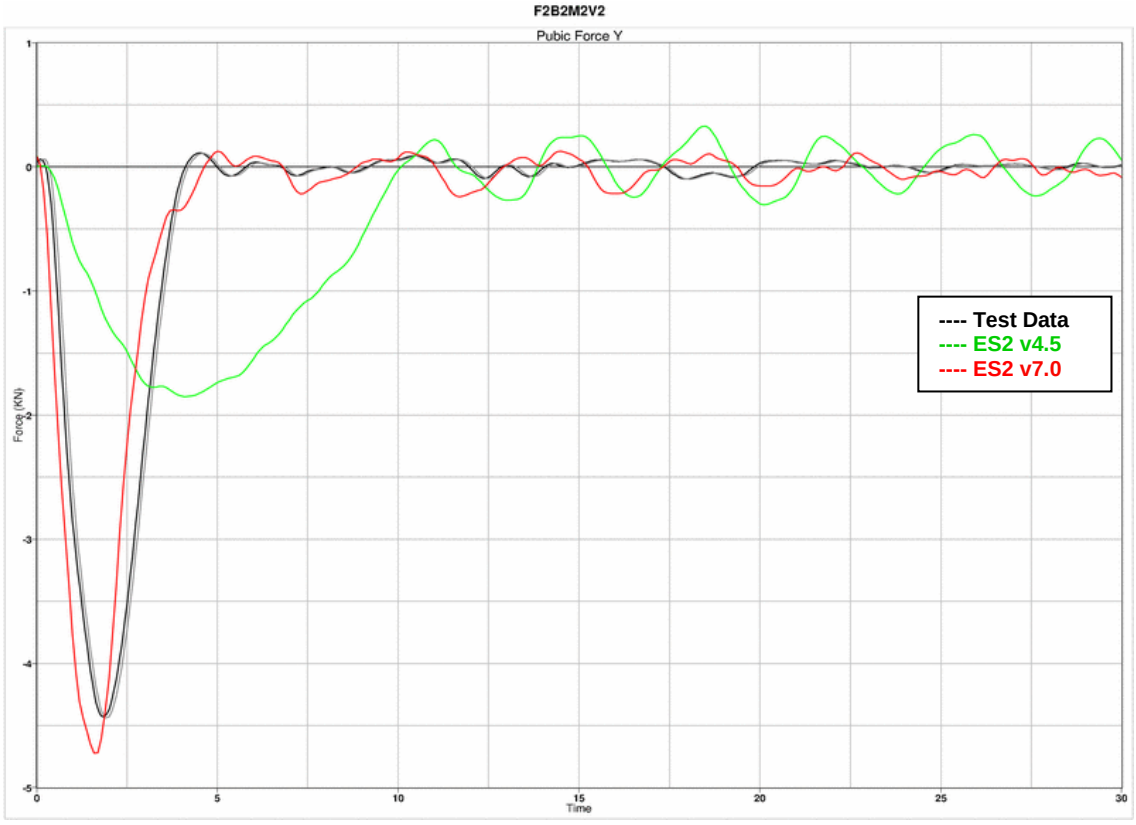
Results for configuration F2B2M2 , low velocity





Results for configuration F2B2M2 , high velocity





11.1.8 Femur stopper test

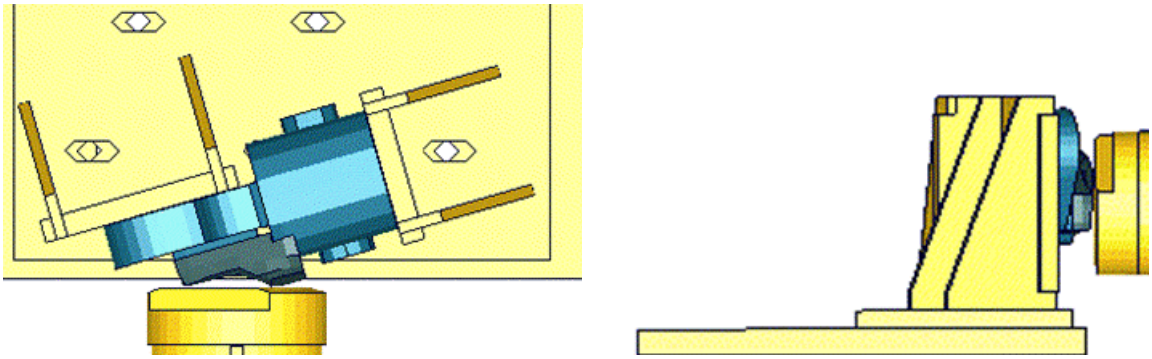
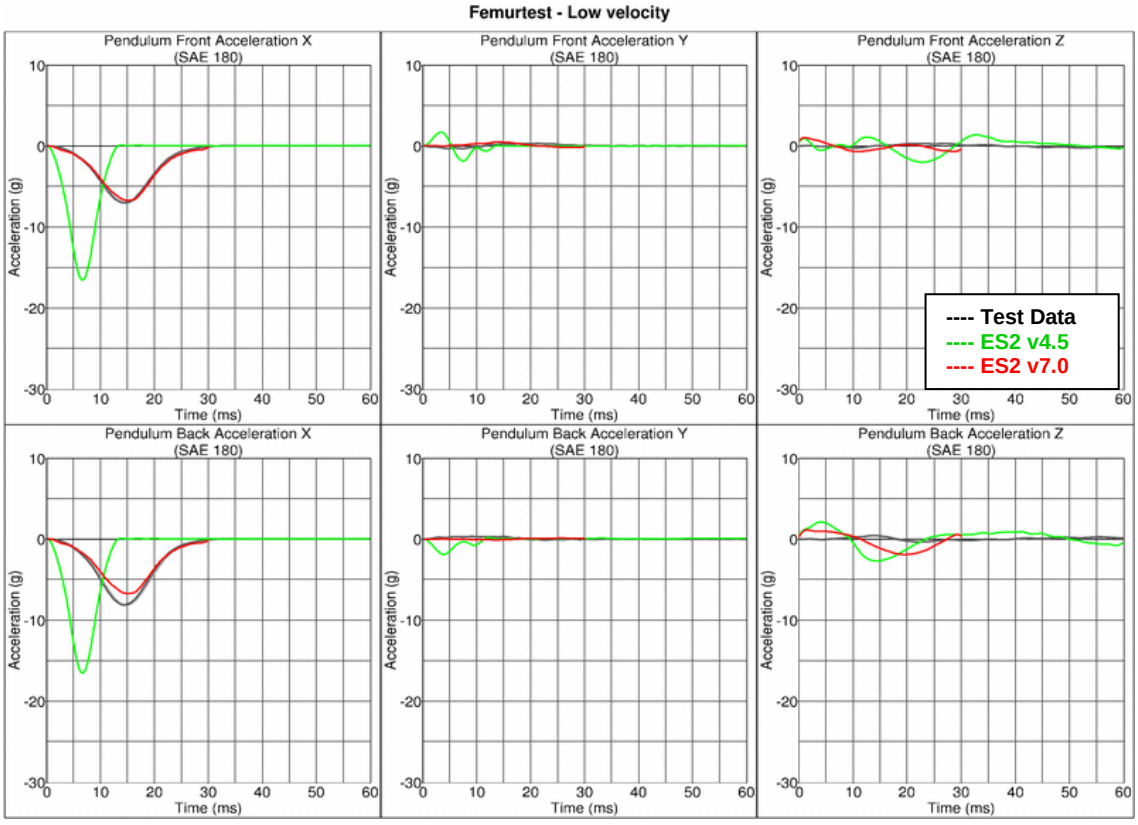


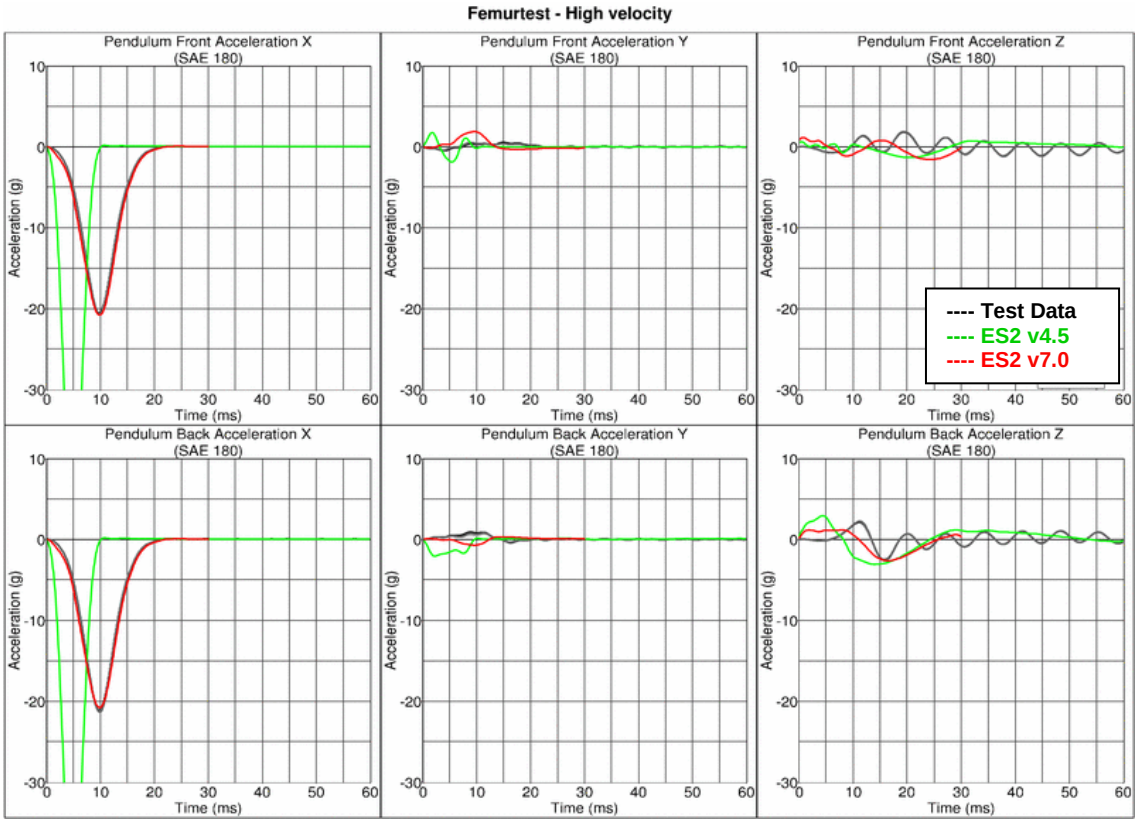
Figure 33: Femur stopper test

The femur stopper is fixed on a test block as shown in the figure above. It is impacted by a pendulum with 2 velocities.
Between v6.0 and v7.0 are no changes in the femur stops. Due to this the results of the v7.0 are compared to a previous version of the femur stop which showed different results. Results of v6.0 and v7.0 are identical.

Results low velocity



Results high velocity



11.2 Rib module tests

11.2.1 Test setup 1

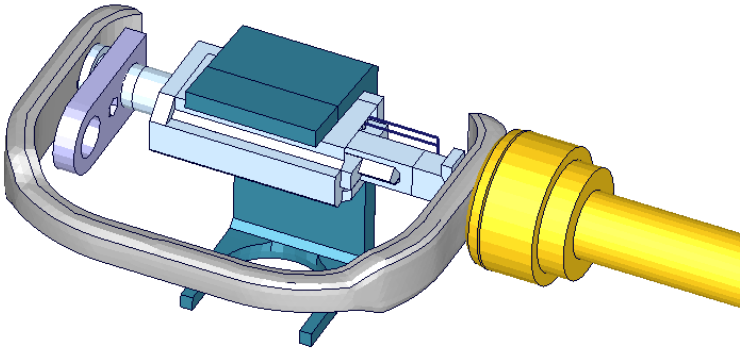
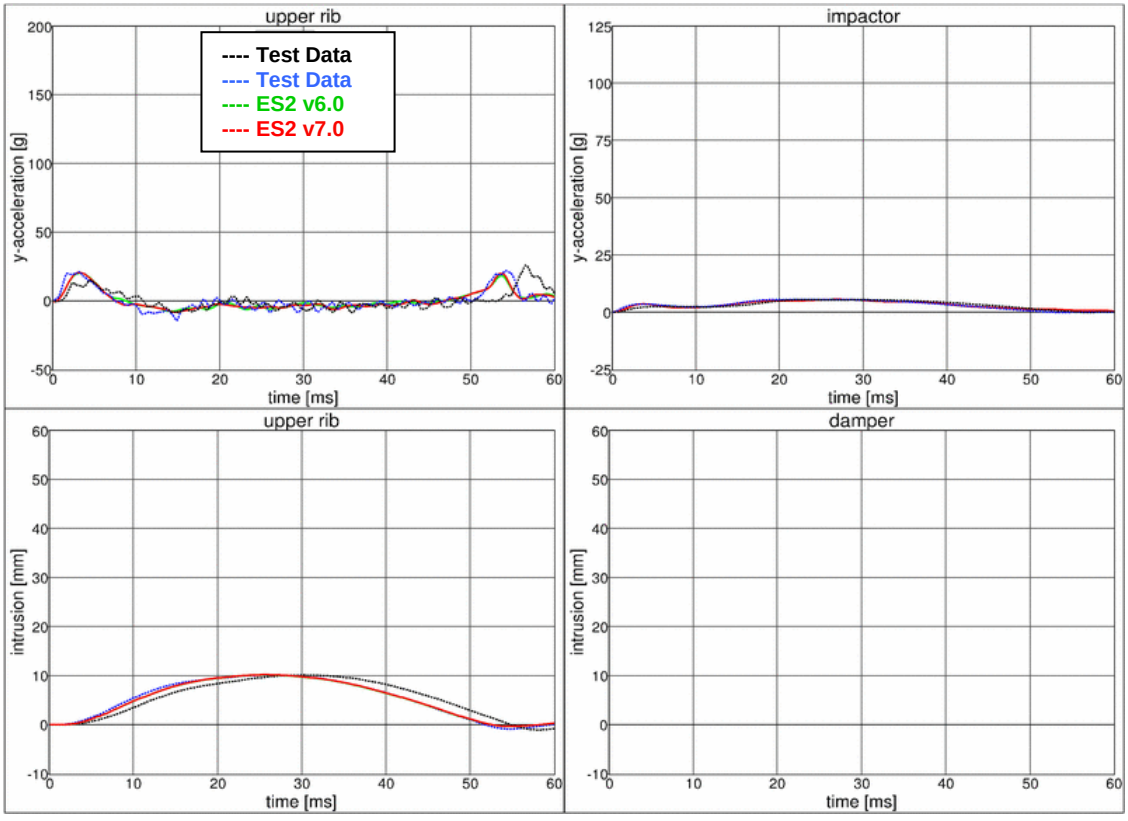


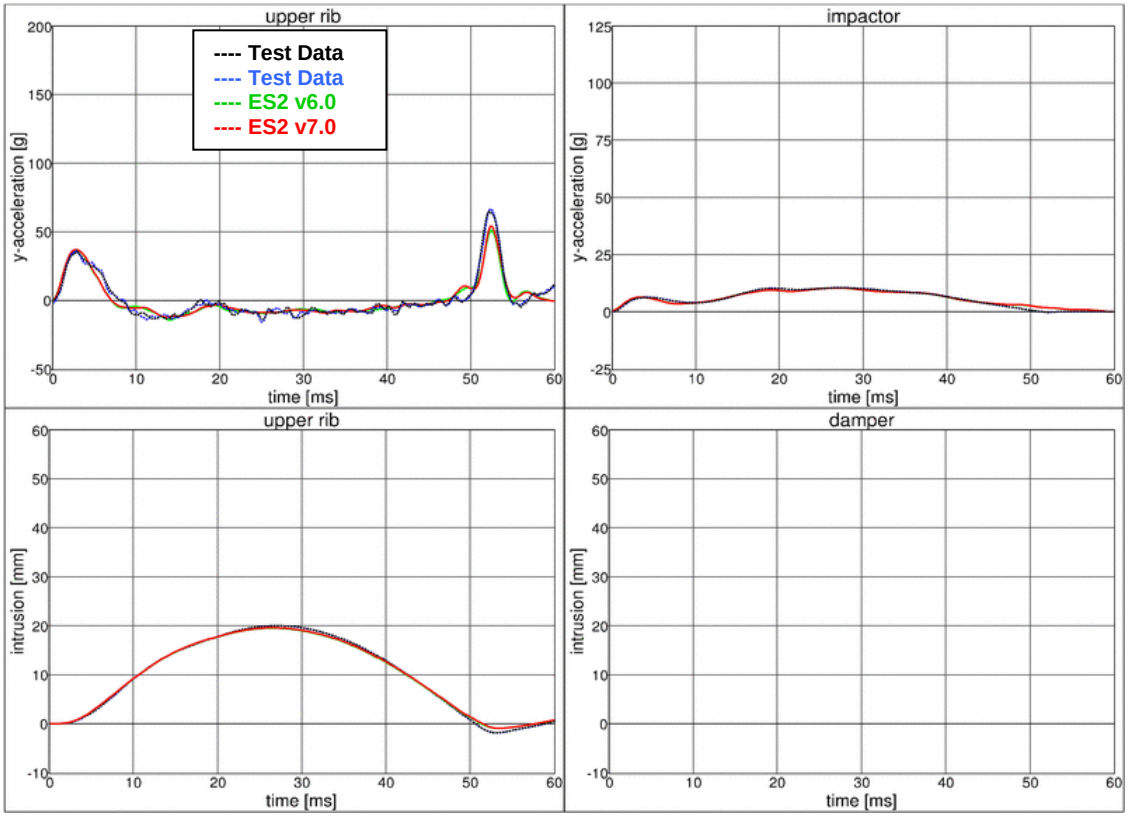
Figure 34: ES-2 rib module test setup 1

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

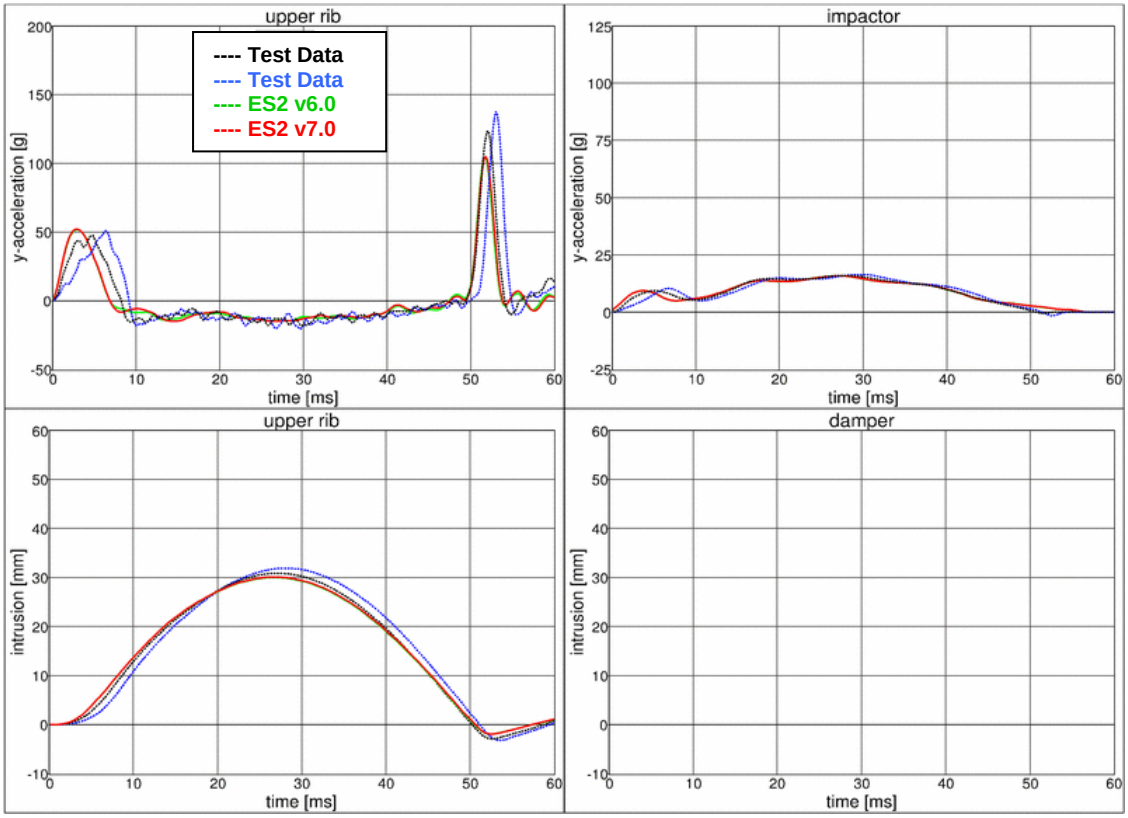
11.2.2 Test setup 1: velocity 1



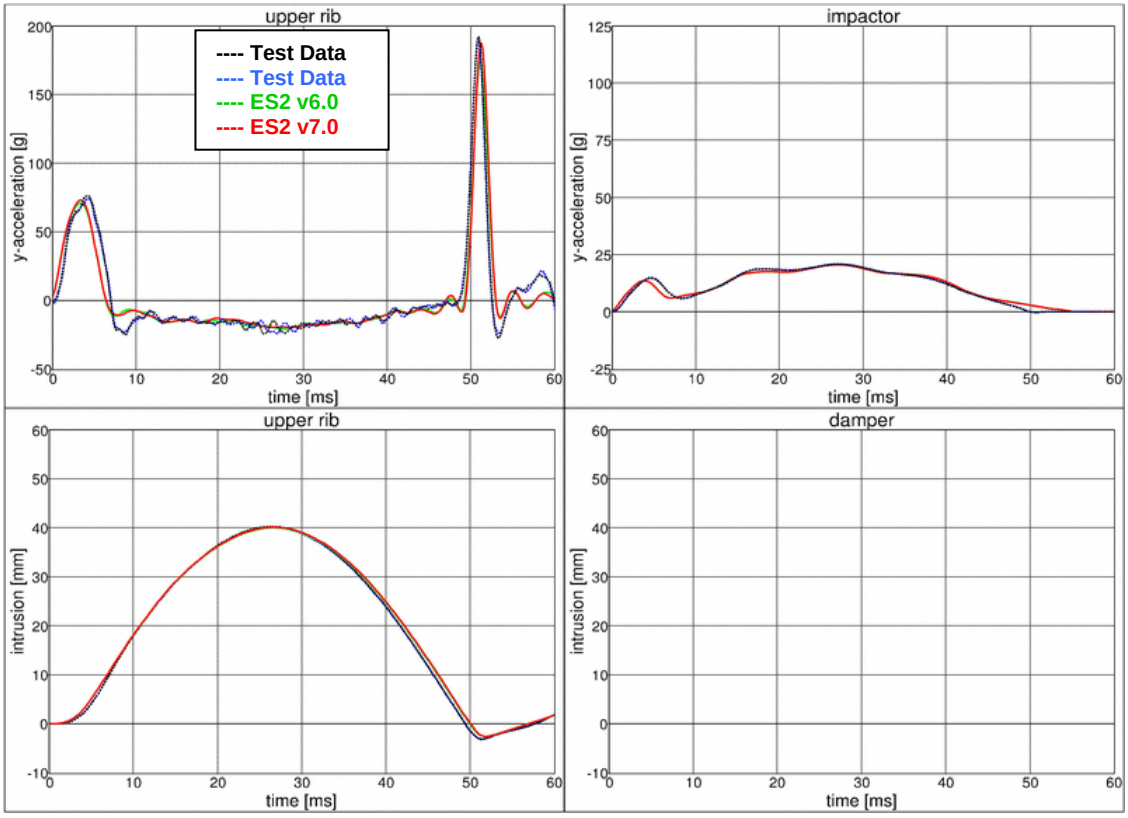
11.2.3 Test setup 1: velocity 2



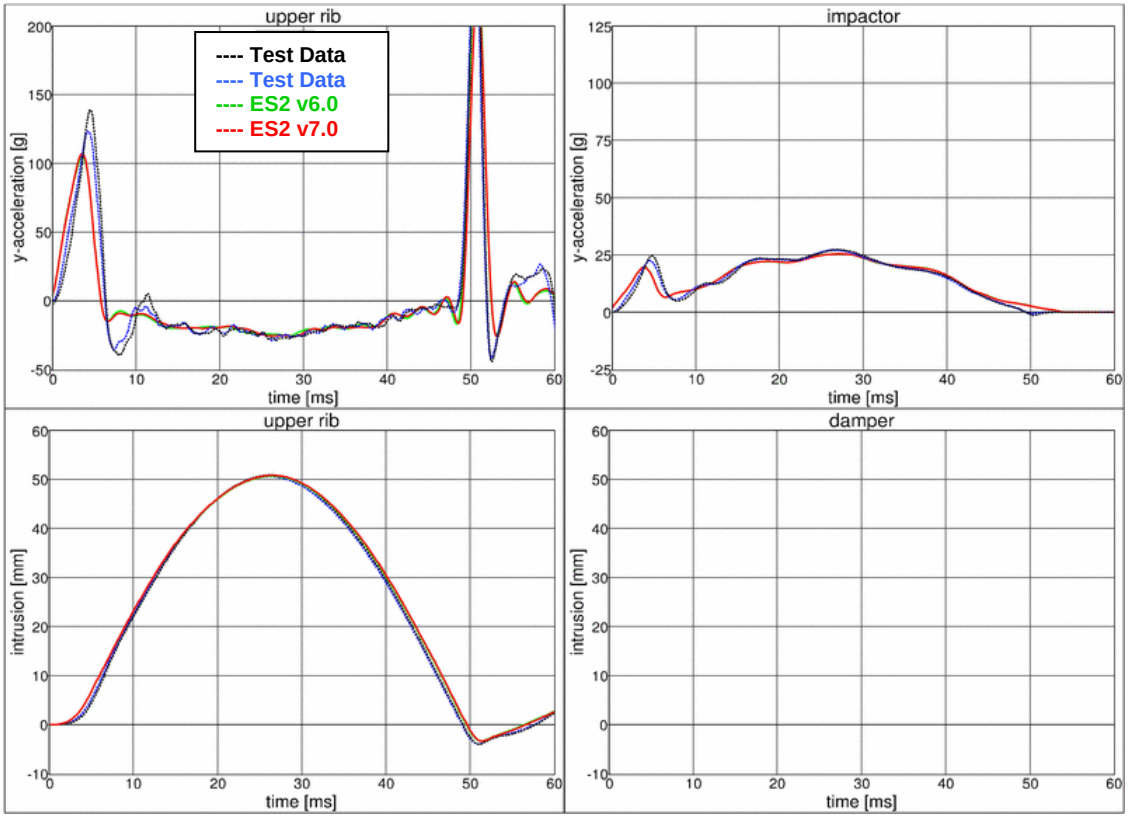
11.2.4 Test setup 1: velocity 3



11.2.5 Test setup 1: velocity 4



11.2.6 Test setup 1: velocity 5



11.2.7 Test setup 2

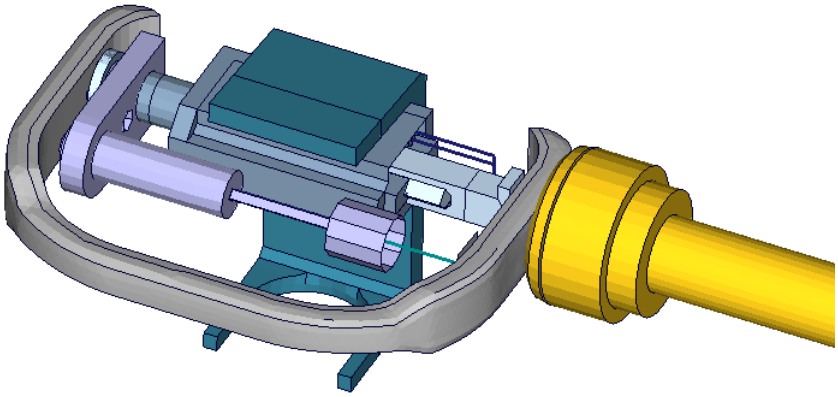
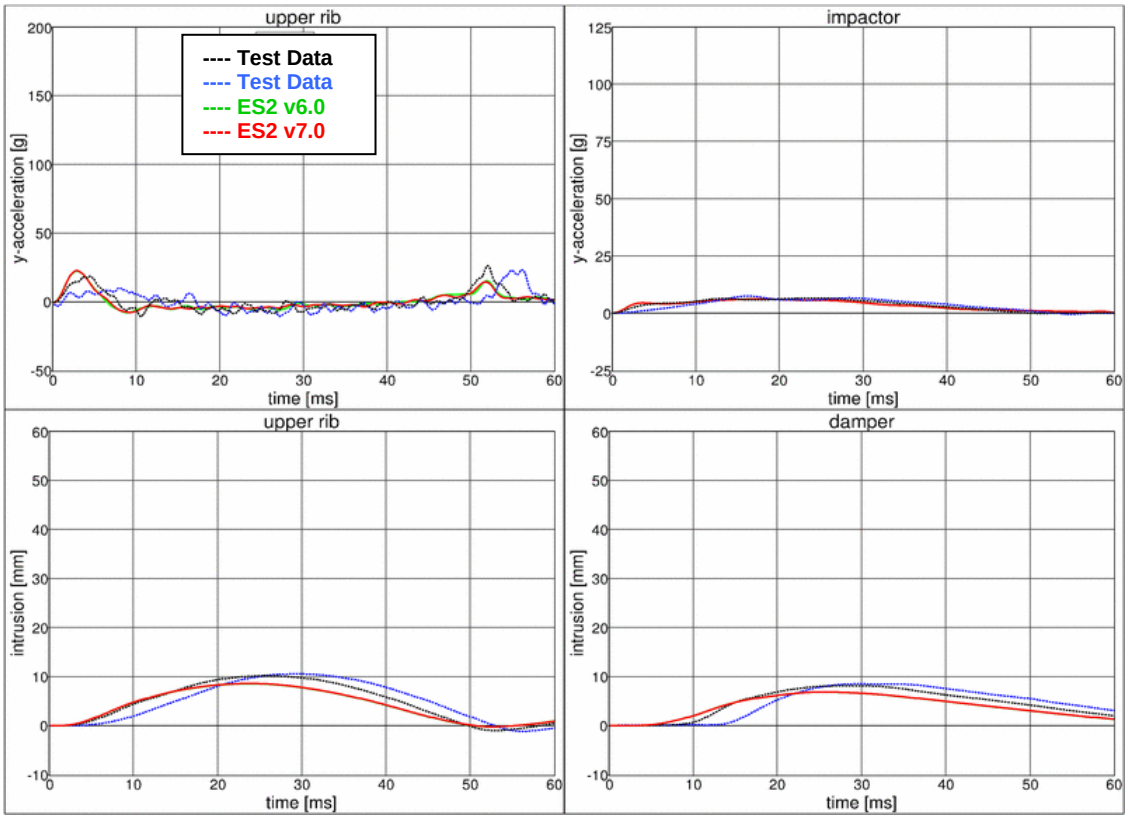


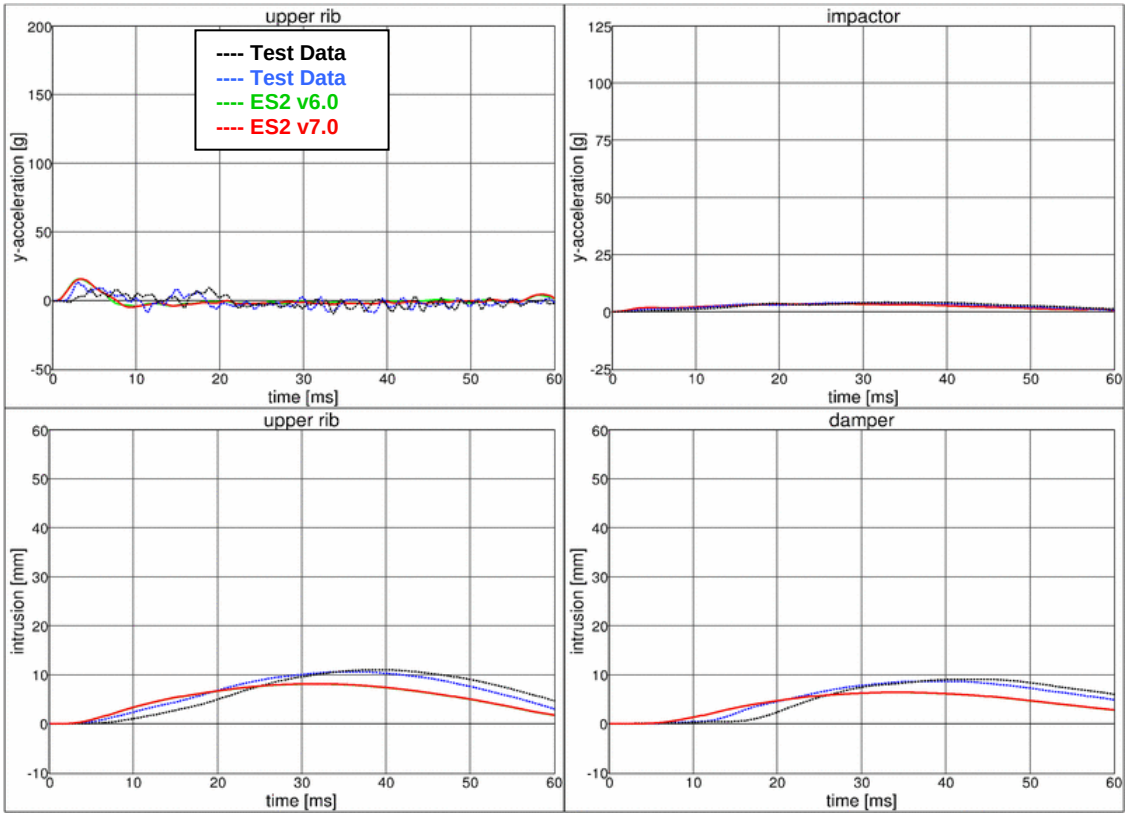
Figure 35: ES-2 rib module test setup 2

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

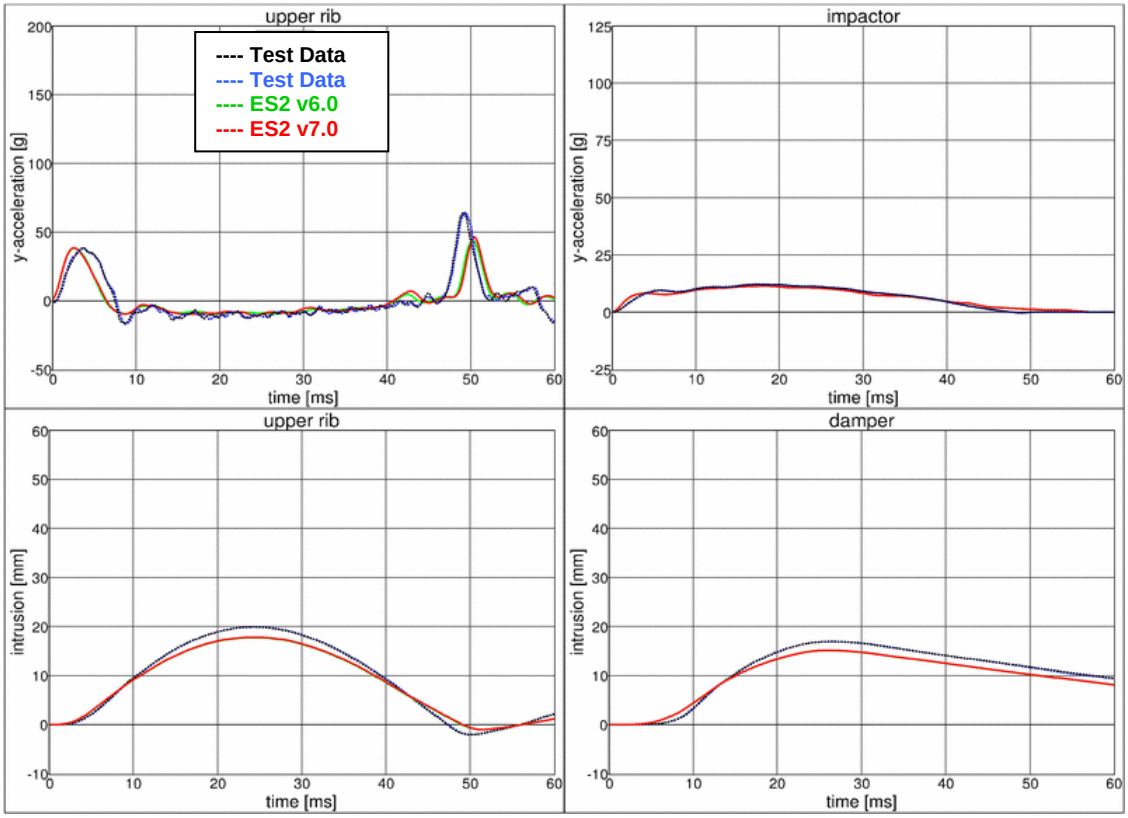
11.2.8 Test setup 2: velocity 1 low mass



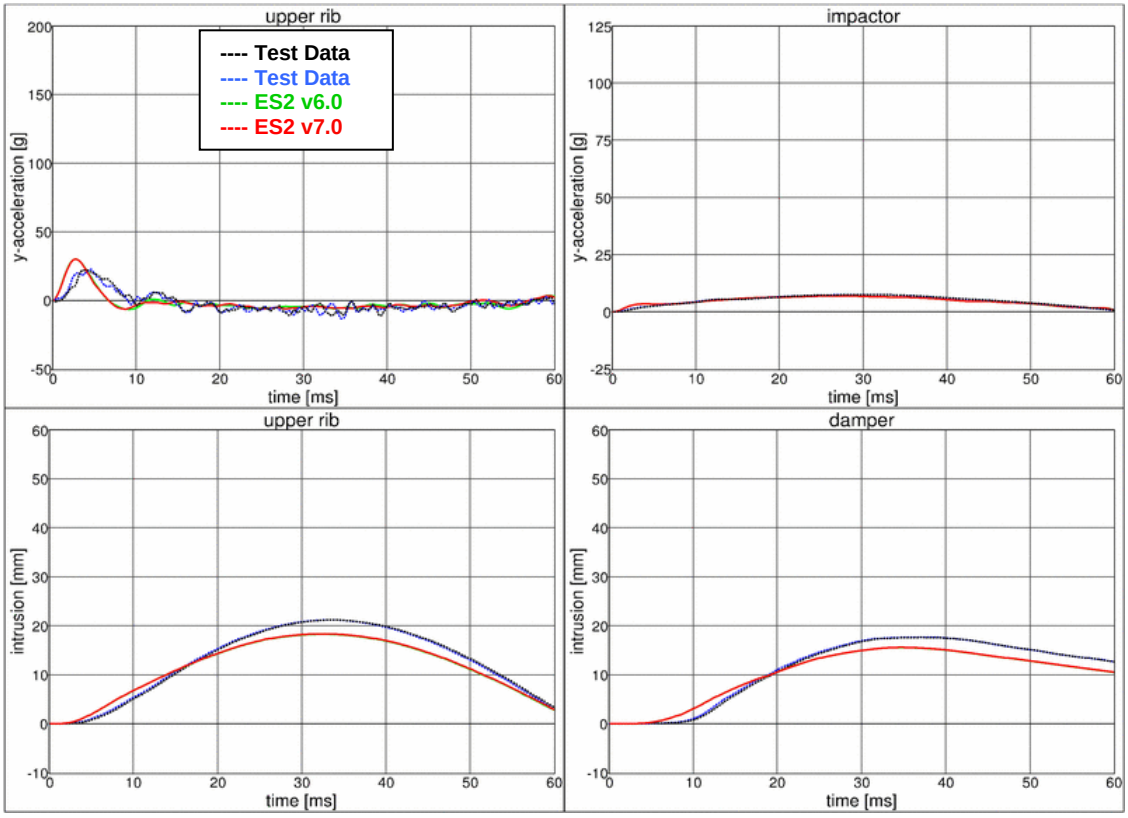
11.2.9 Test setup 2: velocity 1 high mass



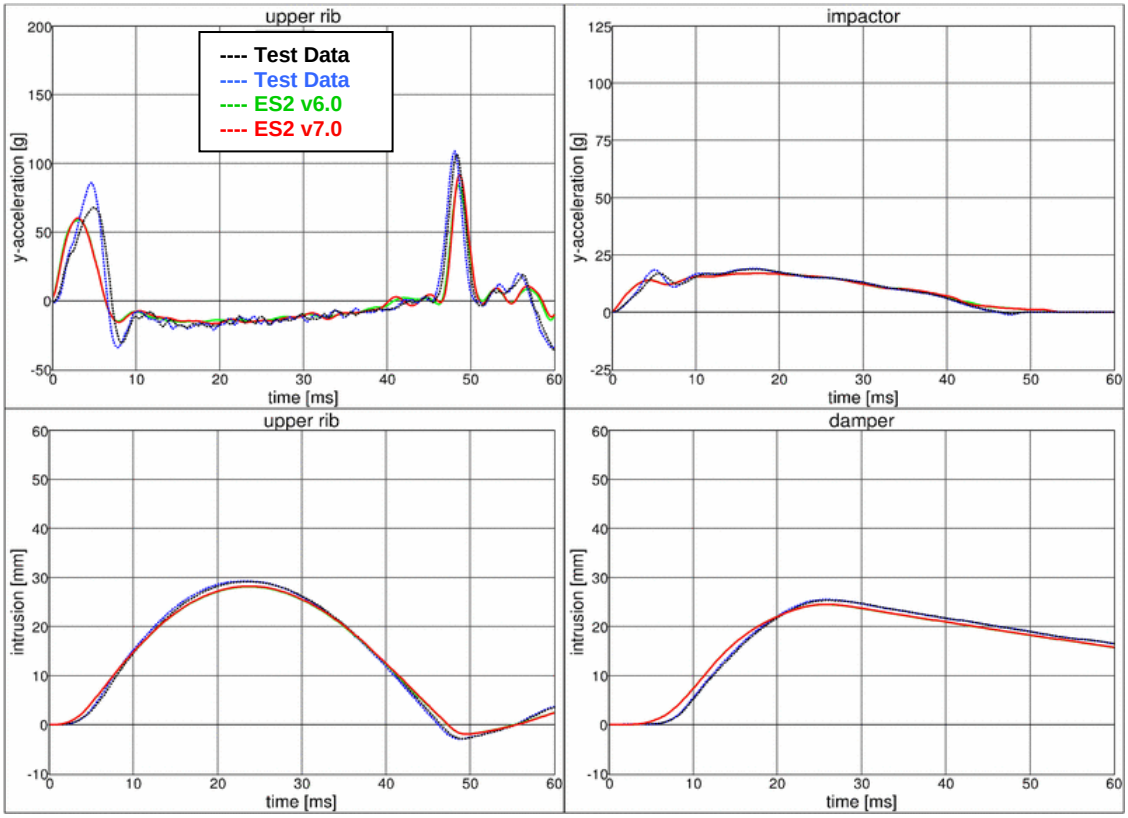
11.2.10 Test setup 2: velocity 2 low mass



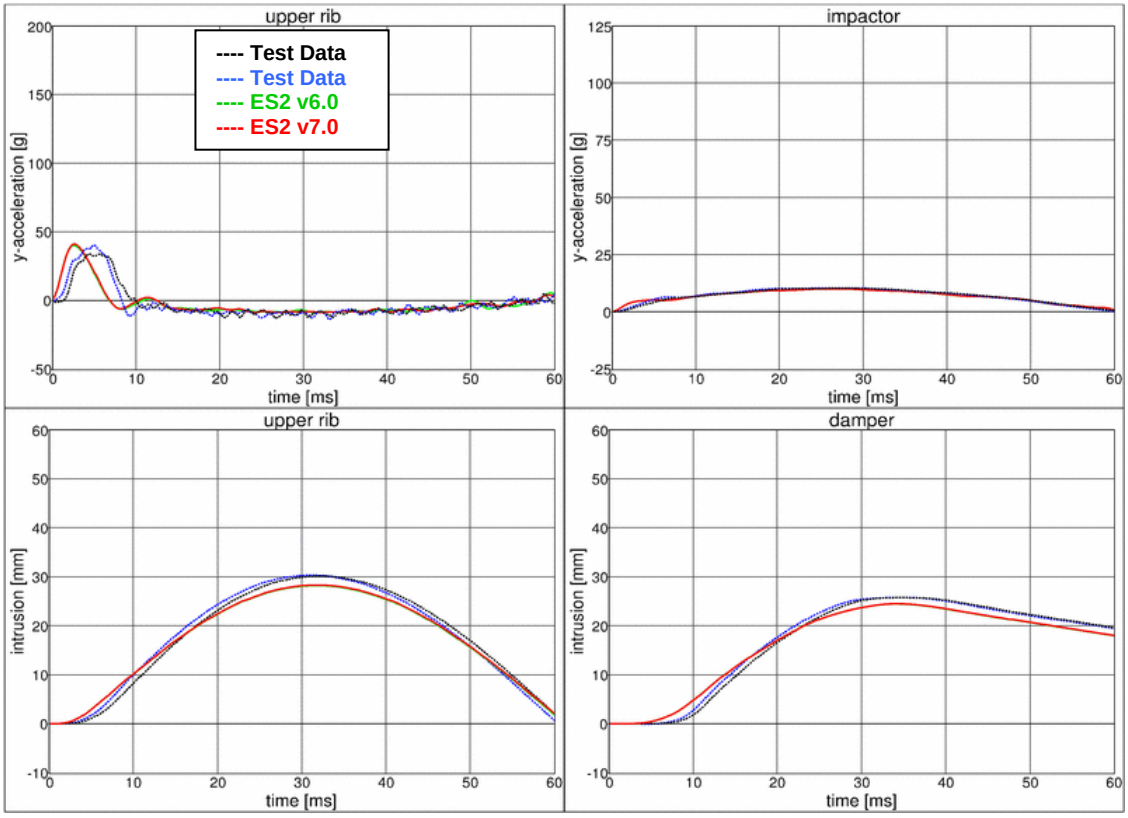
11.2.11 Test setup 2: velocity 2 high mass



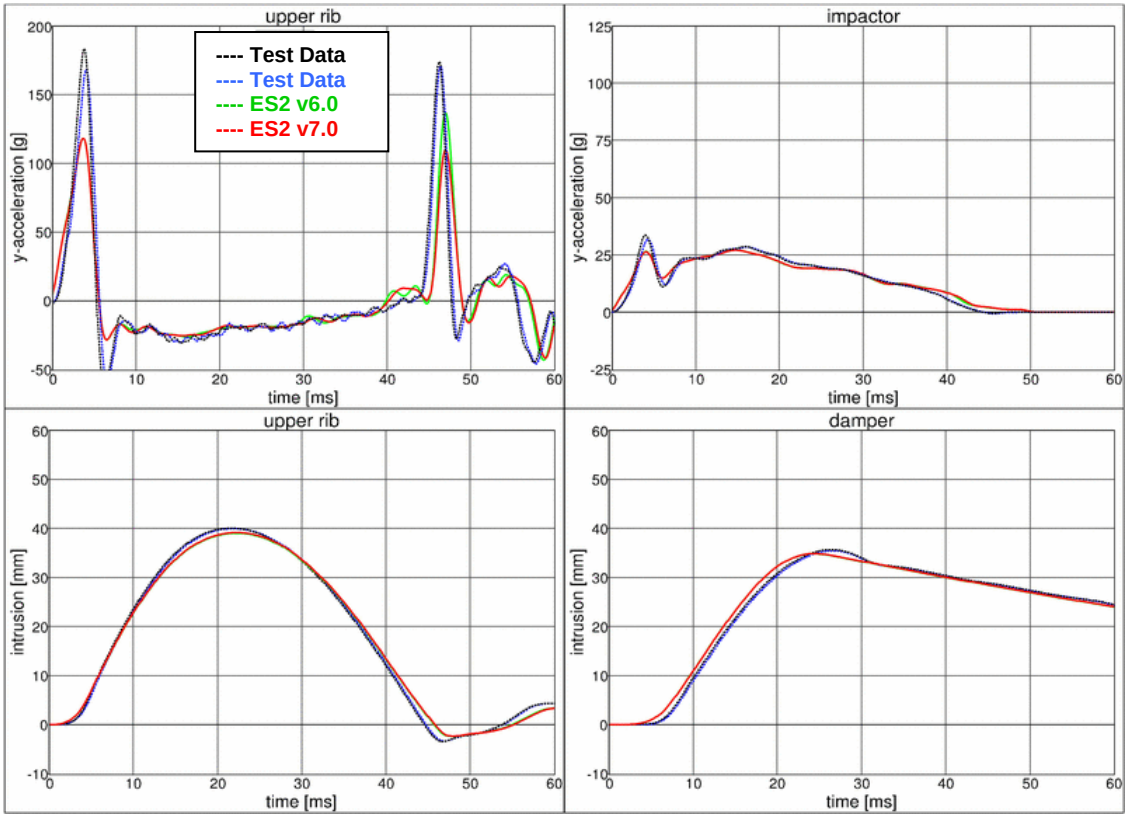
11.2.12 Test setup 2: velocity 3 low mass



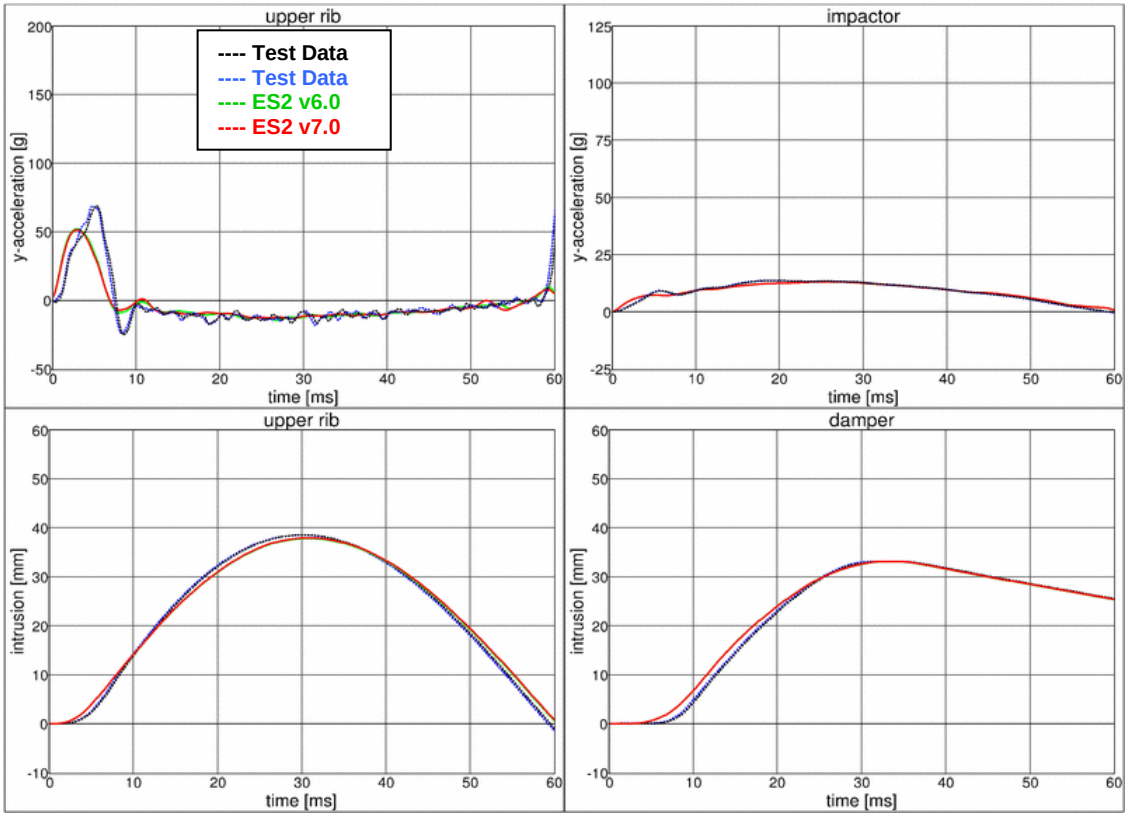
11.2.13 Test setup 2: velocity 3 high mass



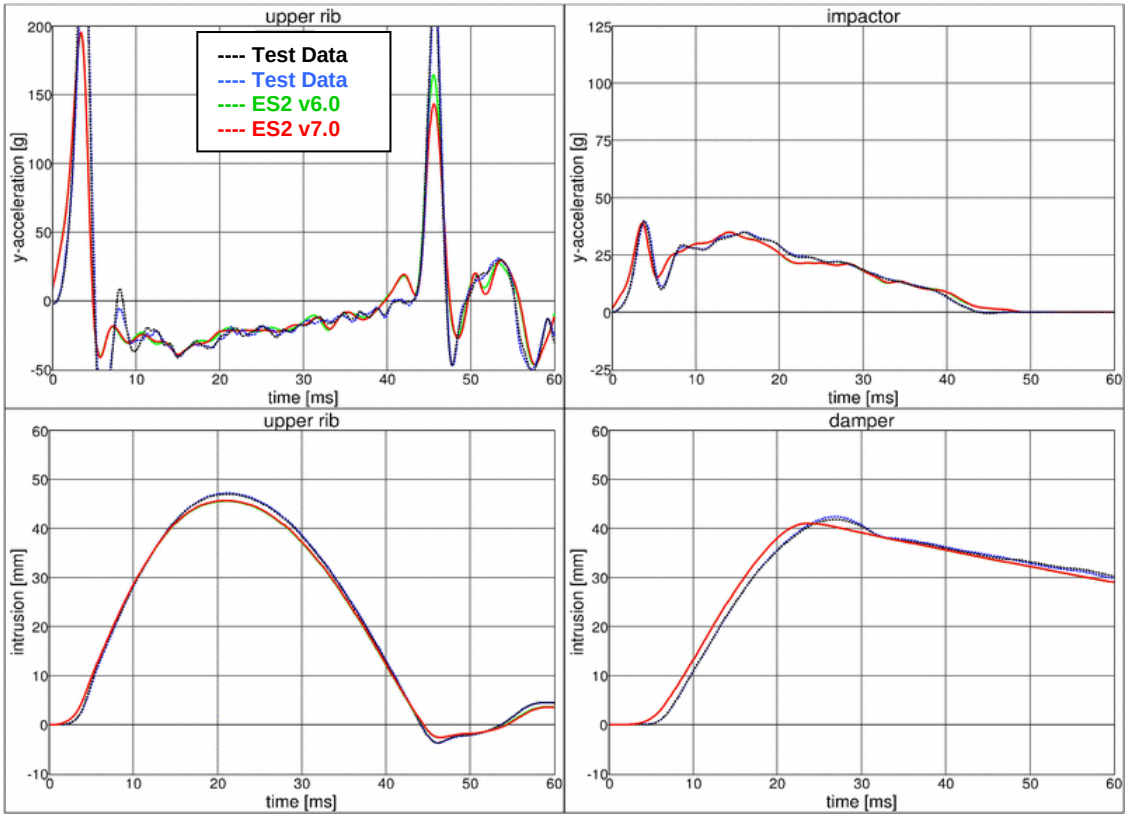
11.2.14 Test setup 2: velocity 4 low mass



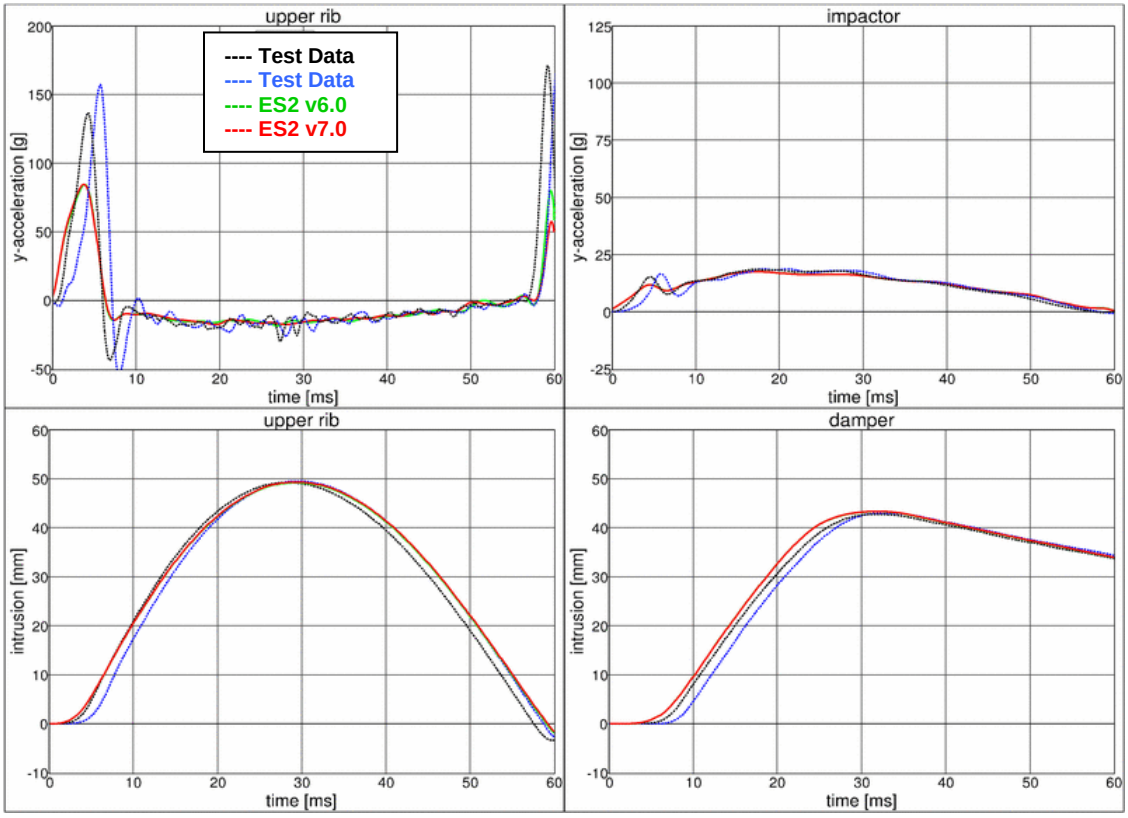
11.2.15 Test setup 2: velocity 4 high mass



11.2.16 Test setup 2: velocity 5 low mass



11.2.17 Test setup 2: velocity 5 high mass



11.2.18 Test setup 3

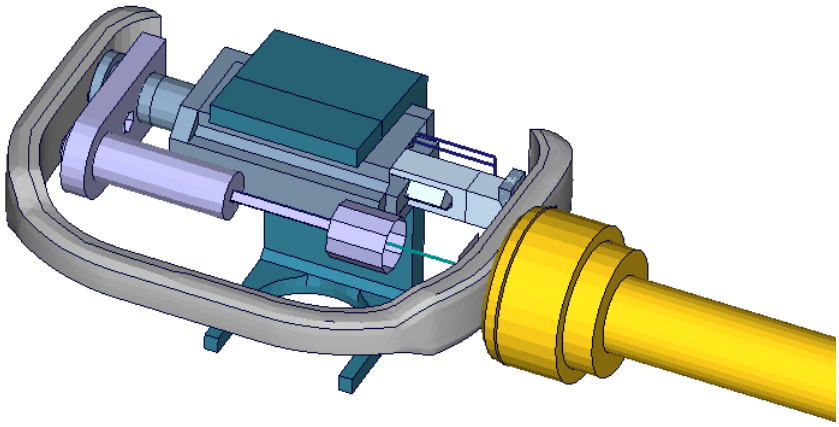
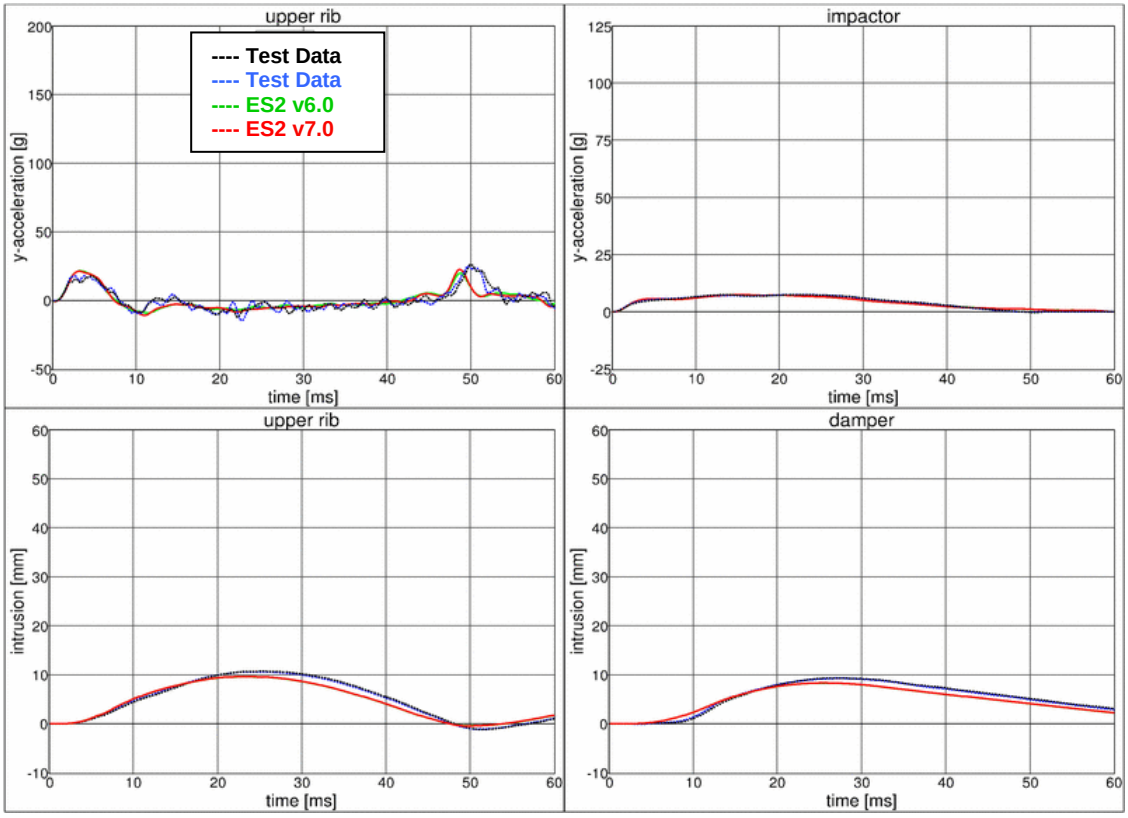


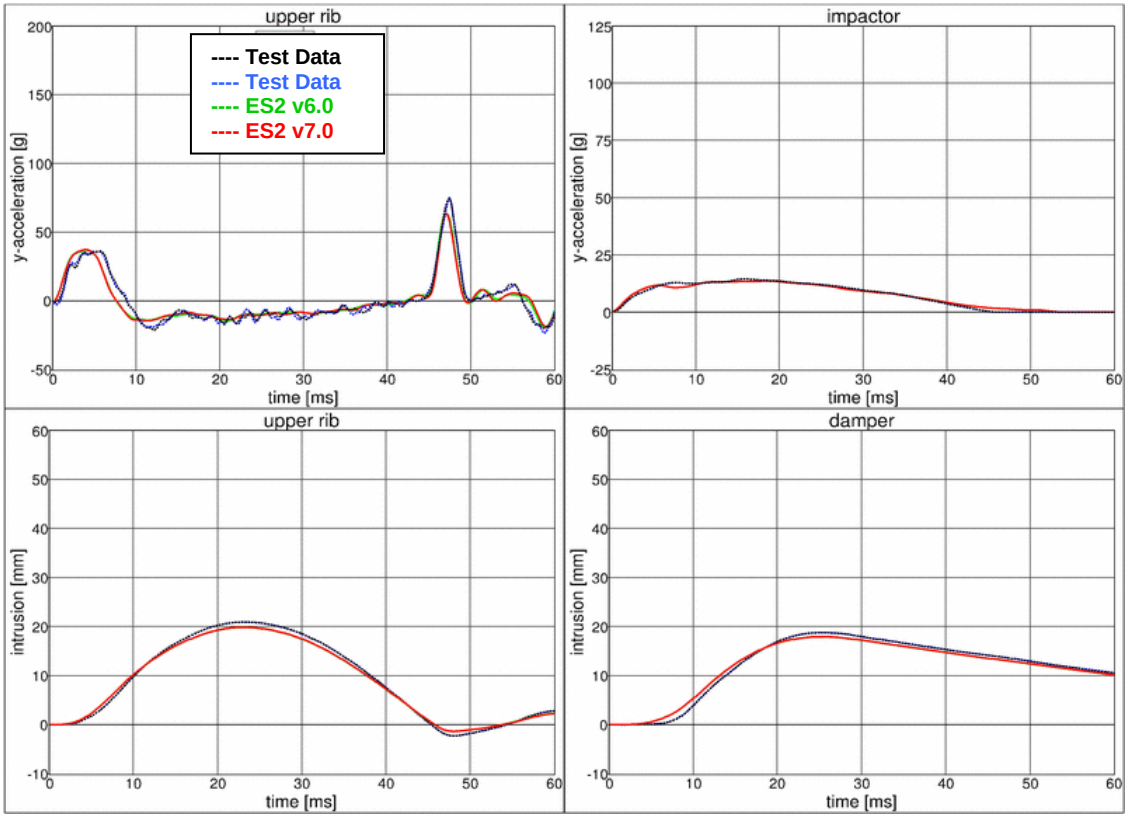
Figure 36: ES-2 rib module test setup 3

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

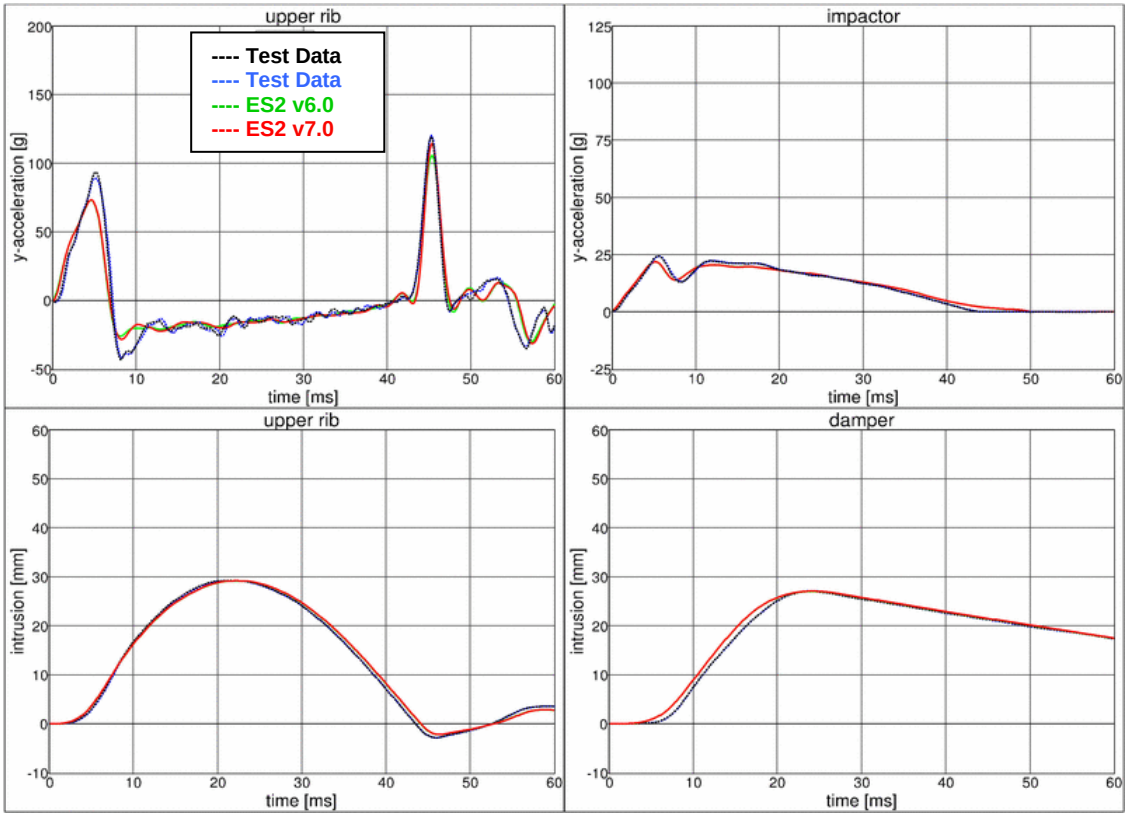
11.2.19 Test setup 3: velocity 1



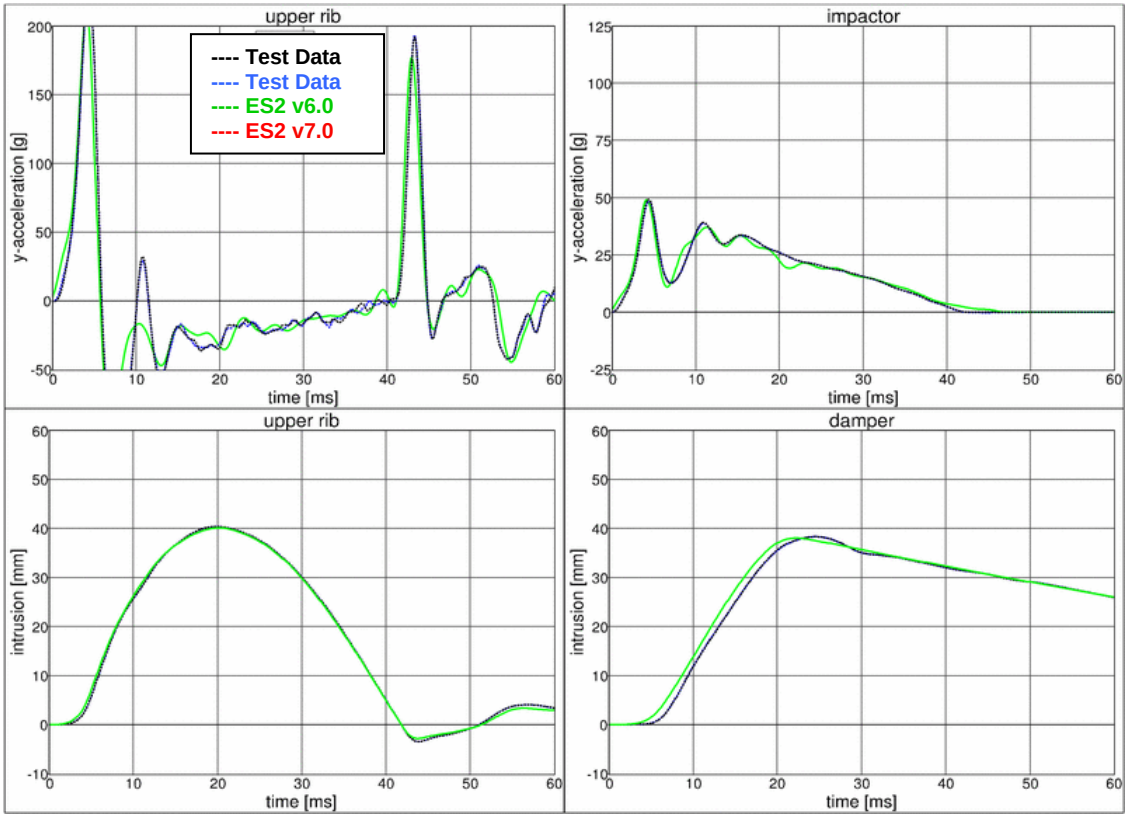
11.2.20 Test setup 3: velocity 2



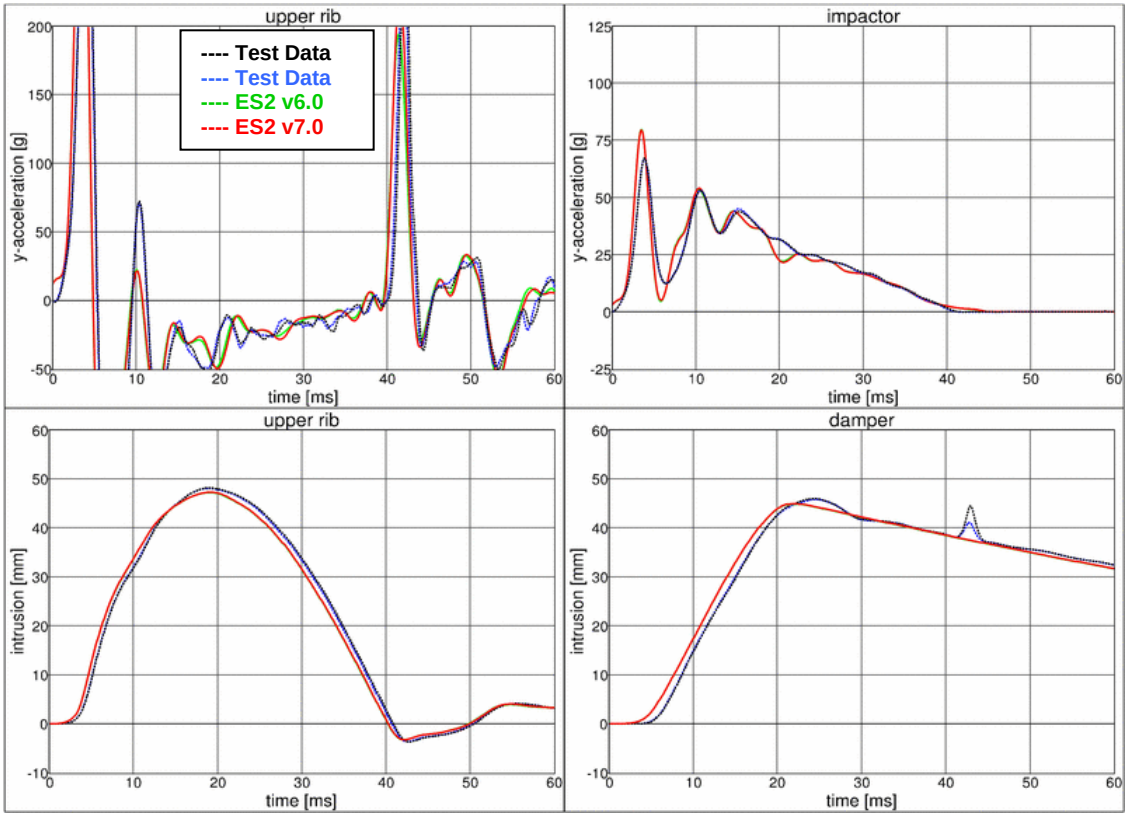
11.2.21 Test setup 3: velocity 3



11.2.22 Test setup 3: velocity 4



11.2.23 Test setup 3: velocity 5



11.2.24 Test setup 4

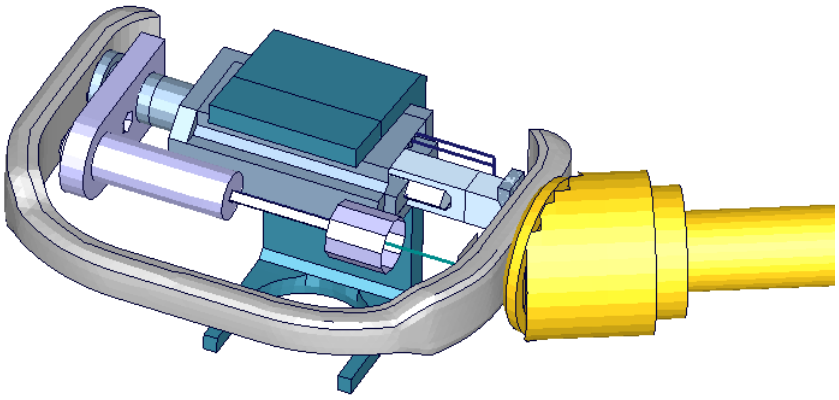
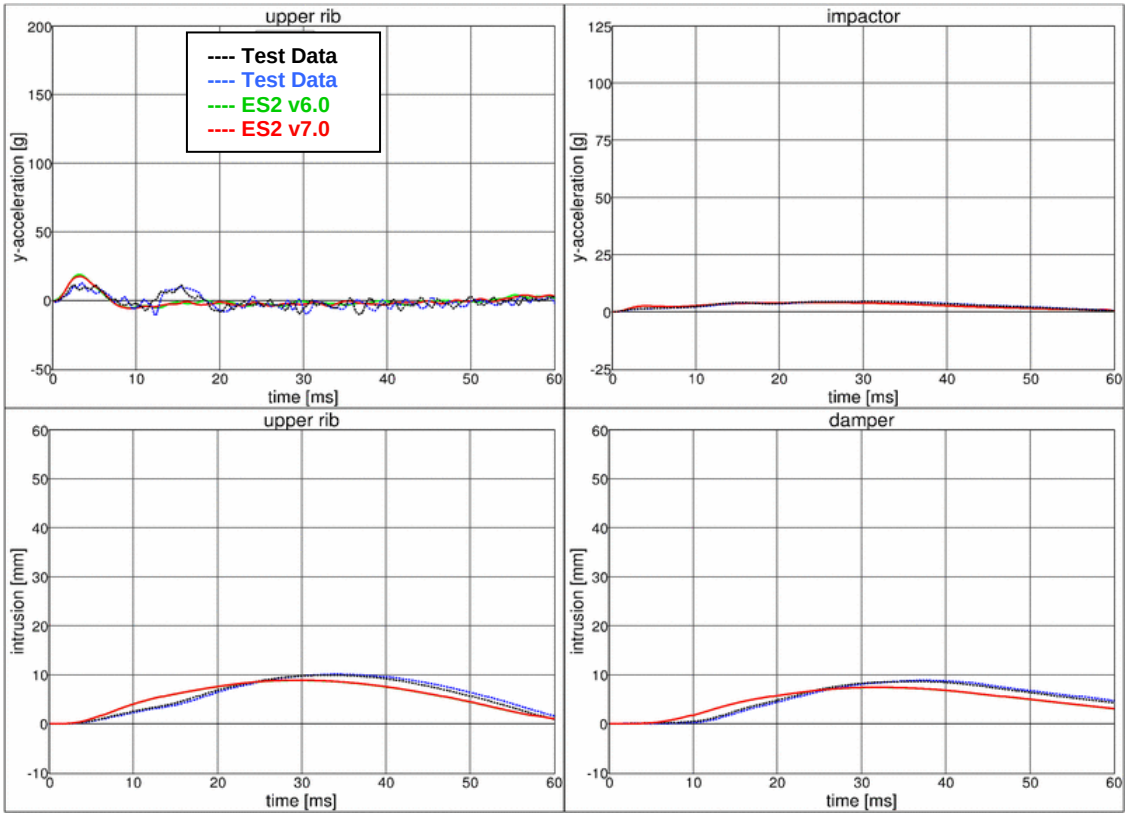


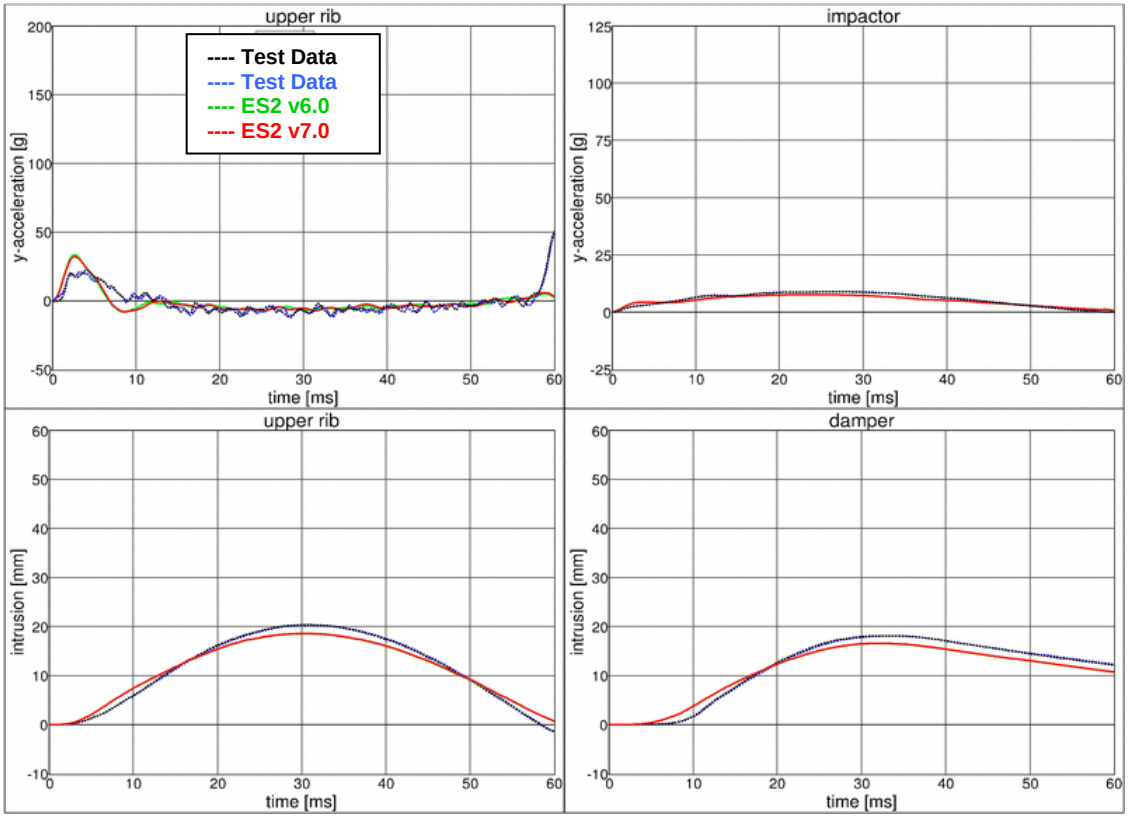
Figure 37: ES-2 rib module test setup 4

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

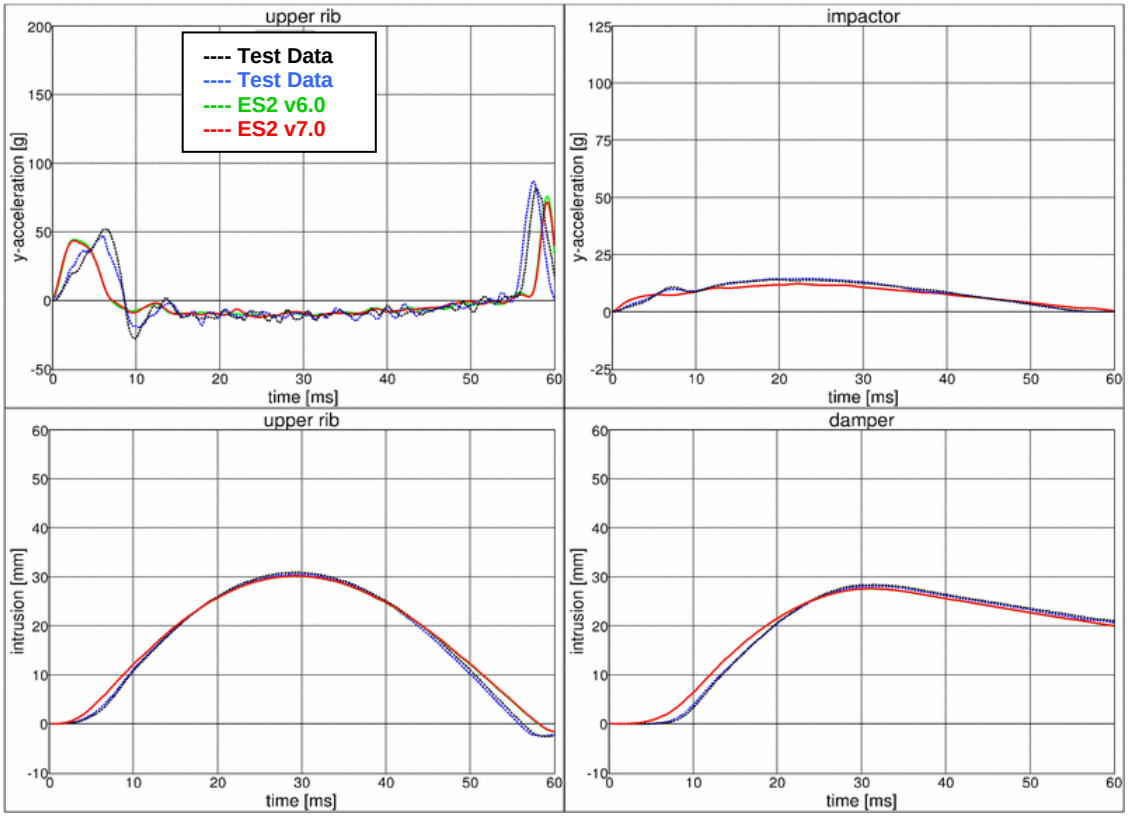
11.2.25 Test setup 4: velocity 1



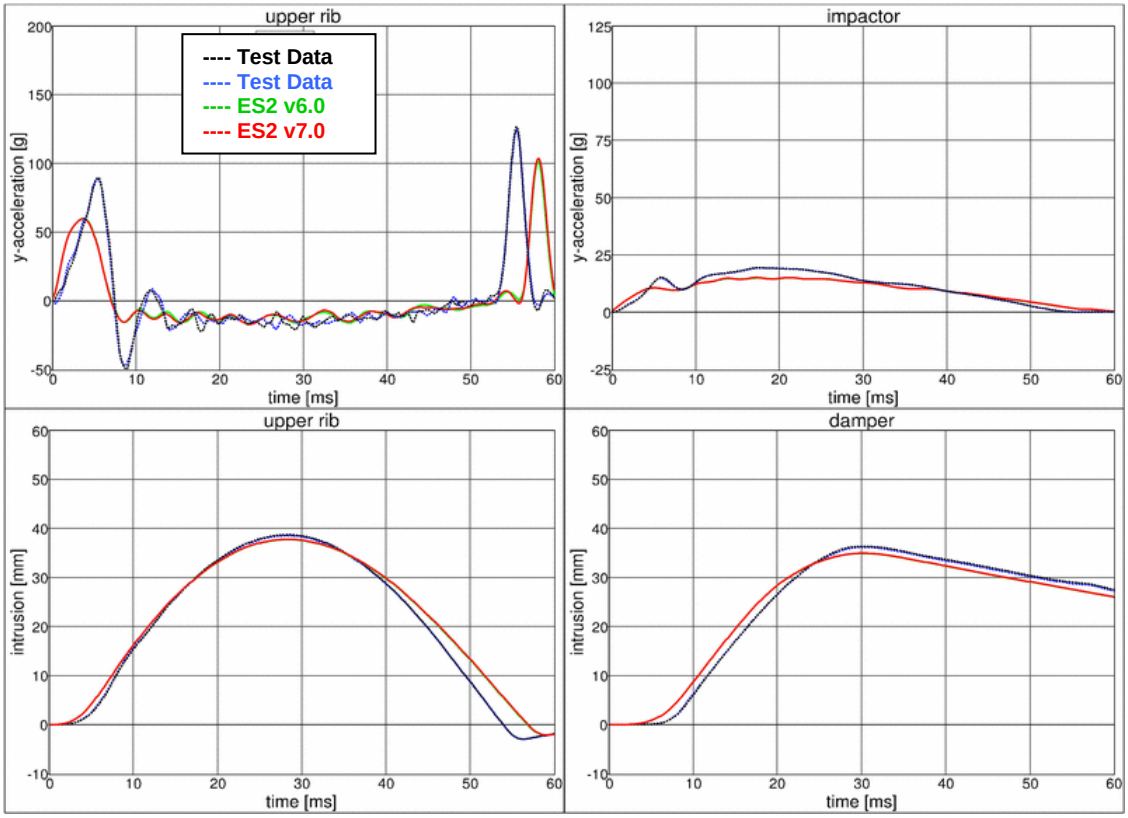
11.2.26 Test setup 4: velocity 2



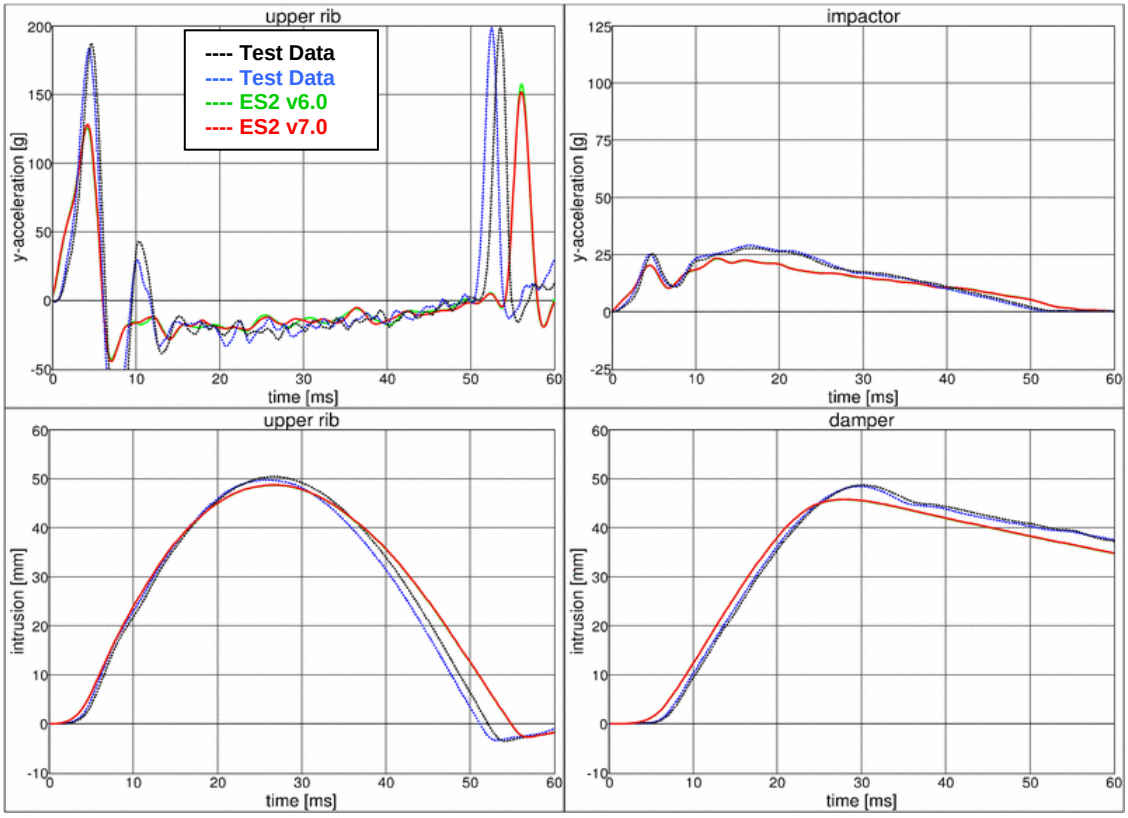
11.2.27 Test setup 4: velocity 3



11.2.28 Test setup 4: velocity 4



11.2.29 Test setup 4: velocity 5



12. Certification tests

12.1 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 200mm.

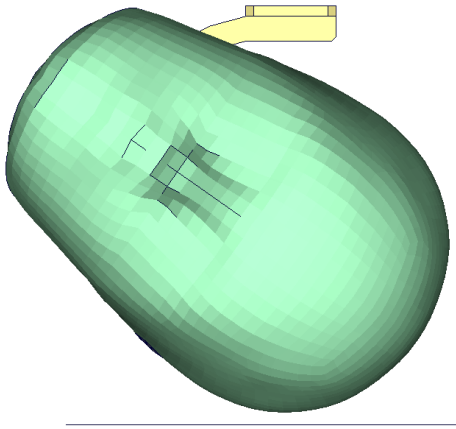
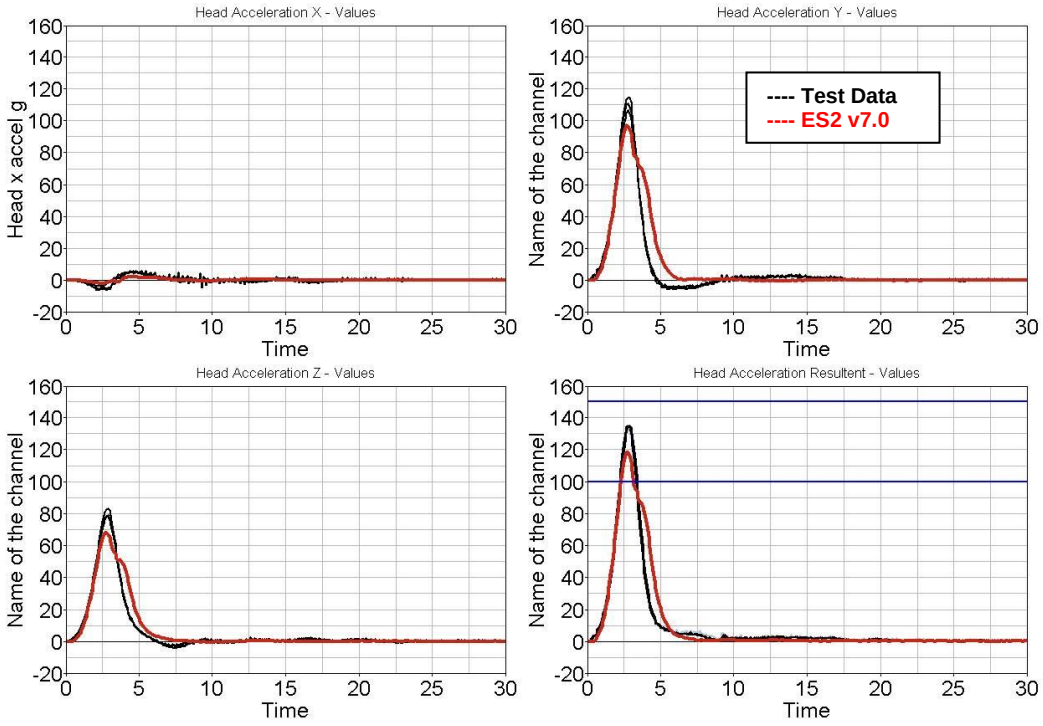


Figure 38: ES-2 head drop test setup

12.1.1 Results



12.2 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.

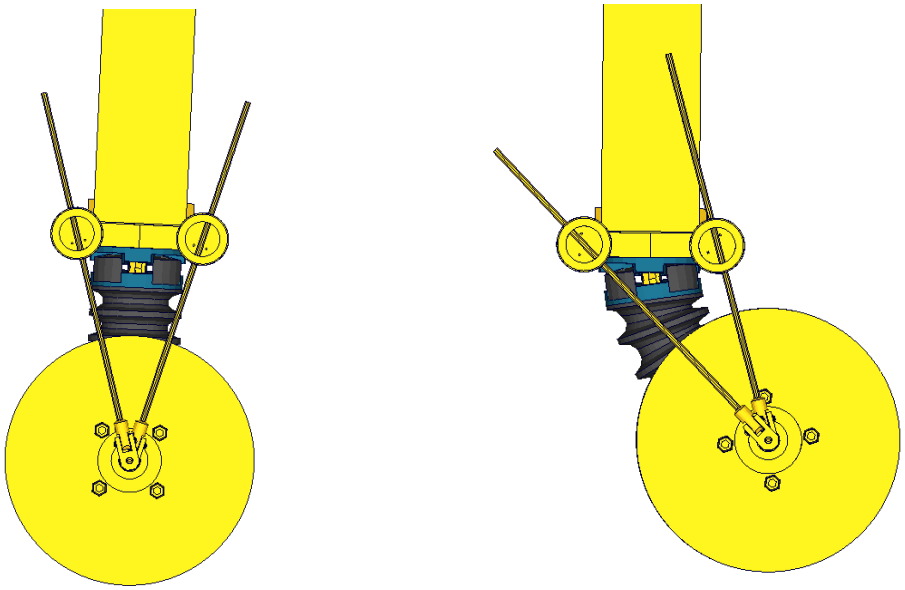
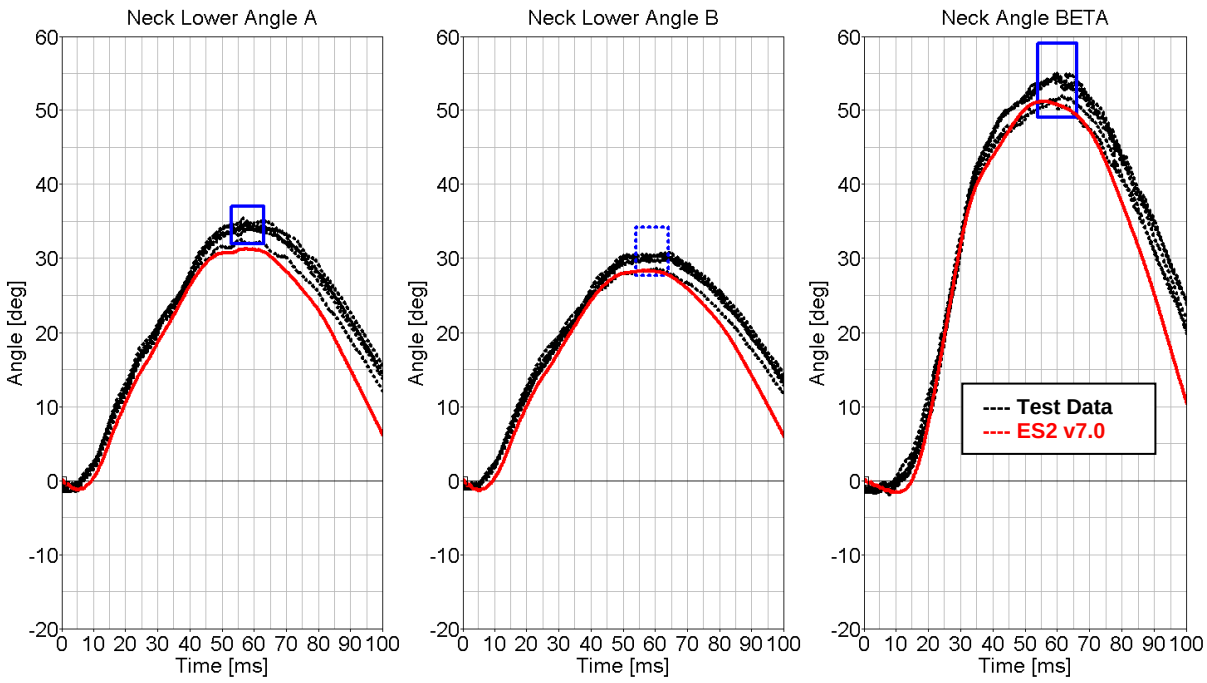


Figure 39: ES-2 neck calibration test setup

12.2.1 Results



12.3 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

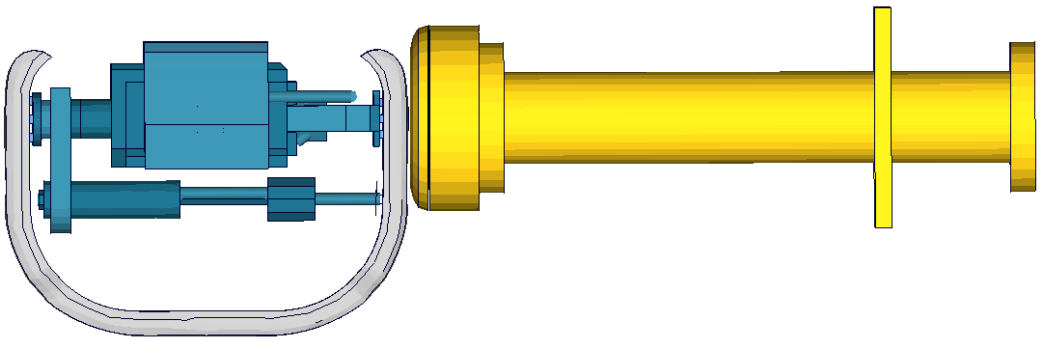
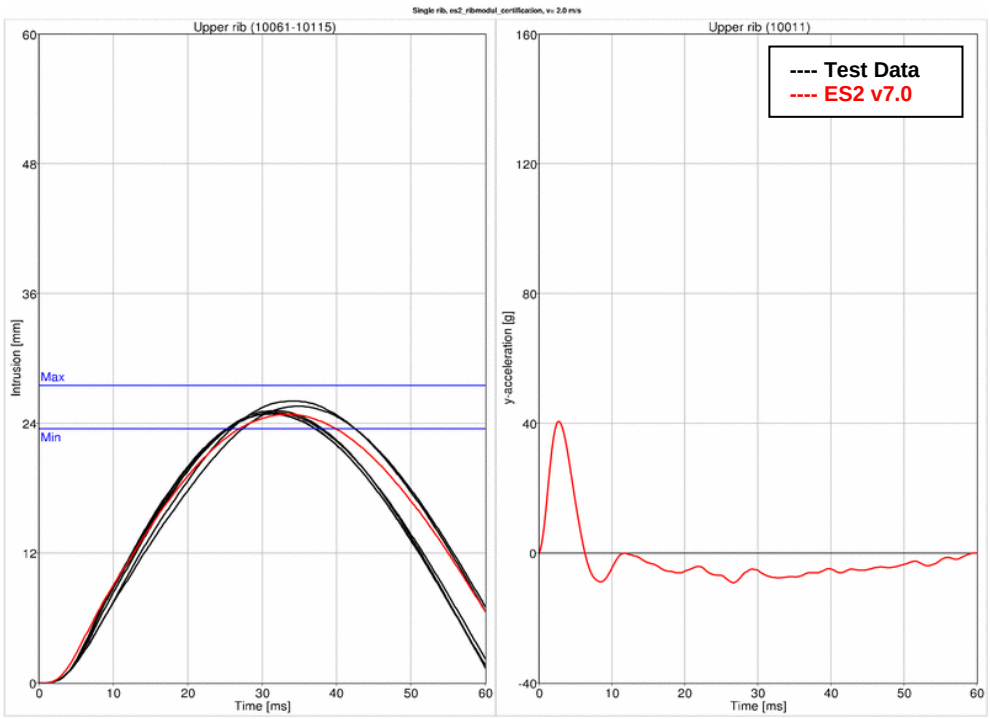
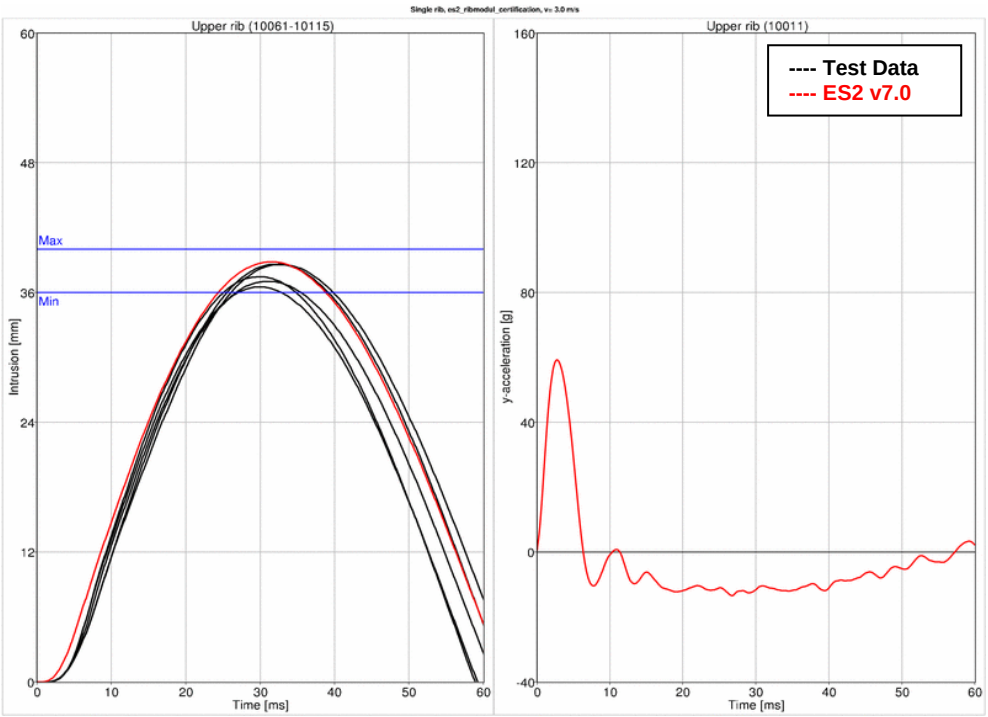


Figure 40: ES-2 rib calibration test setup

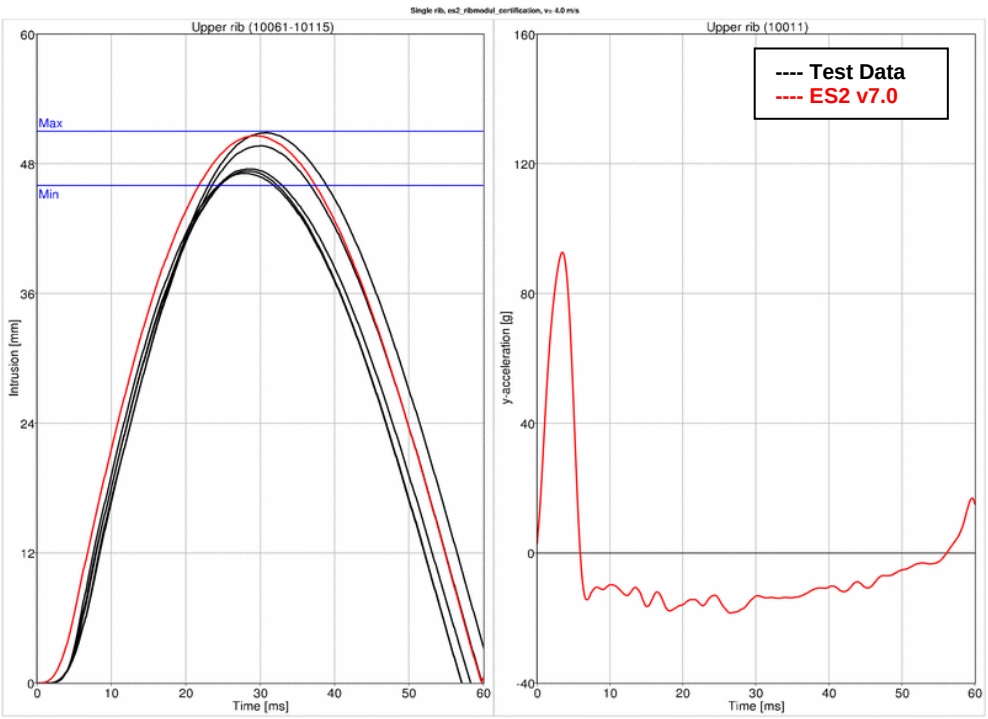
12.3.1 Results low velocity



12.3.2 Results medium velocity



12.3.3 Results high velocity



12.4 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.
- Between v6.0 and v7.0 are no changes in the lumbar spine. Due to this the results of the v7.0 are compared to a previous version of the lumbar spine which showed different results. Results of v6.0 and v7.0 are identical.

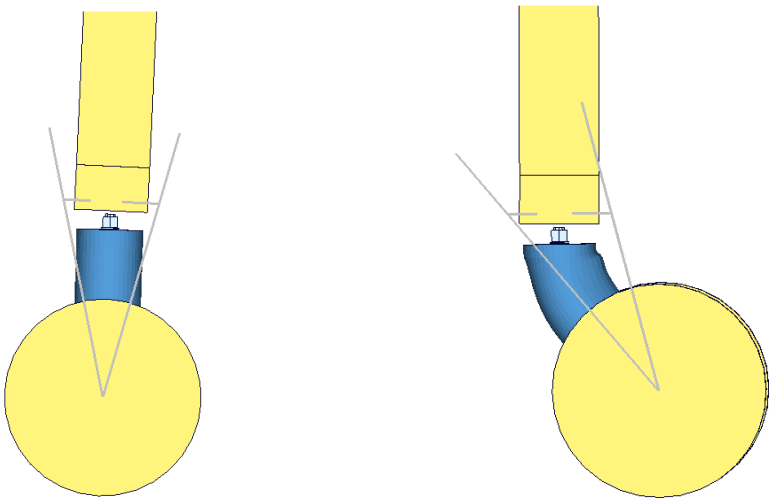
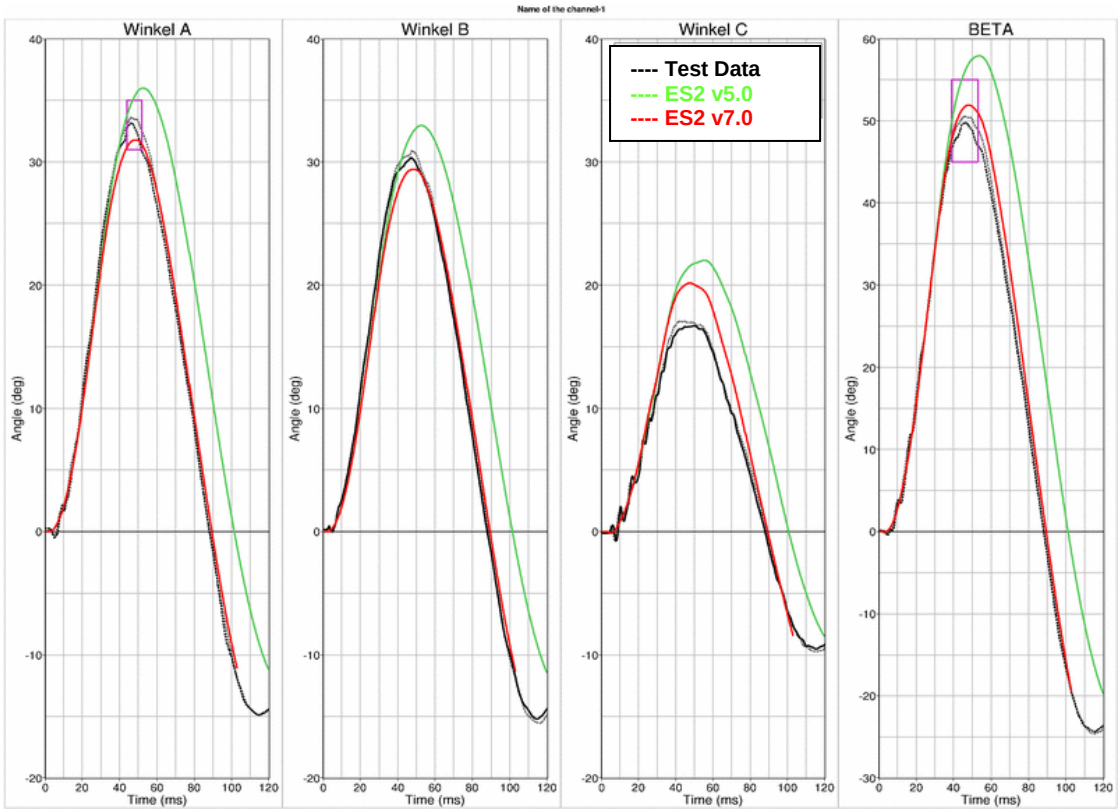


Figure 41: ES-2 lumbar spine calibration test setup

12.4.1 Results



12.5 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

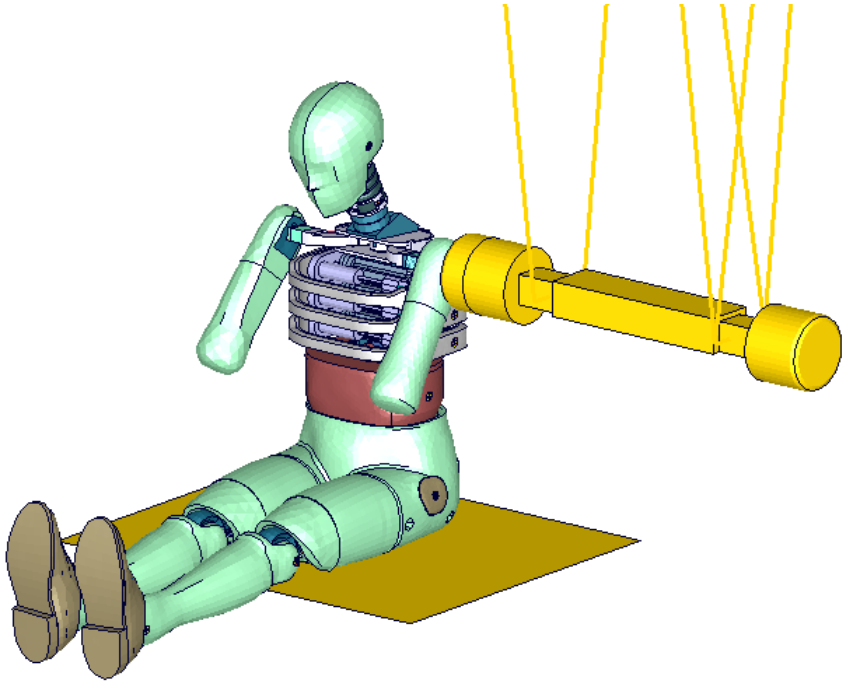
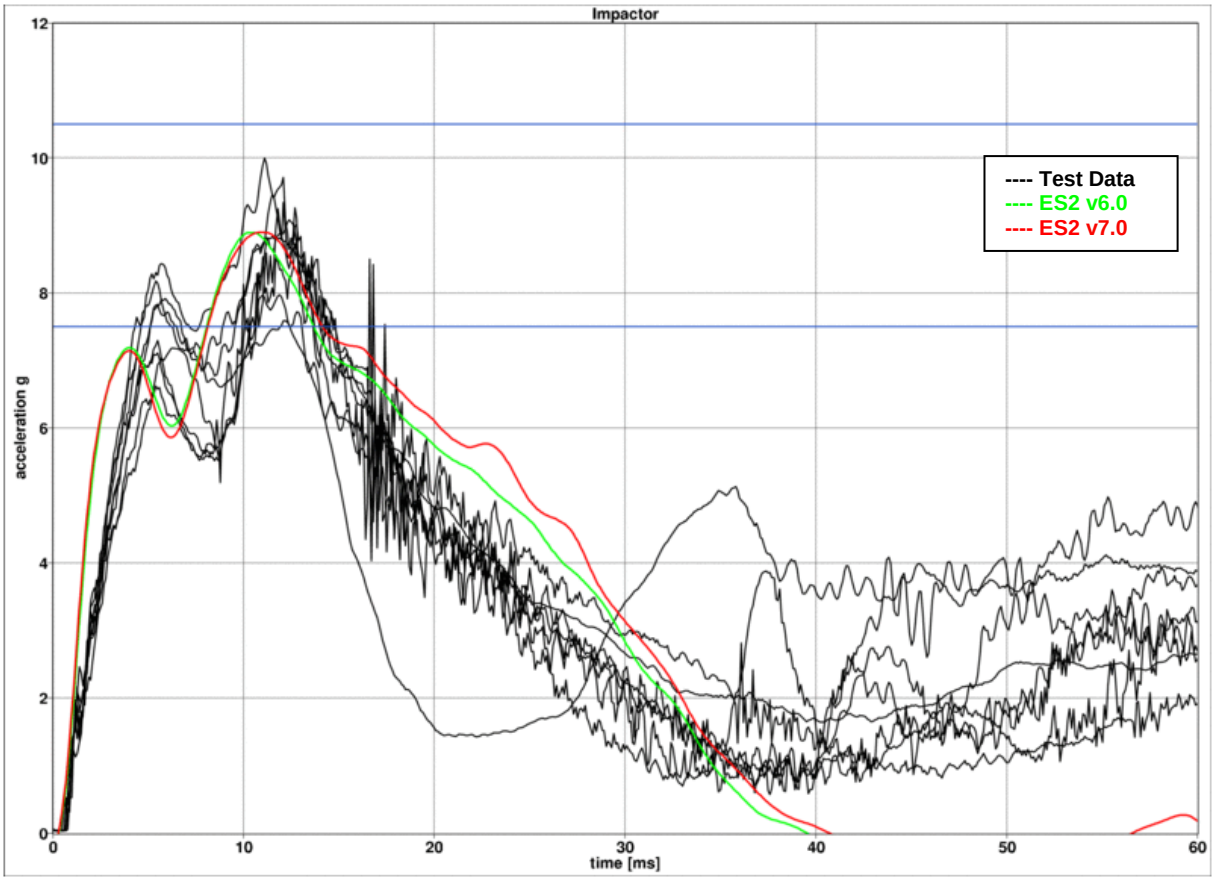


Figure 42: ES-2 shoulder certification test setup

12.5.1 Results



12.6 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.

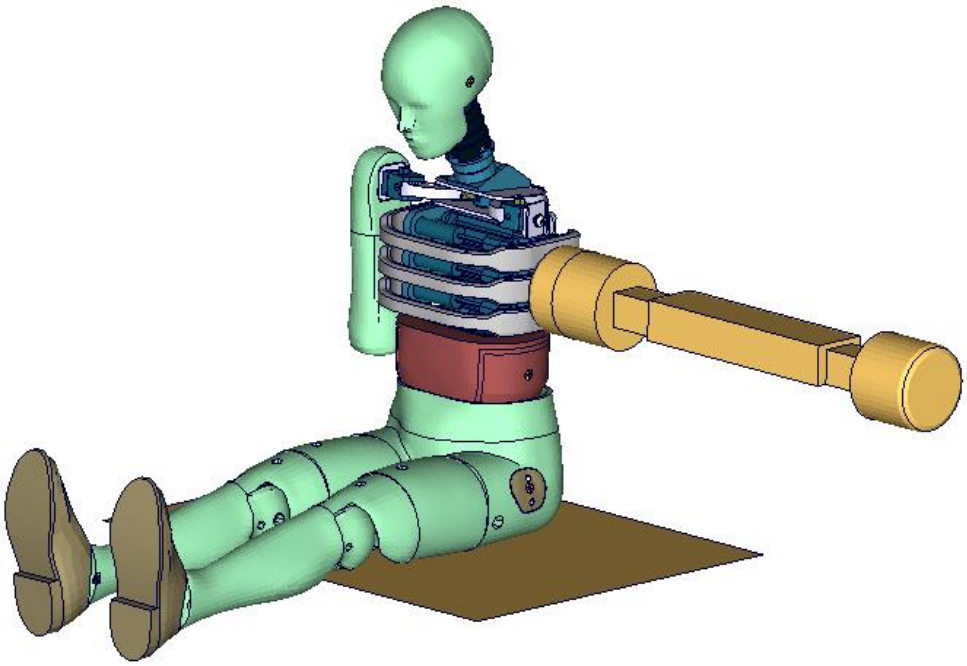
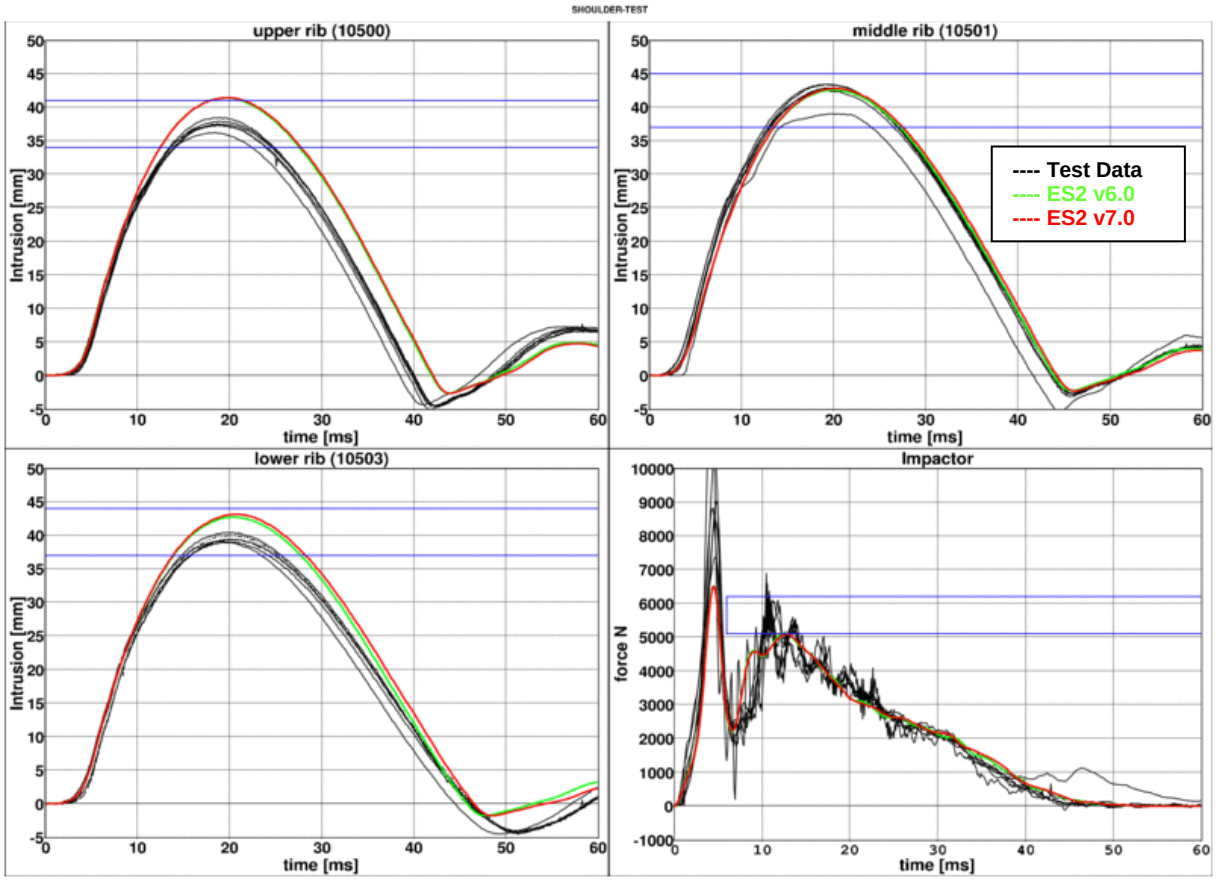


Figure 43: ES-2 thorax certification test setup

12.6.1 Results



12.7 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

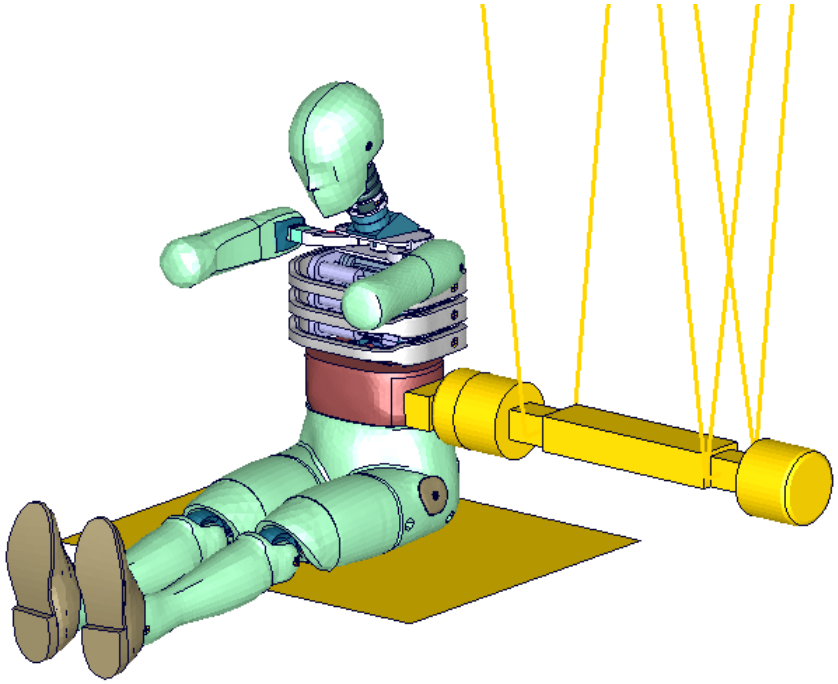
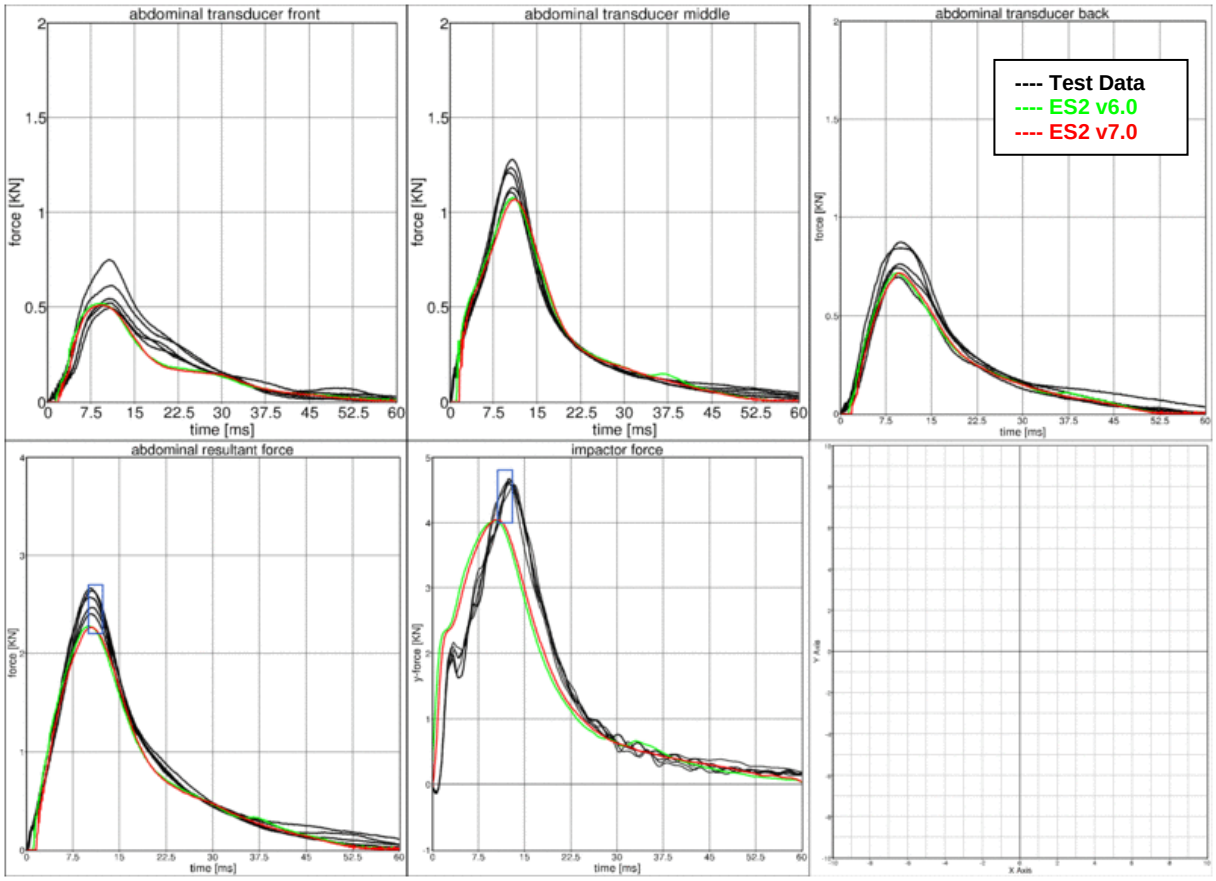


Figure 44: ES-2 abdomen certification test setup

12.7.1 Results



12.8 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

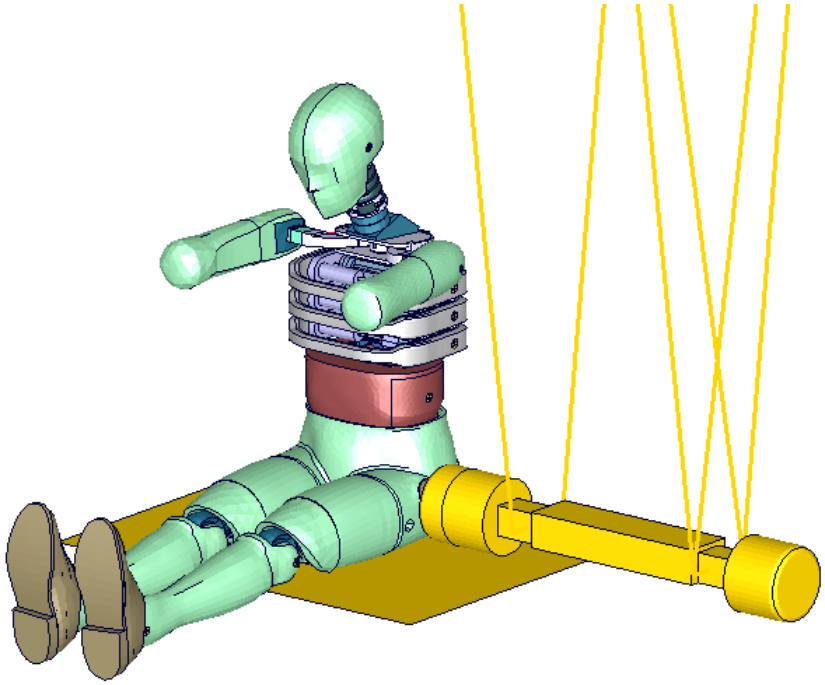
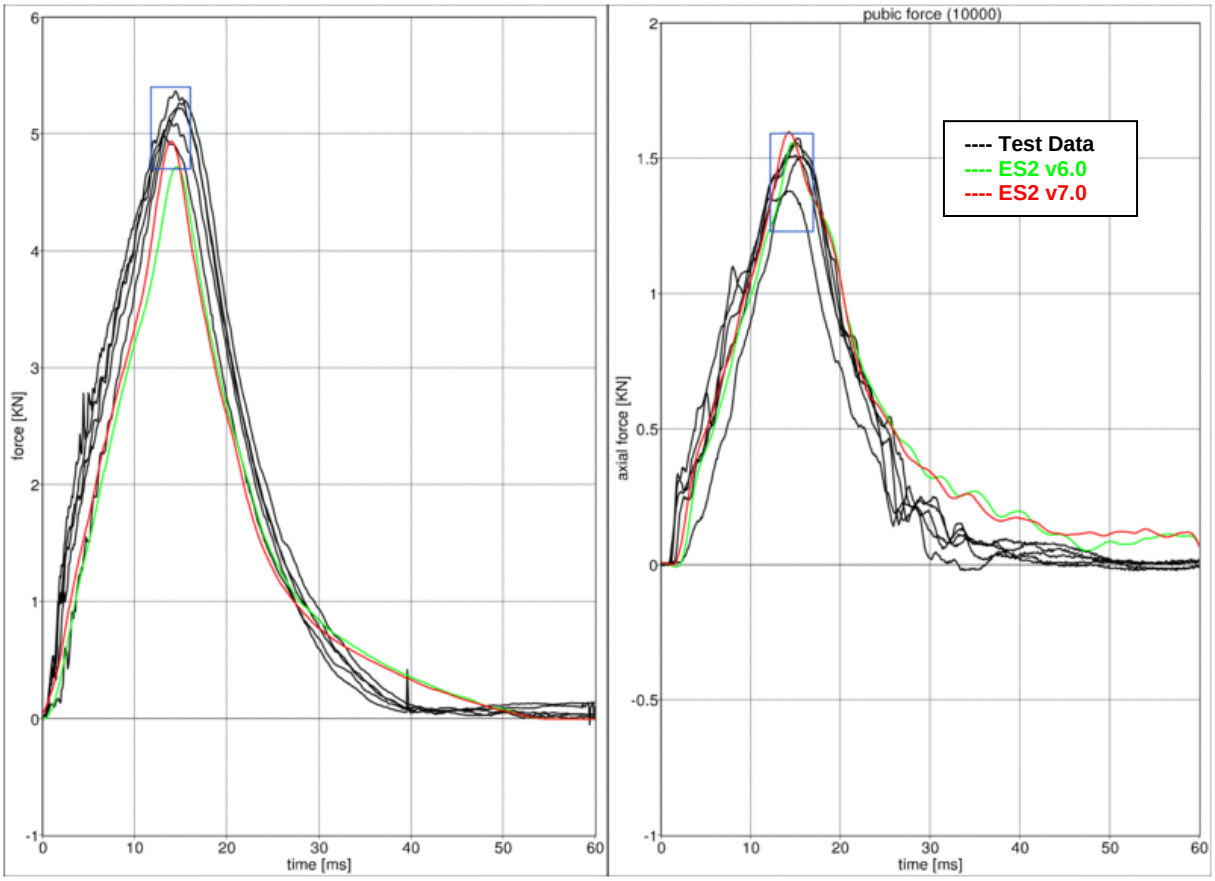


Figure 45: ES-2 pelvis certification test setup

12.8.1 Results



13. Performance

13.1 Configuration D1: Plane Barrier

Boundaries:

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

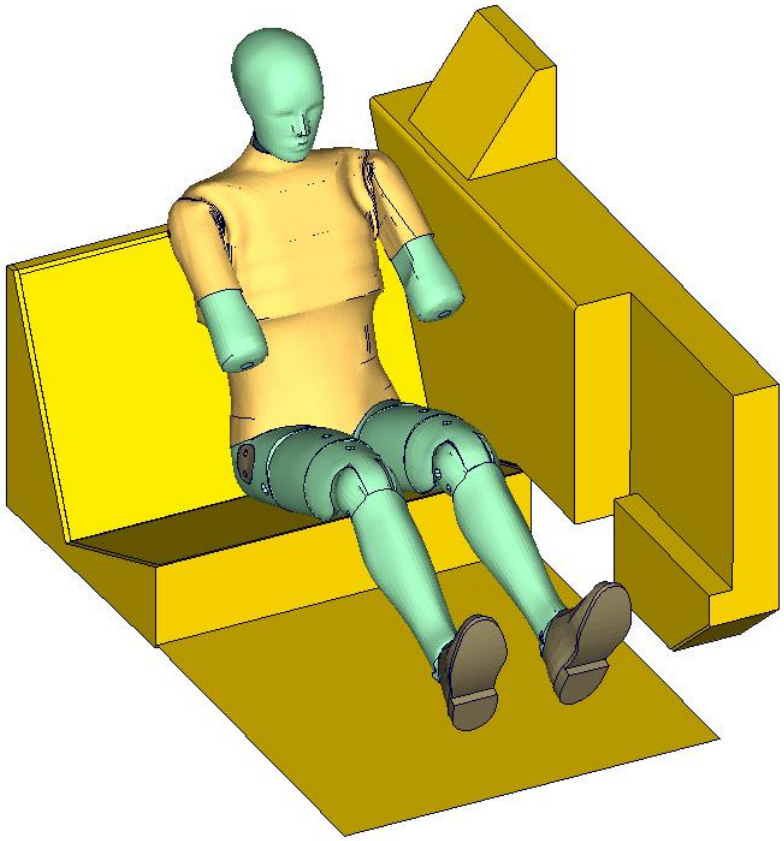
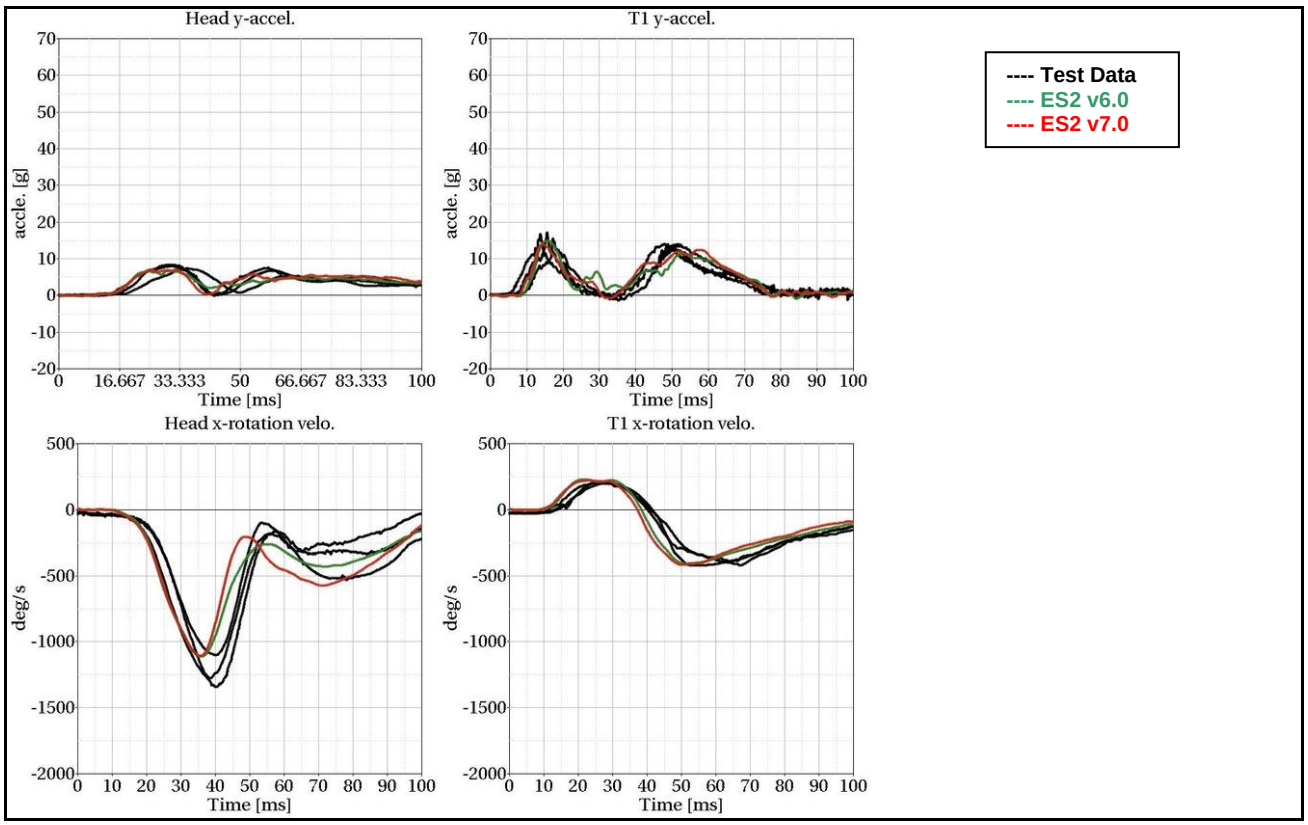
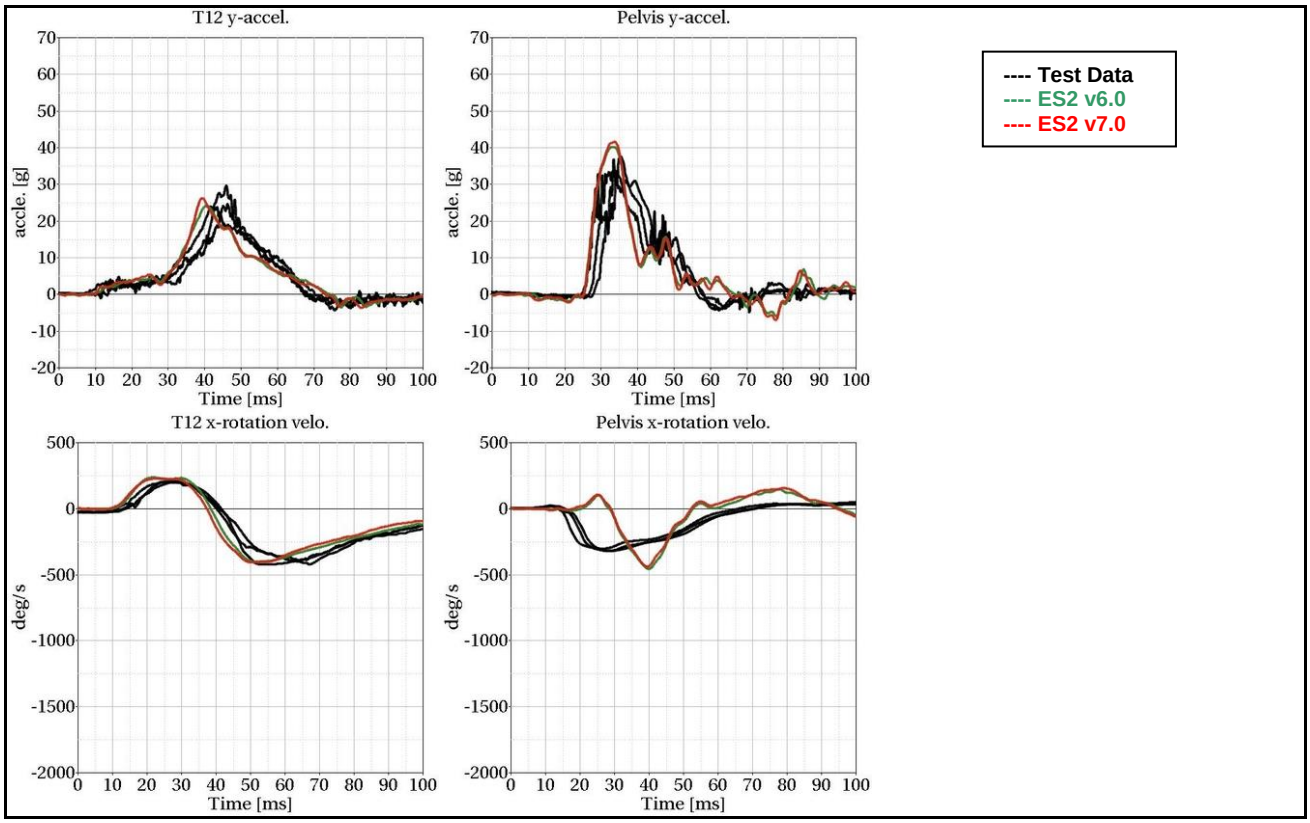
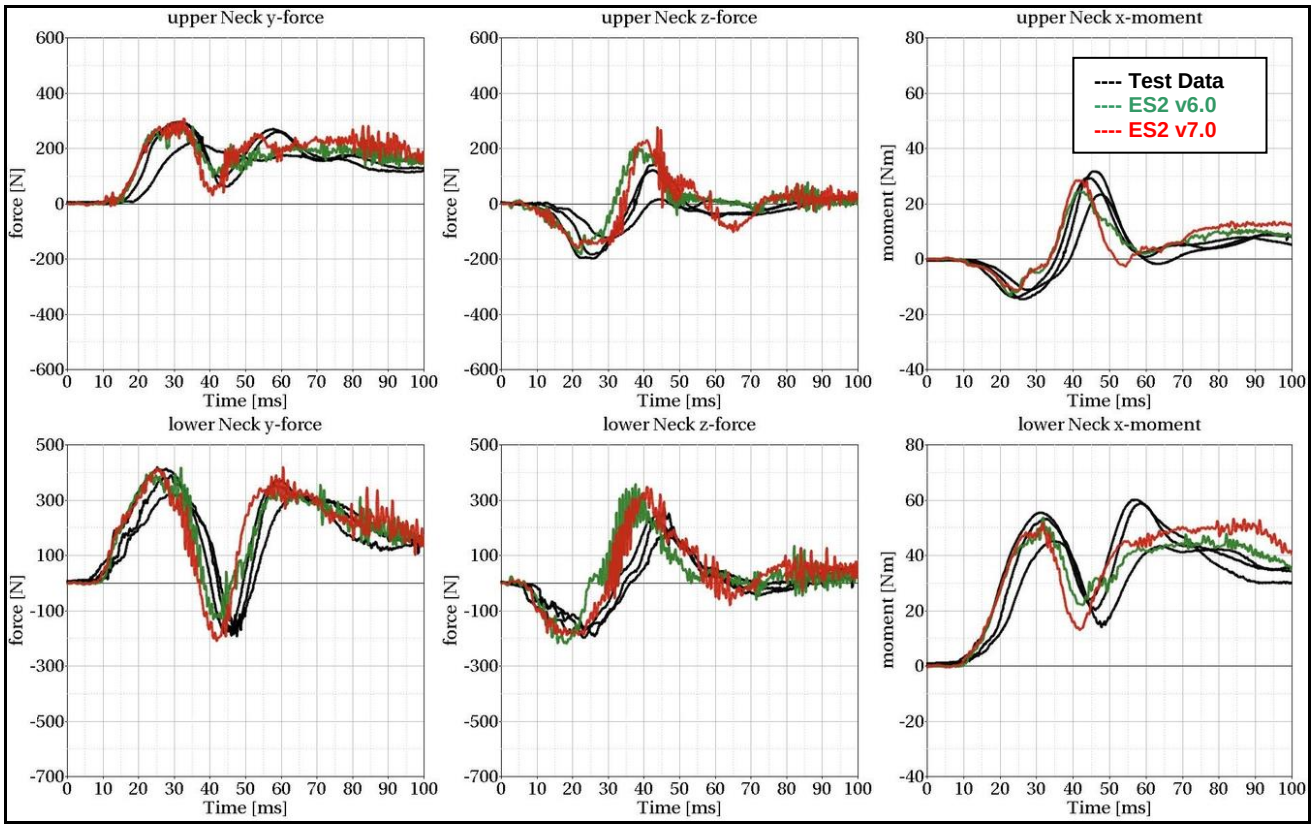


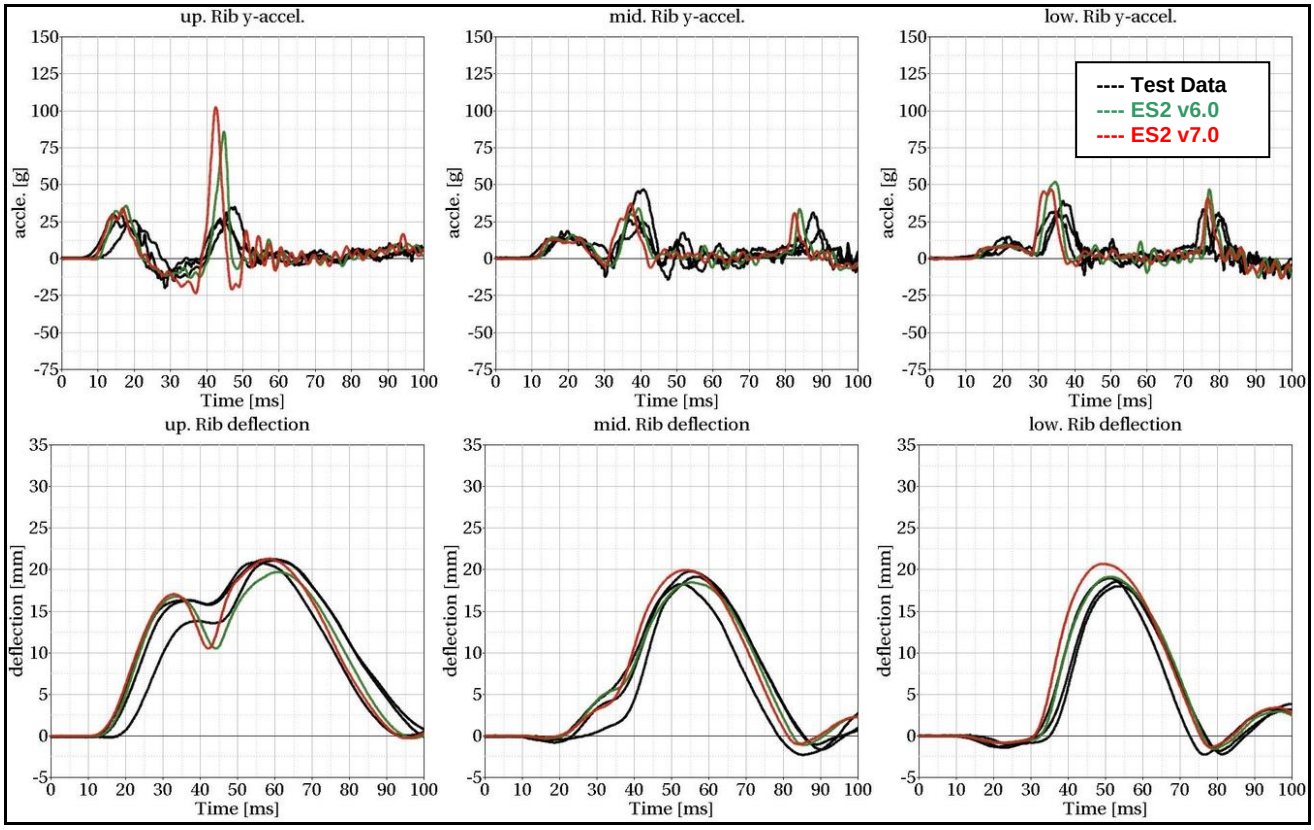
Figure 46: D1 plane barrier test setup

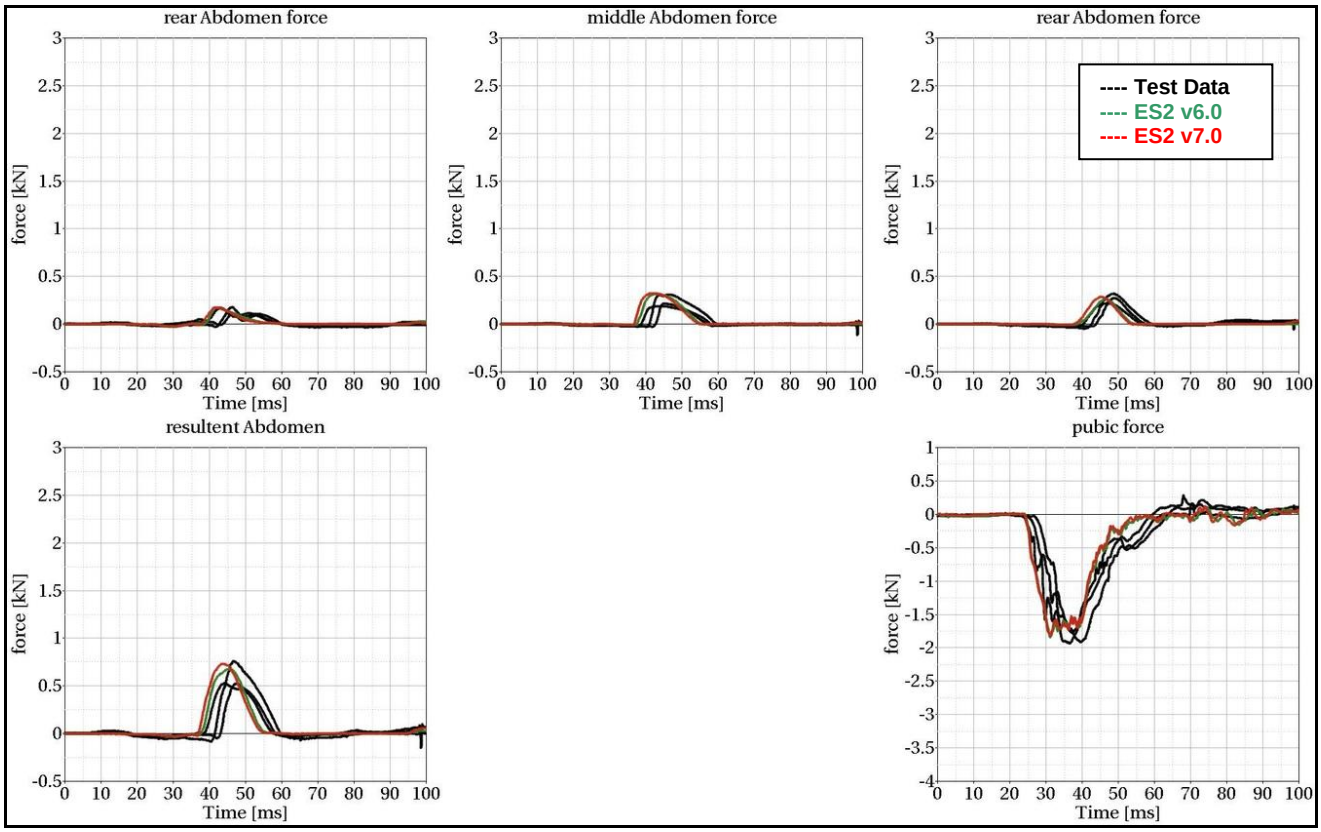
13.1.1 Results at low velocity impact

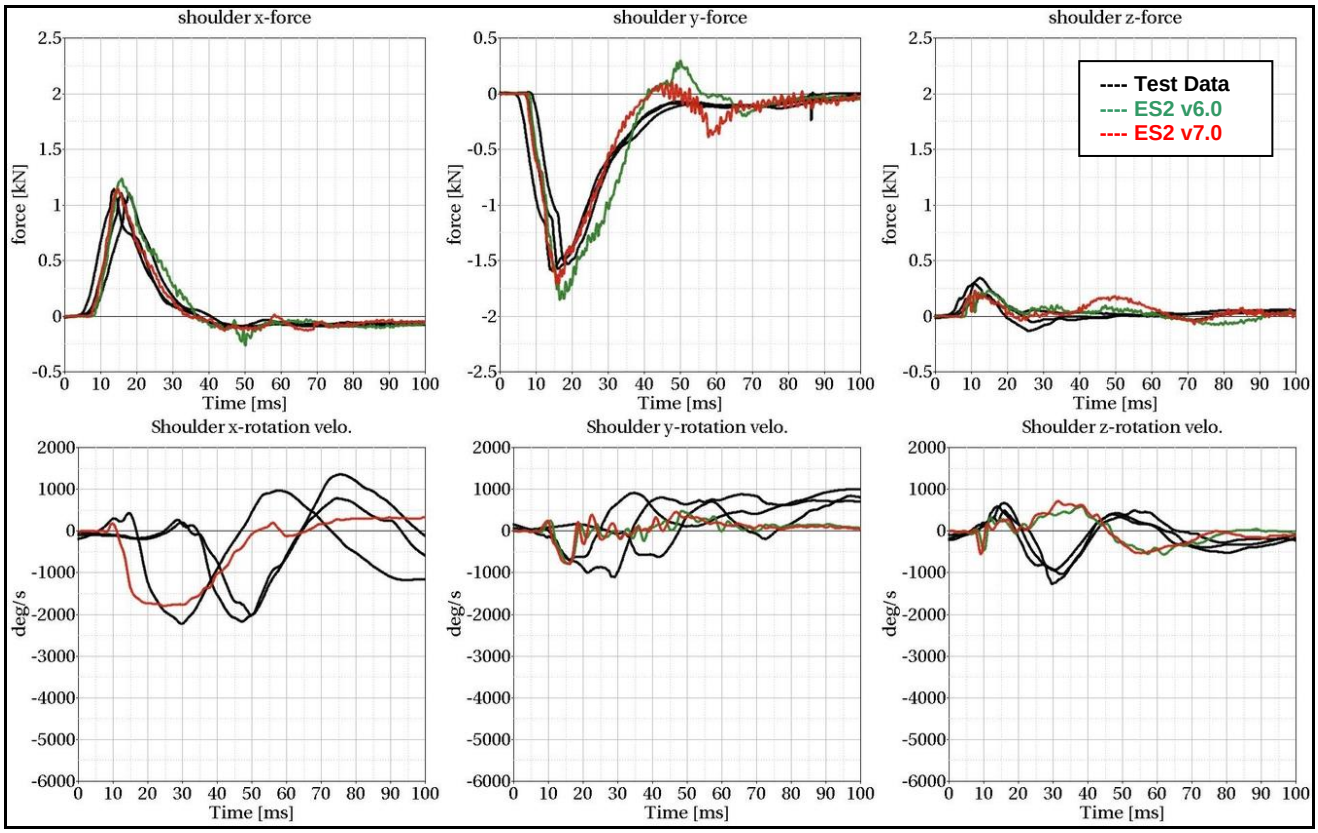


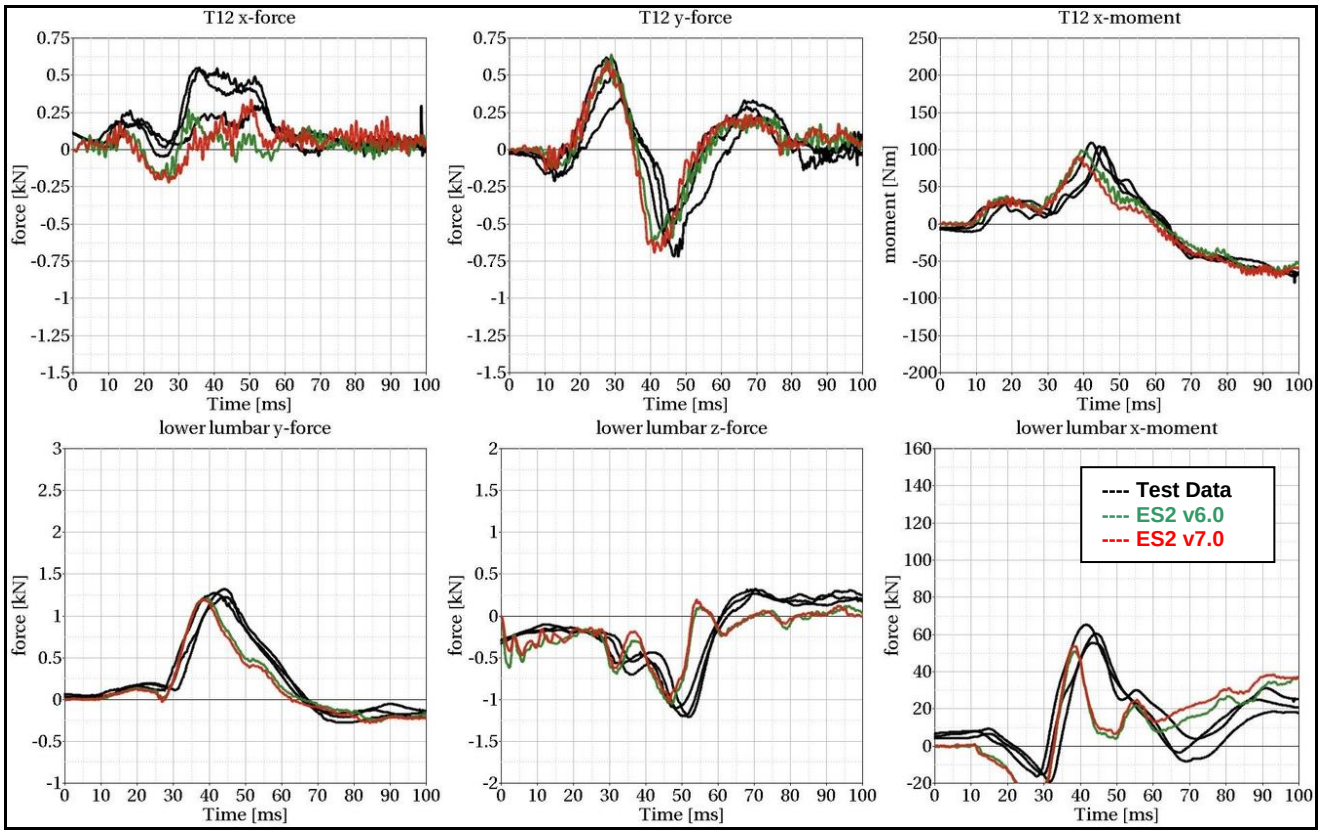



upper Neck y-force
upper Neck z-force
upper Neck x-moment
lower Neck y-force
lower Neck z-force
lower Neck x-moment
force [N]
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0


up. Rib y-accel.
mid. Rib y-accel.
low. Rib y-accel.
up. Rib deflection
mid. Rib deflection
low. Rib deflection
accle. [g]
deflection [mm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0


rear Abdomen force
middle Abdomen force
rear Abdomen force
---- Test Data
---- ES2 v6.0
---- ES2 v7.0
resultent Abdomen
pubic force
force [kN]
Time [ms]


shoulder x-force
shoulder y-force
shoulder z-force
---- Test Data
---- ES2 v6.0
---- ES2 v7.0
Shoulder x-rotation velo.
Shoulder y-rotation velo.
Shoulder z-rotation velo.
force [kN]
deg/s
Time [ms]


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 v6.0
---- ES2 v7.0

13.2 Configuration D3: Barrier with pelvis bumper

Boundaries:

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

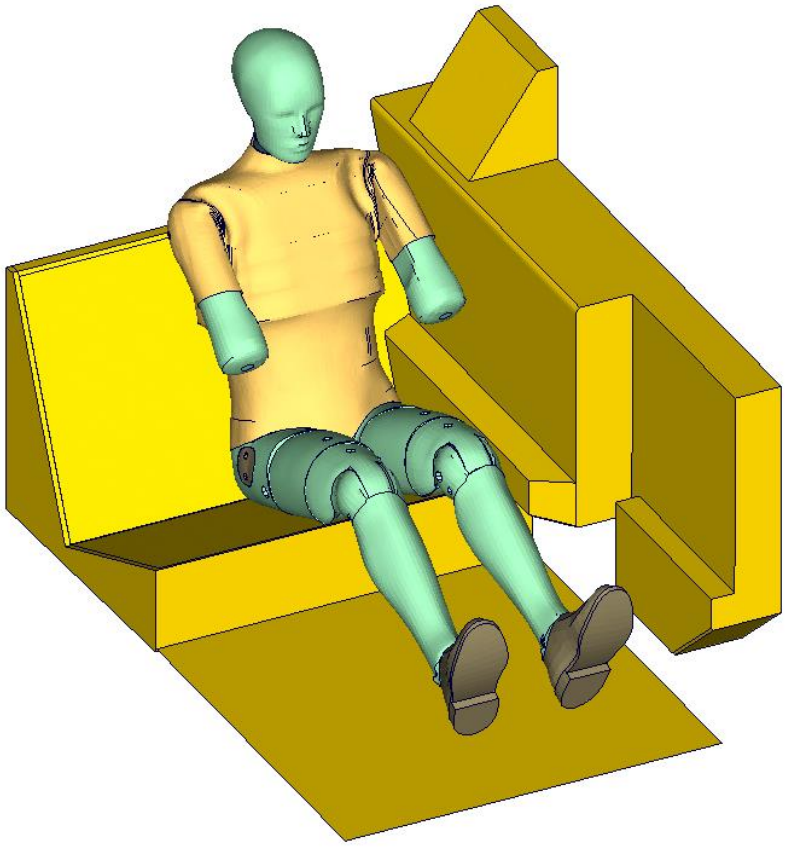
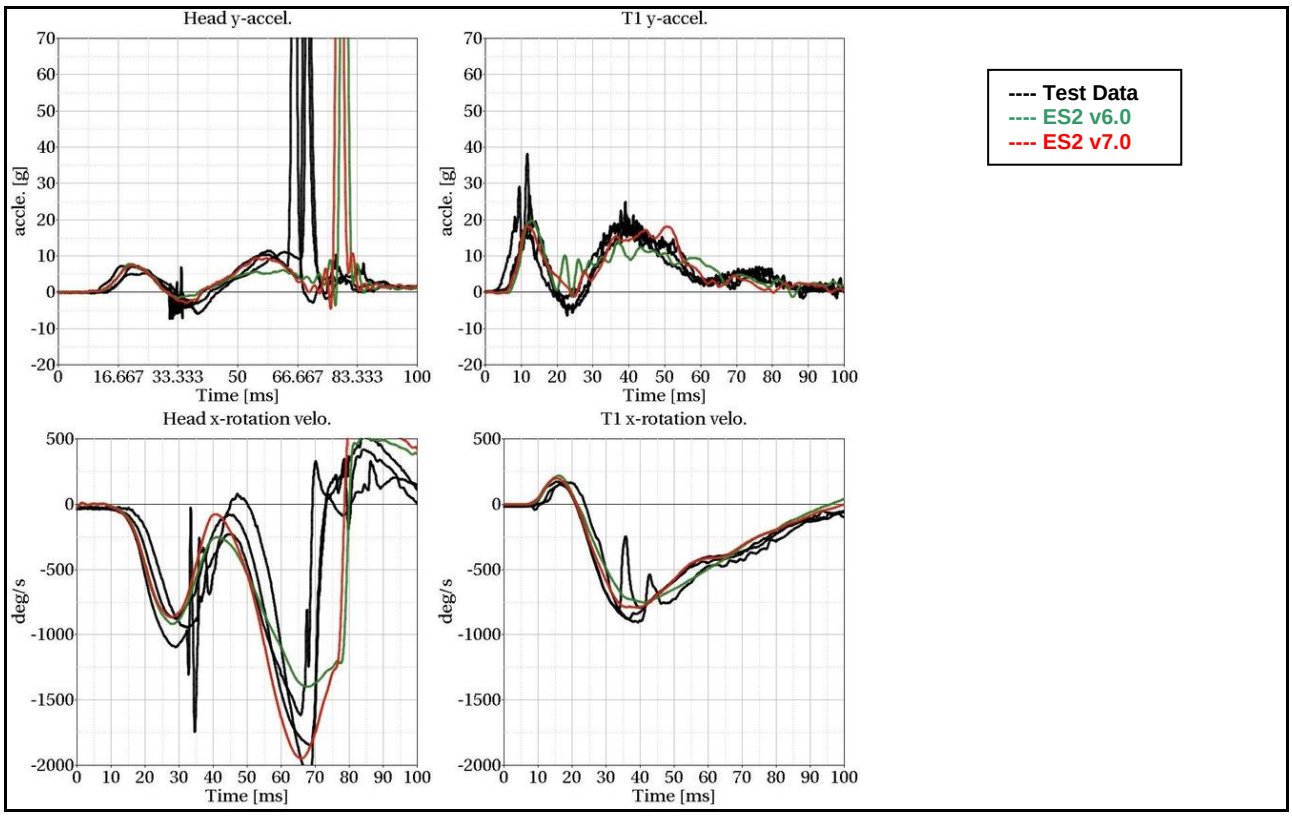
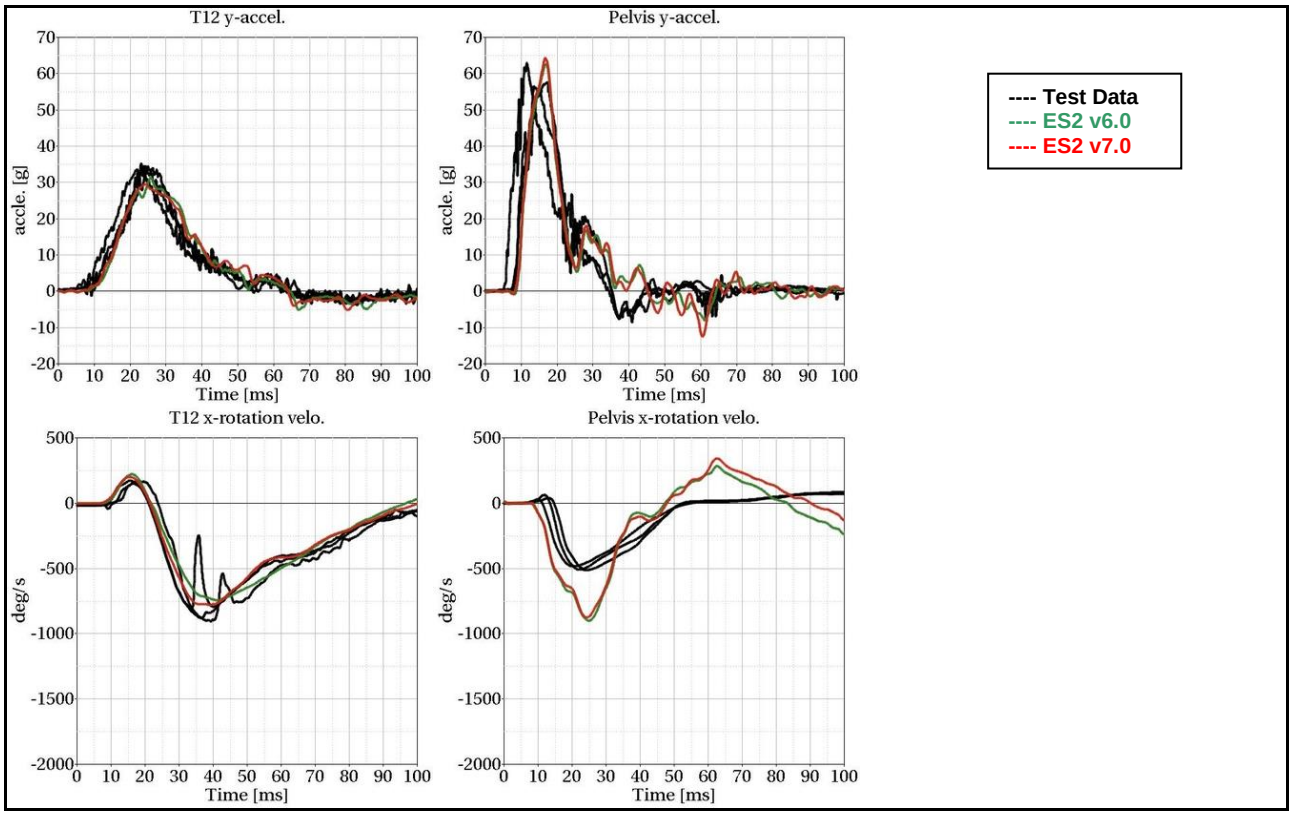
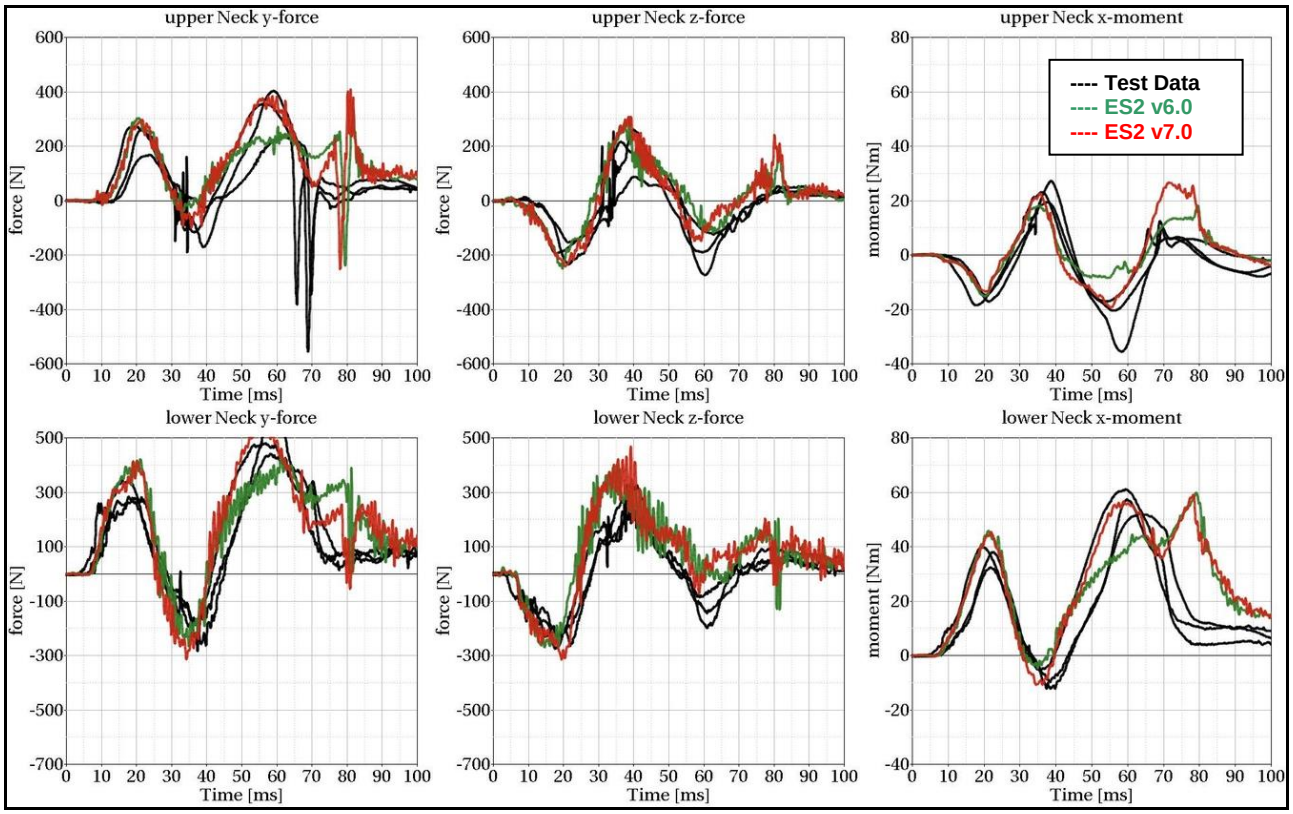


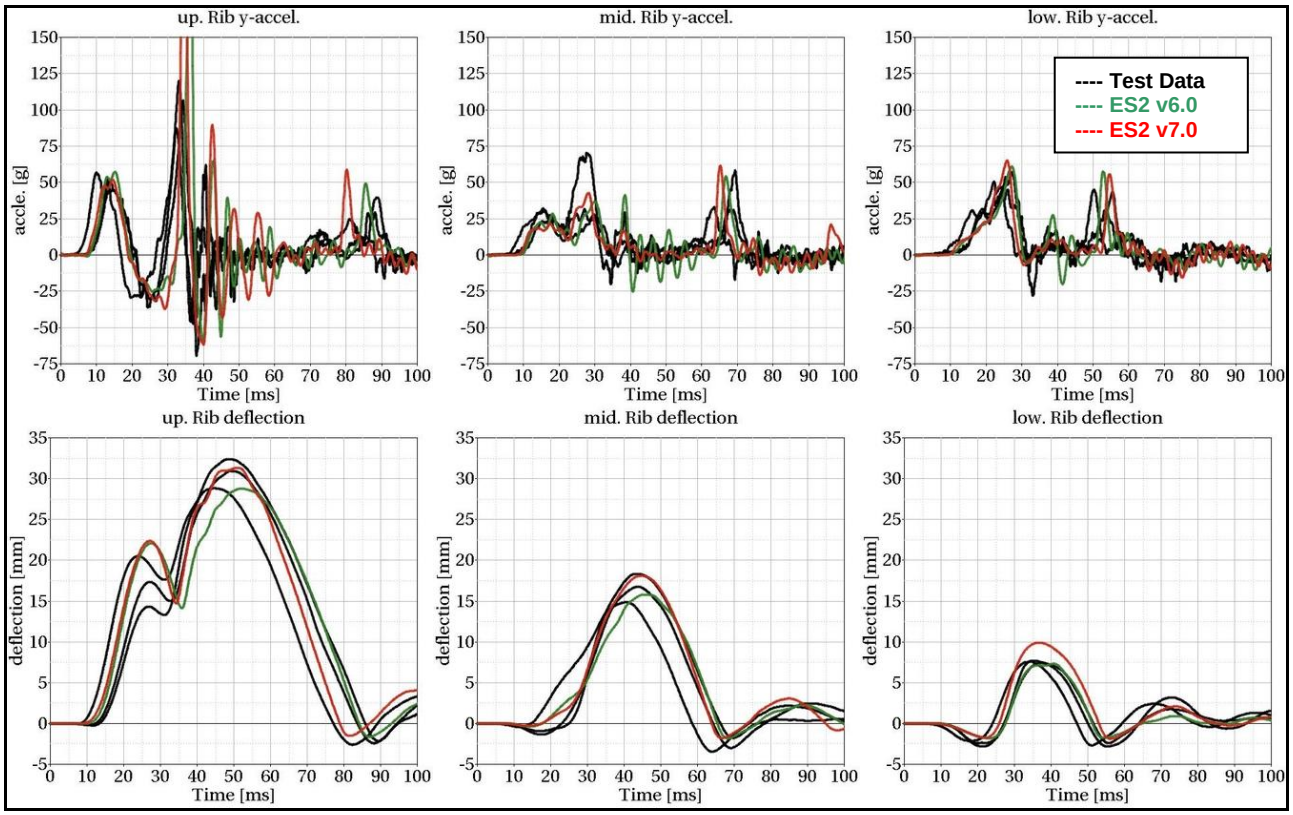
Figure 47: D3 barrier test setup

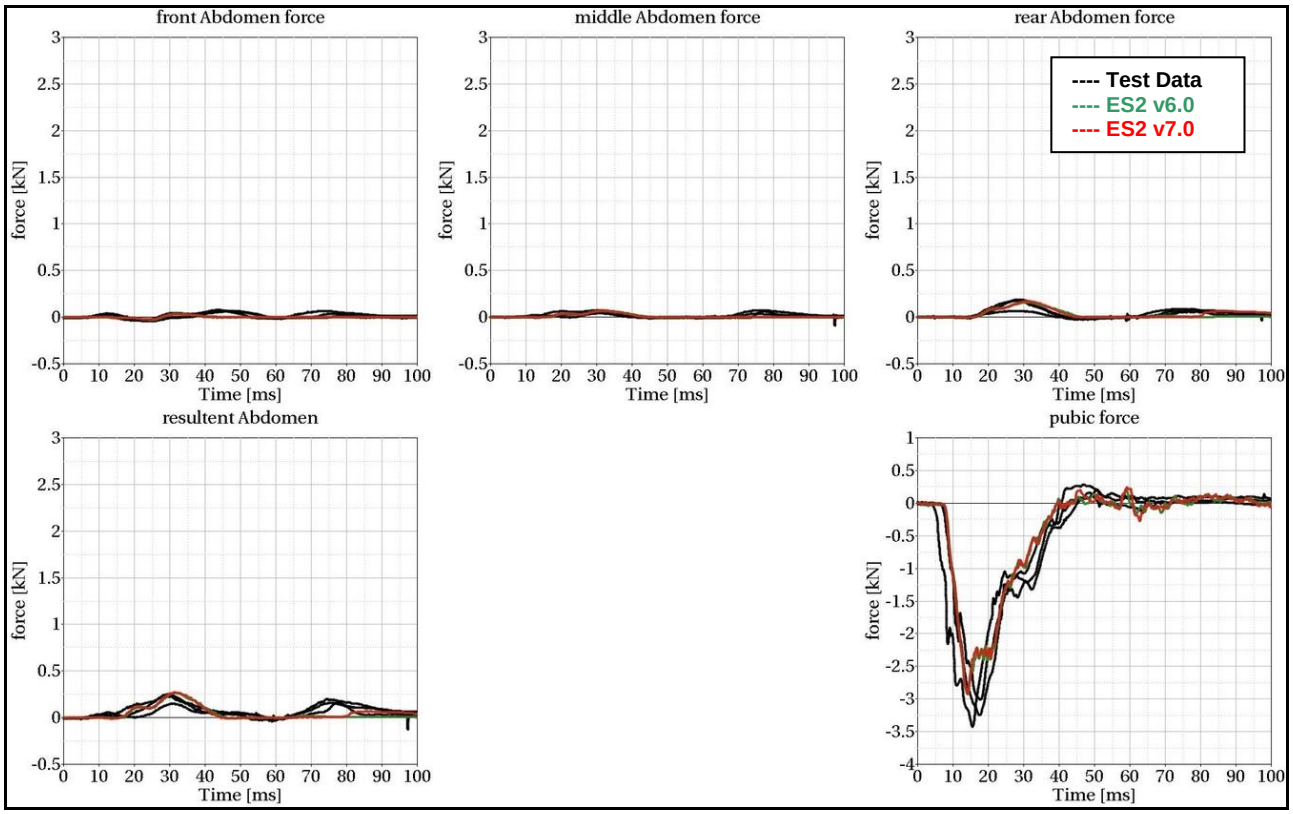
13.2.1 Results at high velocity impact

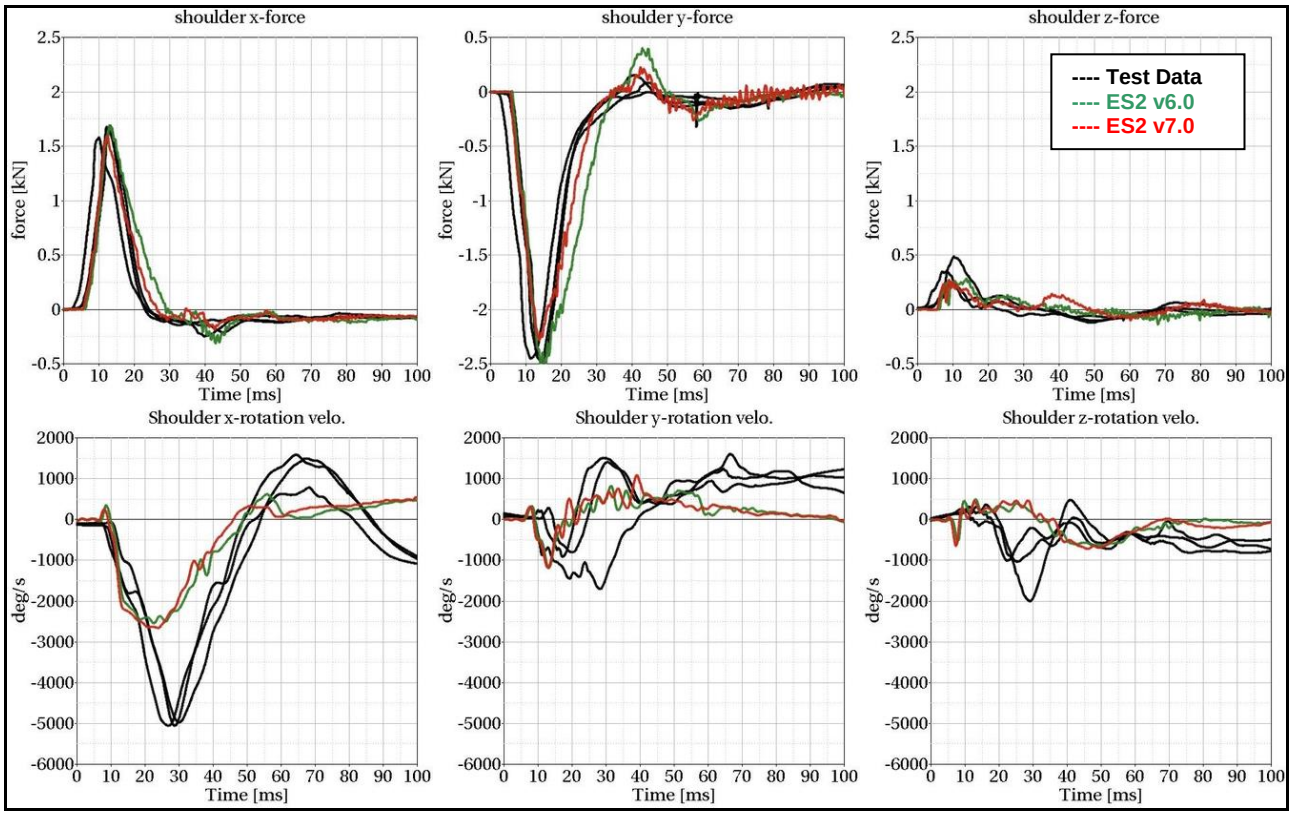


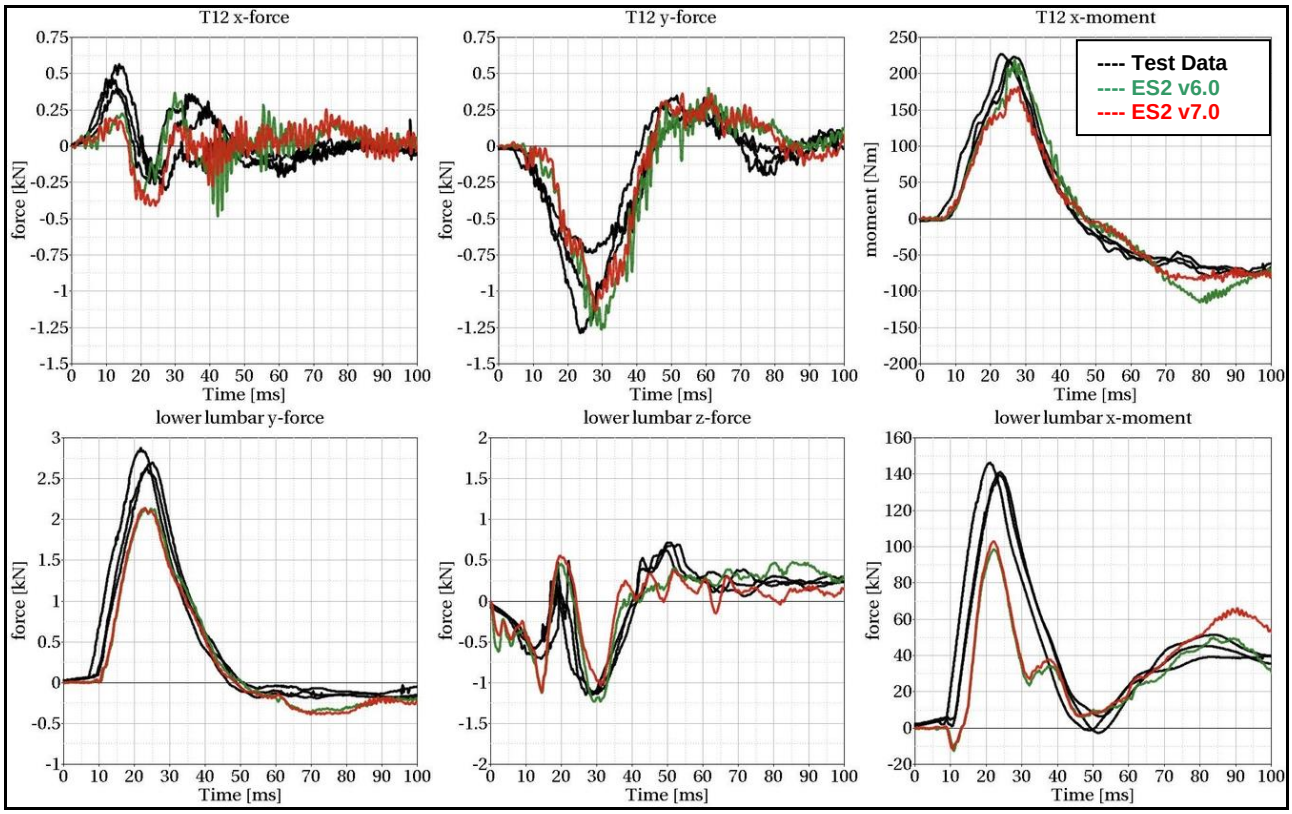



upper Neck y-force
upper Neck z-force
upper Neck x-moment
lower Neck y-force
lower Neck z-force
lower Neck x-moment
force [N]
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0


up. Rib y-accel.
mid. Rib y-accel.
low. Rib y-accel.
up. Rib deflection
mid. Rib deflection
low. Rib deflection
accle. [g]
deflection [mm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0


front Abdomen force
middle Abdomen force
rear Abdomen force
resultent Abdomen
pubic force
force [kN]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0


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 v6.0
---- ES2 v7.0


T12 x-force
T12 y-force
T12 x-moment
lower lumbar y-force
lower lumbar z-force
lower lumbar x-moment
force [kN]
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0

13.3 Configuration D4: Door barrier

Boundaries:

- Rigid barrier (Figure 48)
- Impact speed: High velocity
- Arms in 40 degree position
- Curb edge
- Orthogonal impact

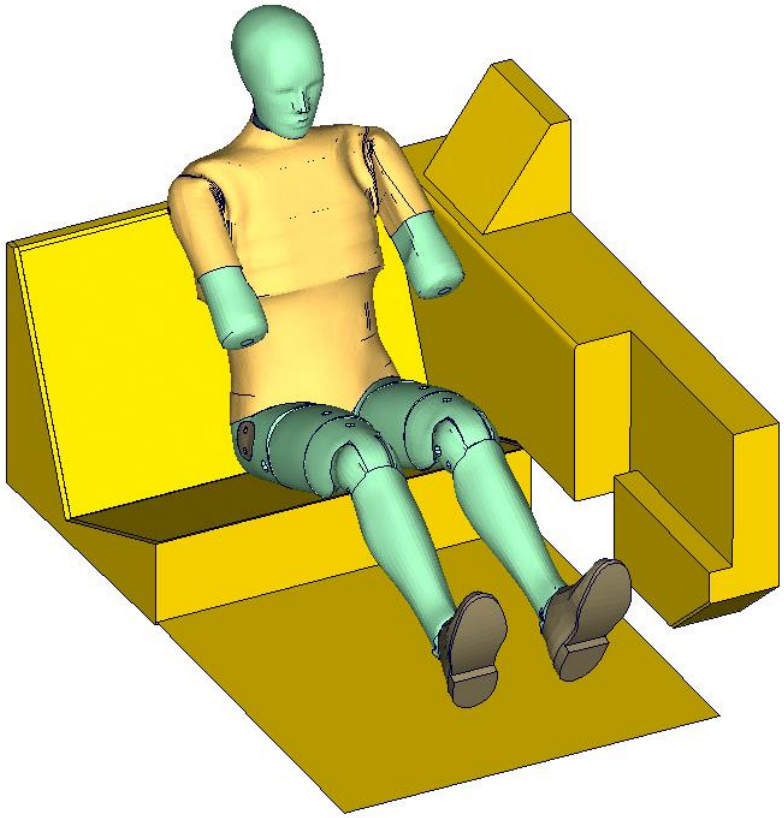
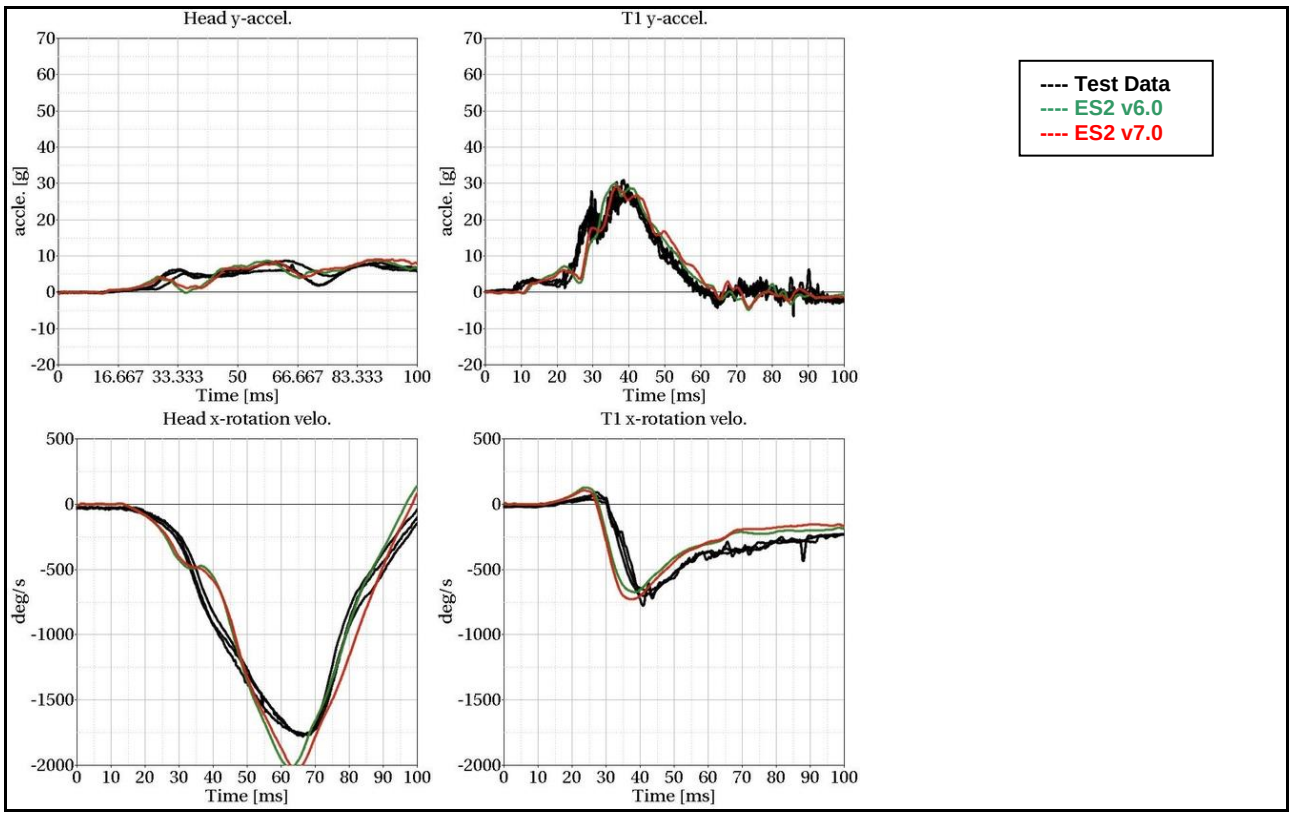
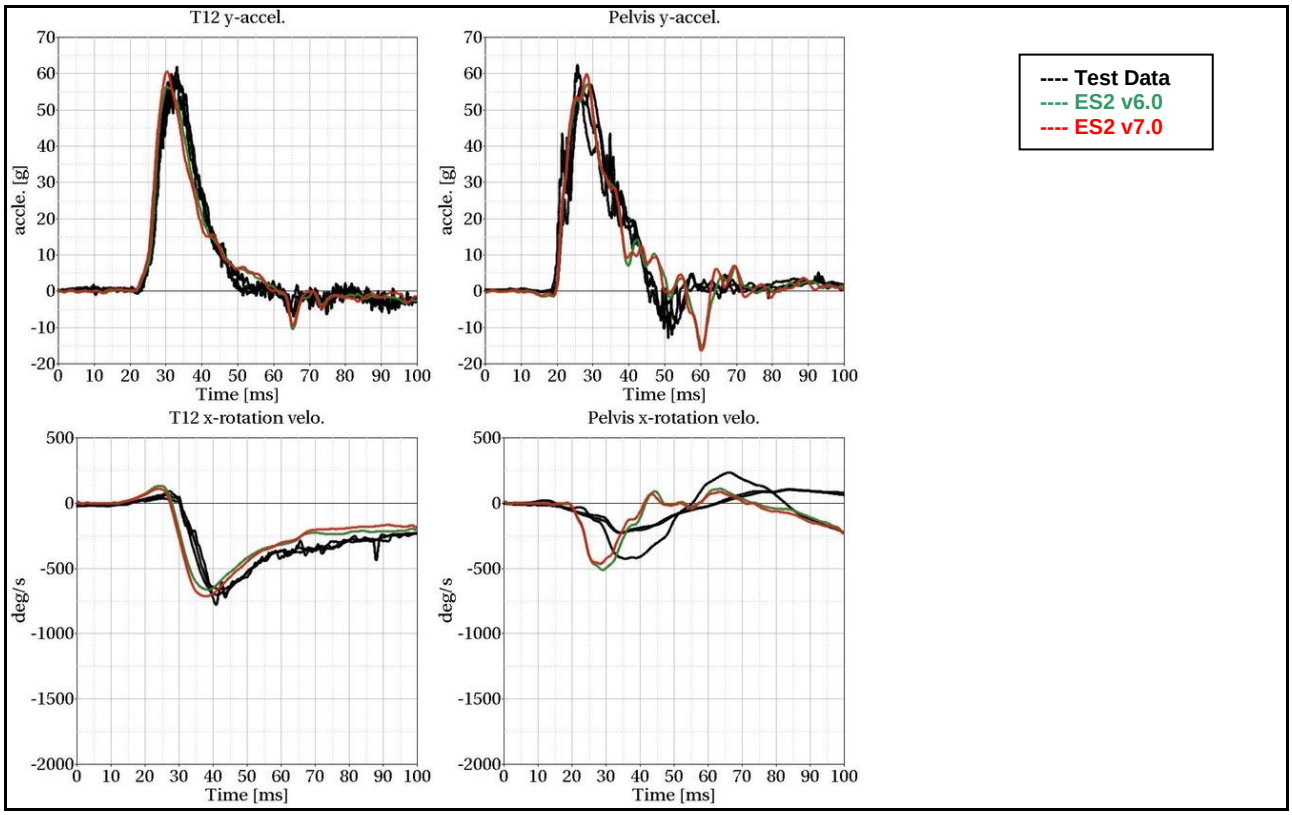
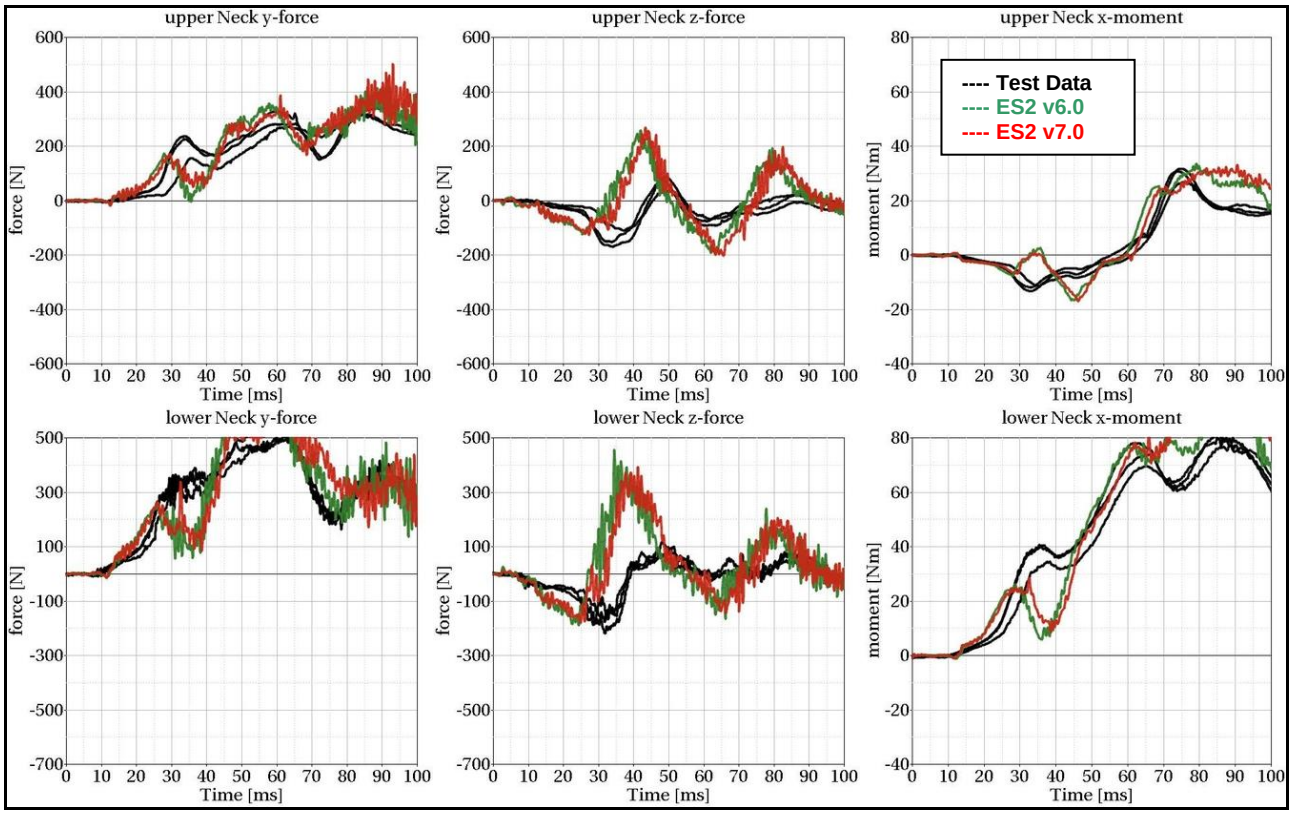


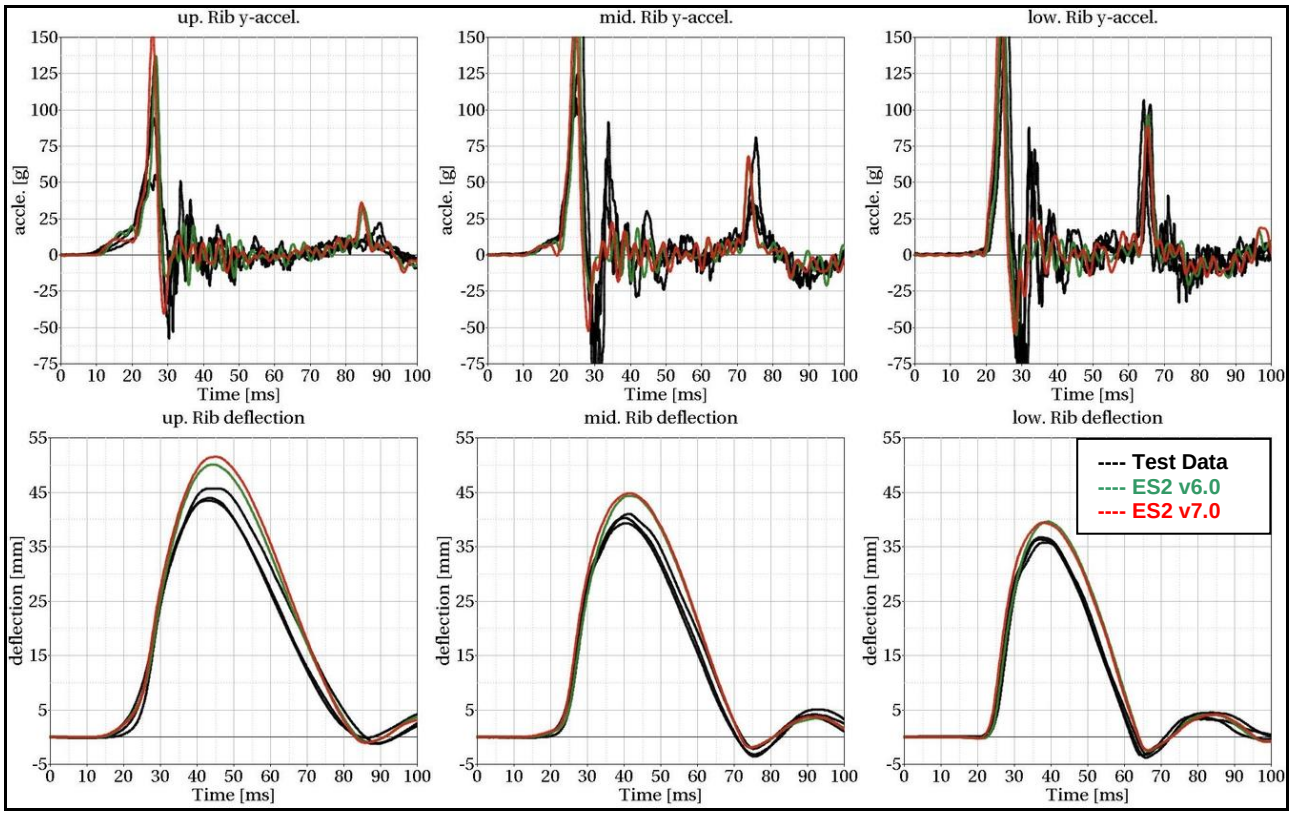
Figure 48: D4 door barrier test setup

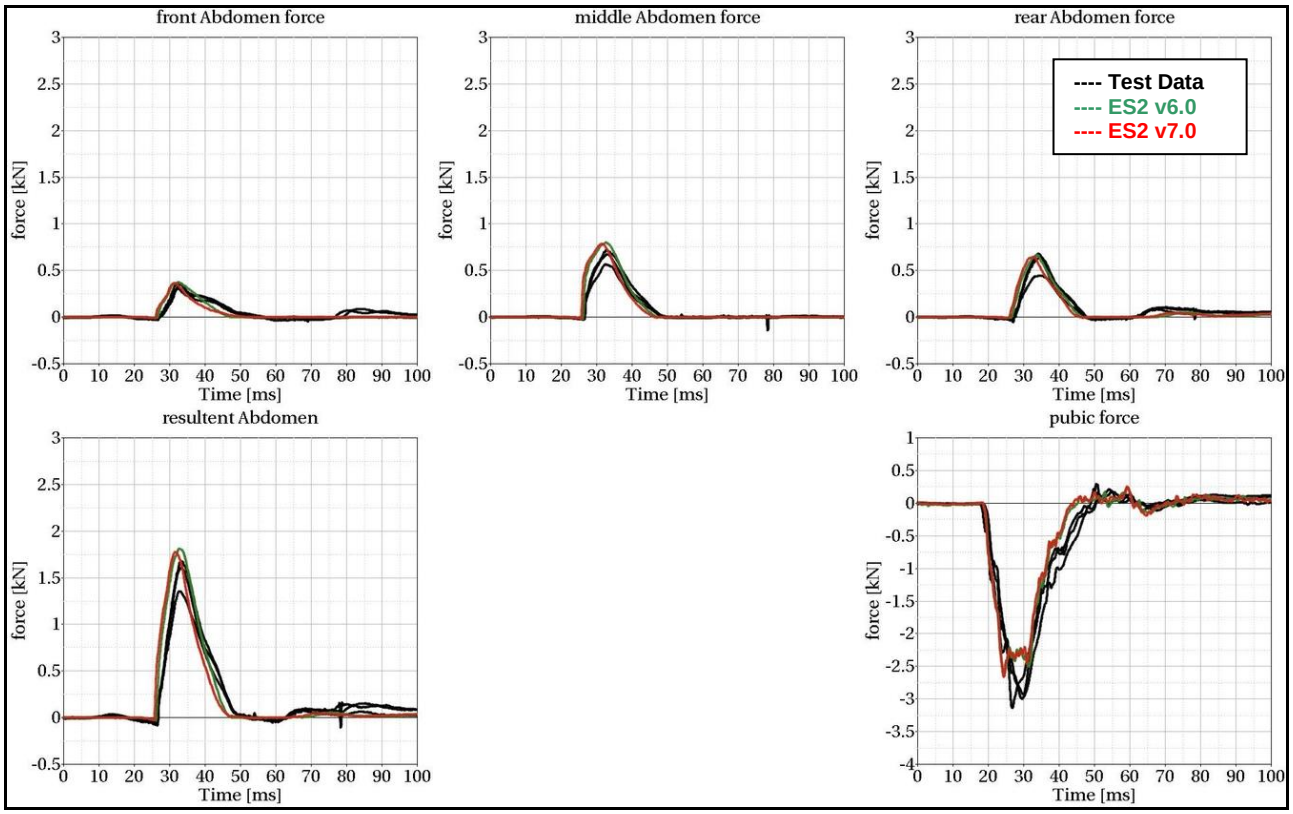
13.3.1 Results at high velocity impact

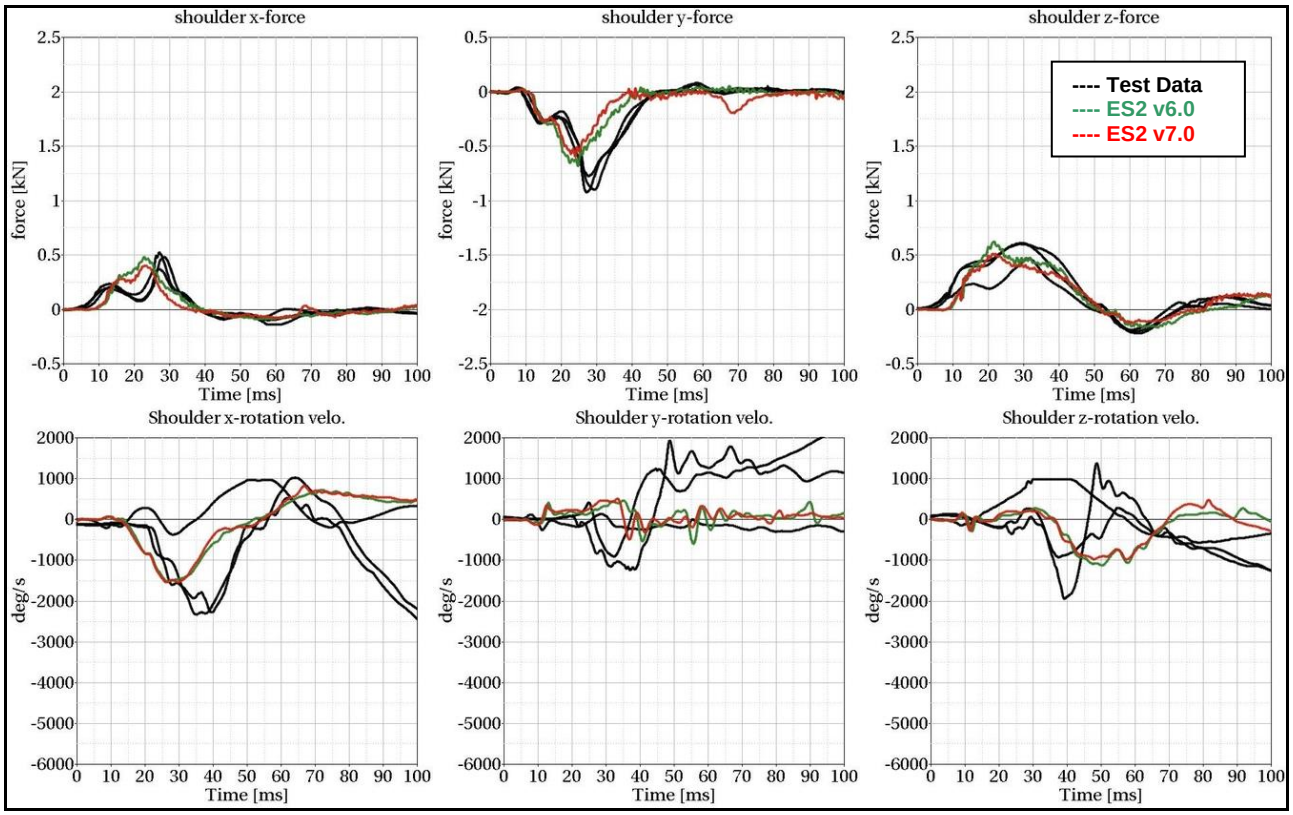


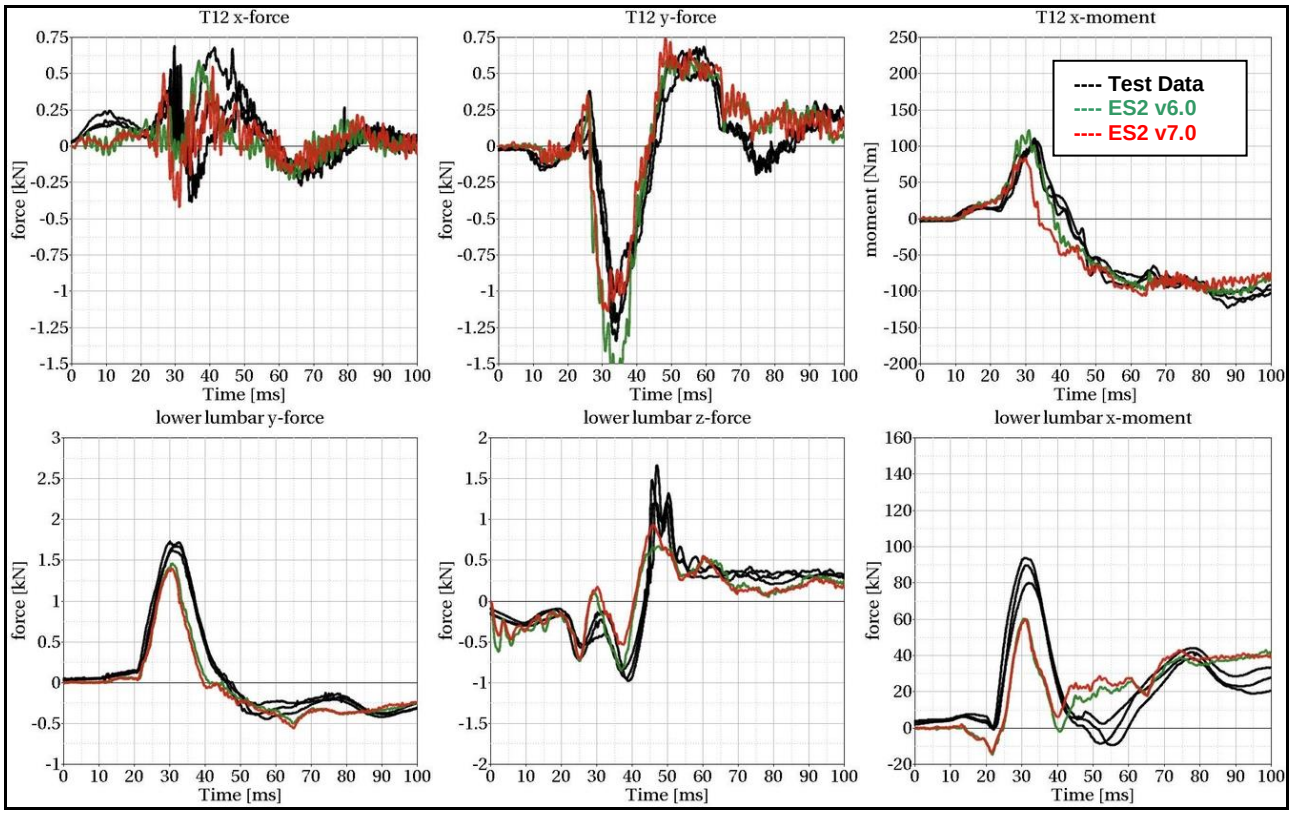



upper Neck y-force
upper Neck z-force
upper Neck x-moment
lower Neck y-force
lower Neck z-force
lower Neck x-moment
force [N]
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0


up. Rib y-accel.
mid. Rib y-accel.
low. Rib y-accel.
up. Rib deflection
mid. Rib deflection
low. Rib deflection
accle. [g]
deflection [mm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0


front Abdomen force
middle Abdomen force
rear Abdomen force
---- Test Data
---- ES2 v6.0
---- ES2 v7.0
resultent Abdomen
pubic force
force [kN]
Time [ms]


shoulder x-force
shoulder y-force
shoulder z-force
---- Test Data
---- ES2 v6.0
---- ES2 v7.0
Shoulder x-rotation velo.
Shoulder y-rotation velo.
Shoulder z-rotation velo.
force [kN]
deg/s
Time [ms]


T12 x-force
T12 y-force
T12 x-moment
lower lumbar y-force
lower lumbar z-force
lower lumbar x-moment
force [kN]
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v6.0
---- ES2 v7.0

13.4 Additional test of ES-2re

13.4.1 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

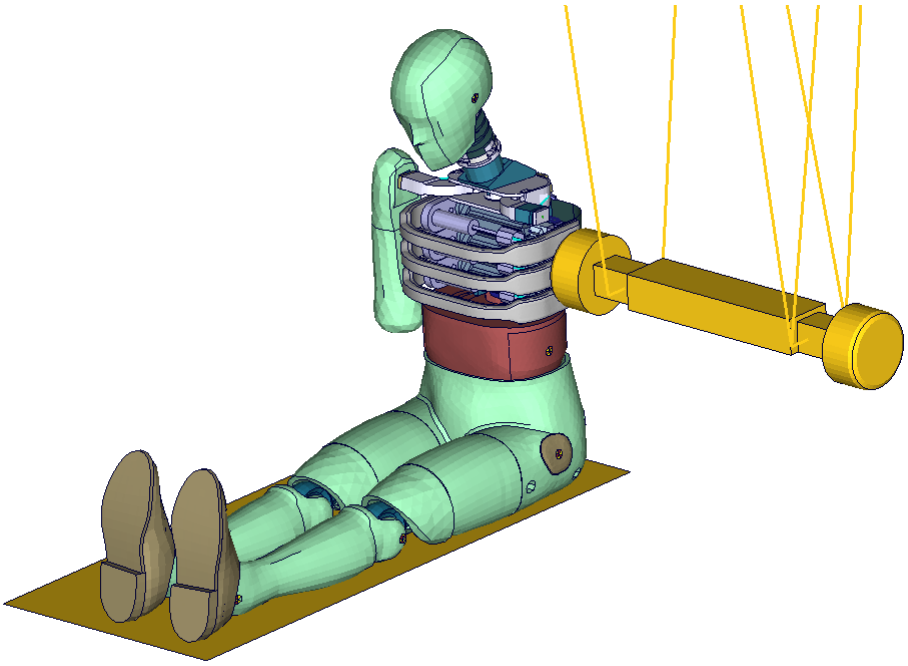
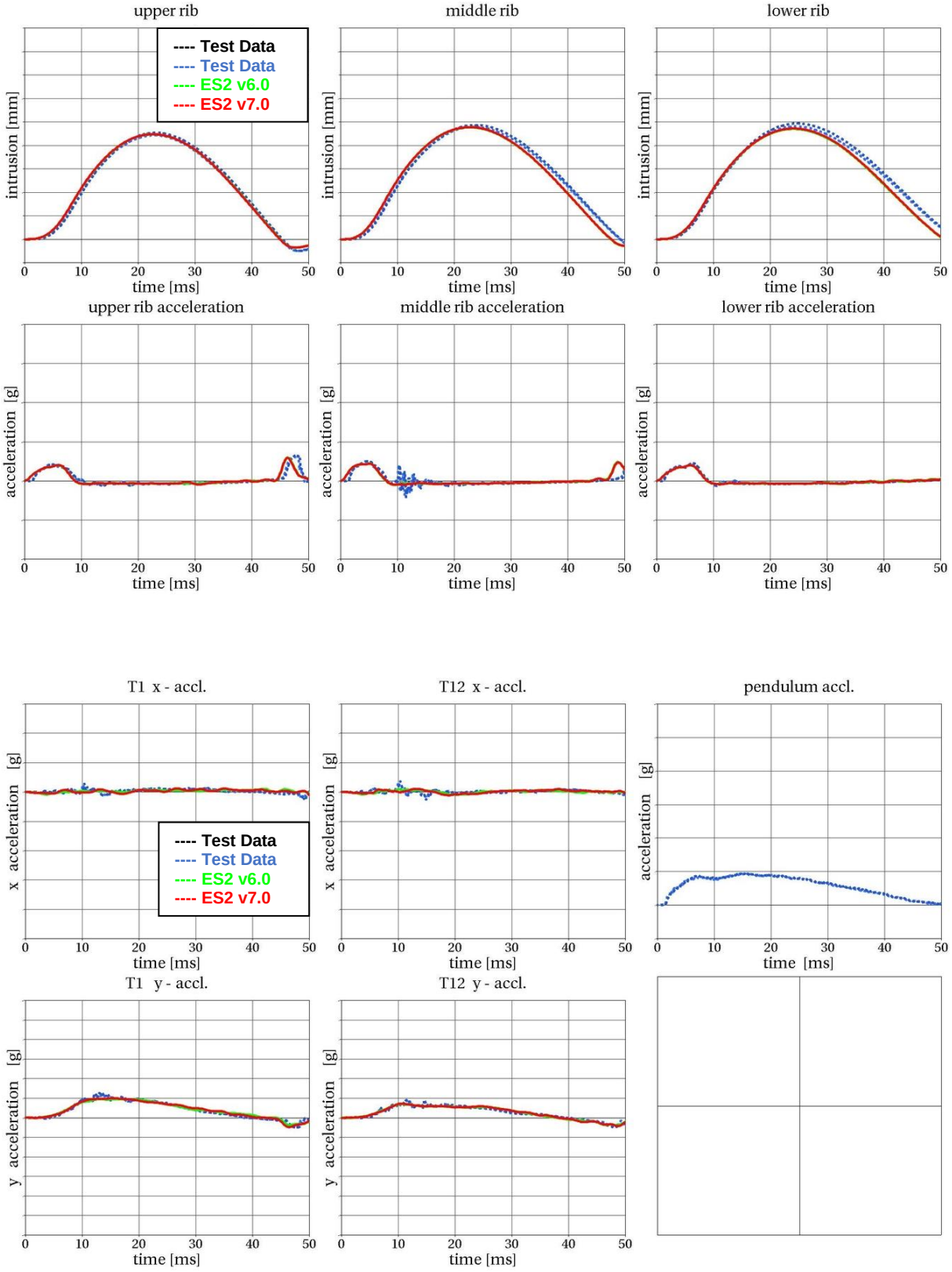
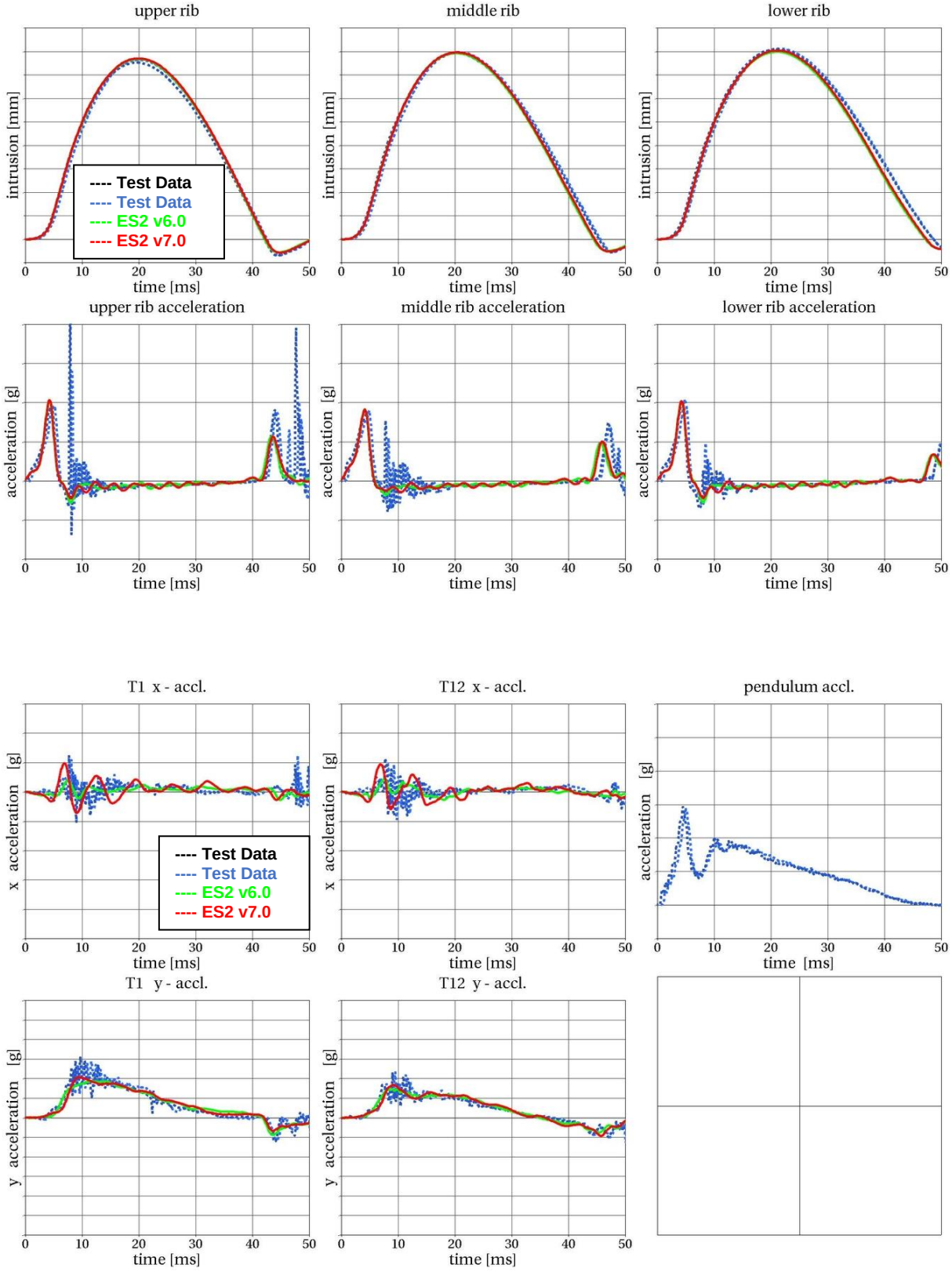


Figure 49: Pendulum impacting the ribs at 90 degrees; without arm and jacket

Results at low velocity



Results at high velocity



13.4.2 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

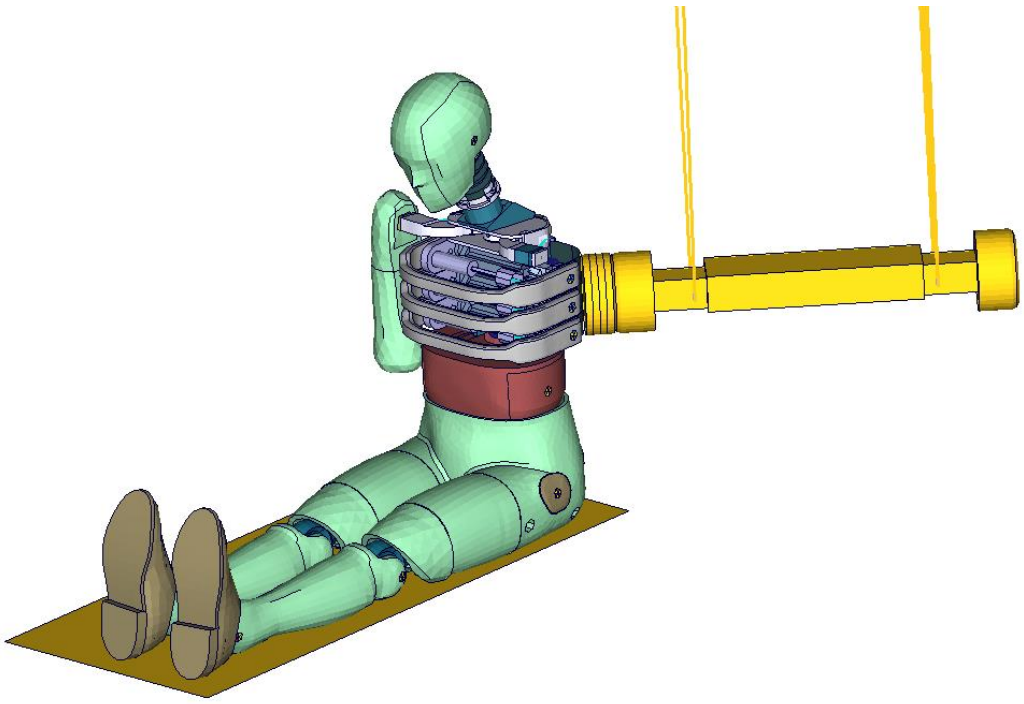
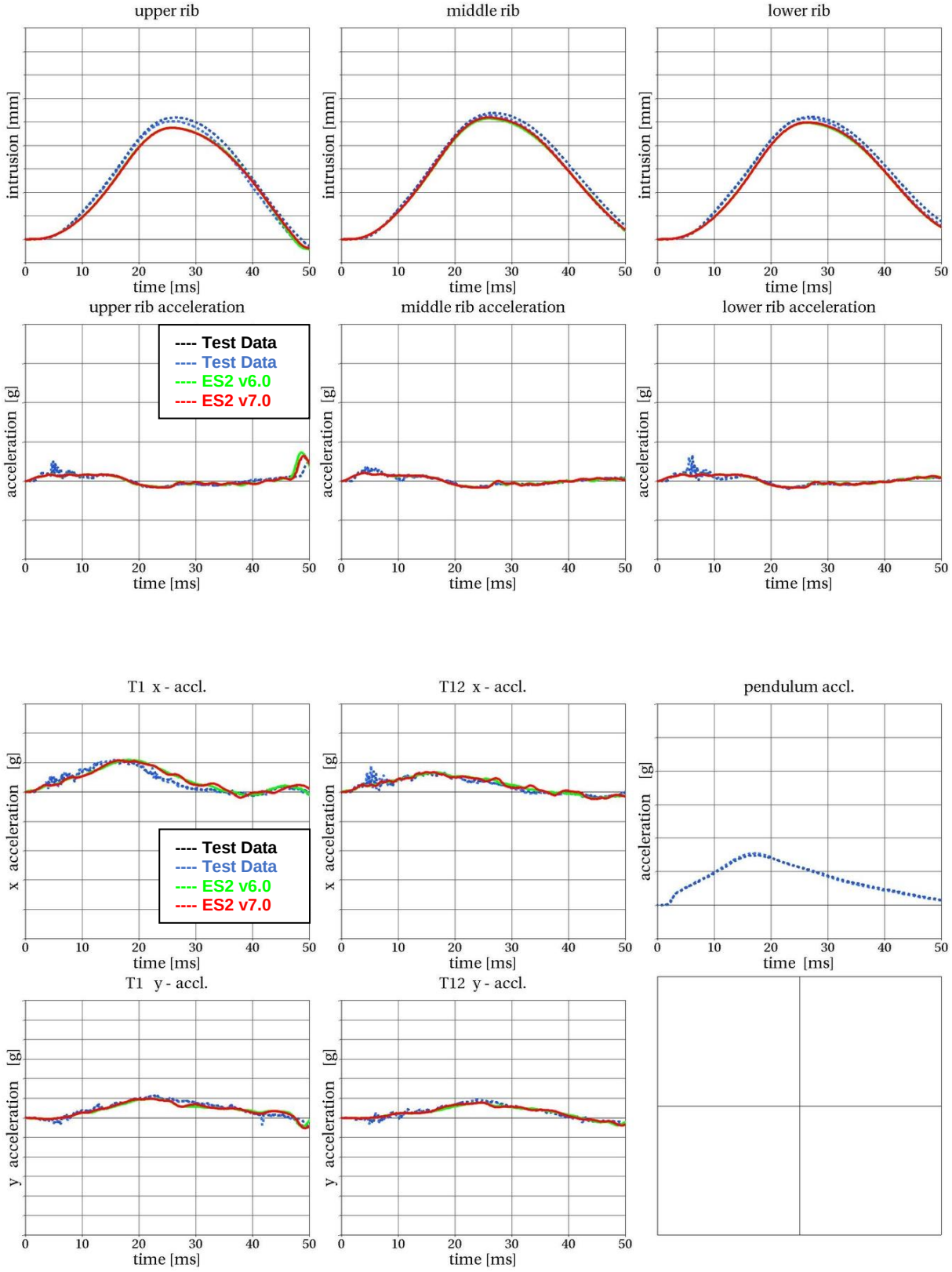
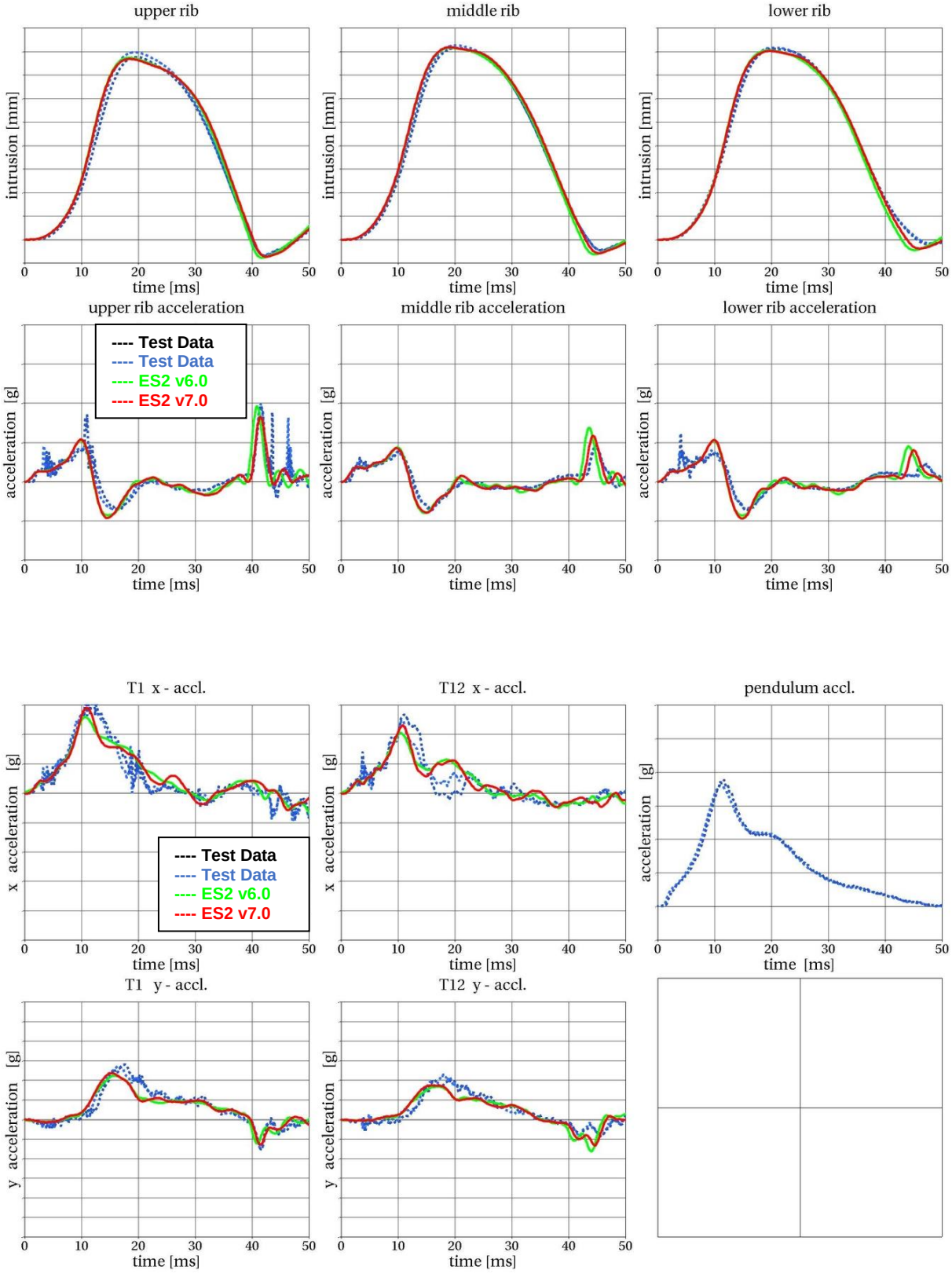


Figure 50: Pendulum impacting the ribs at 45 degrees; without arm and jacket

Results at low velocity



Results at high velocity



13.4.3 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

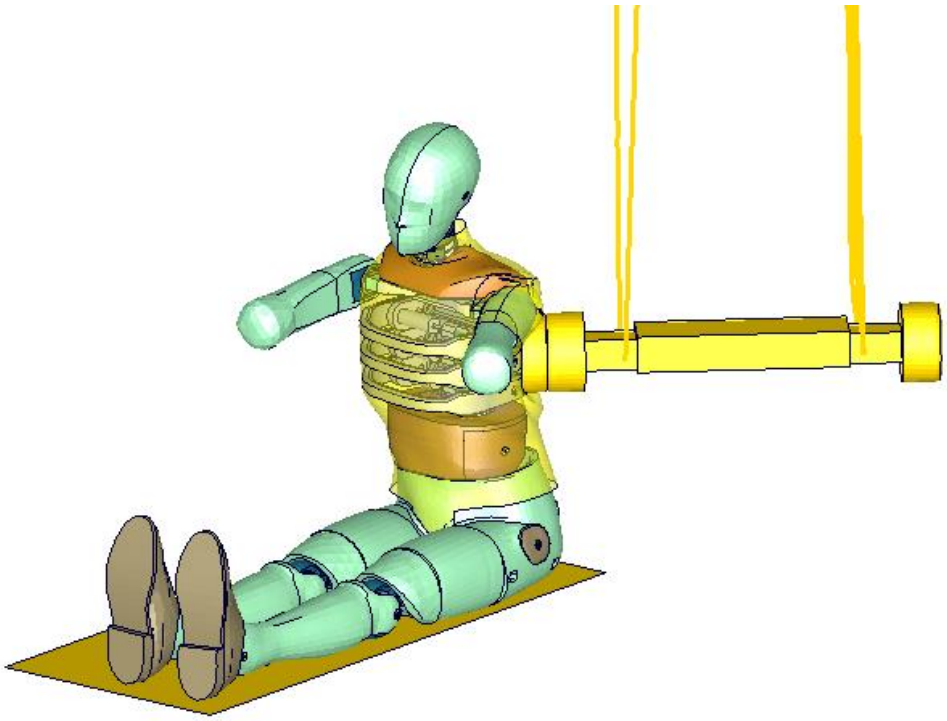
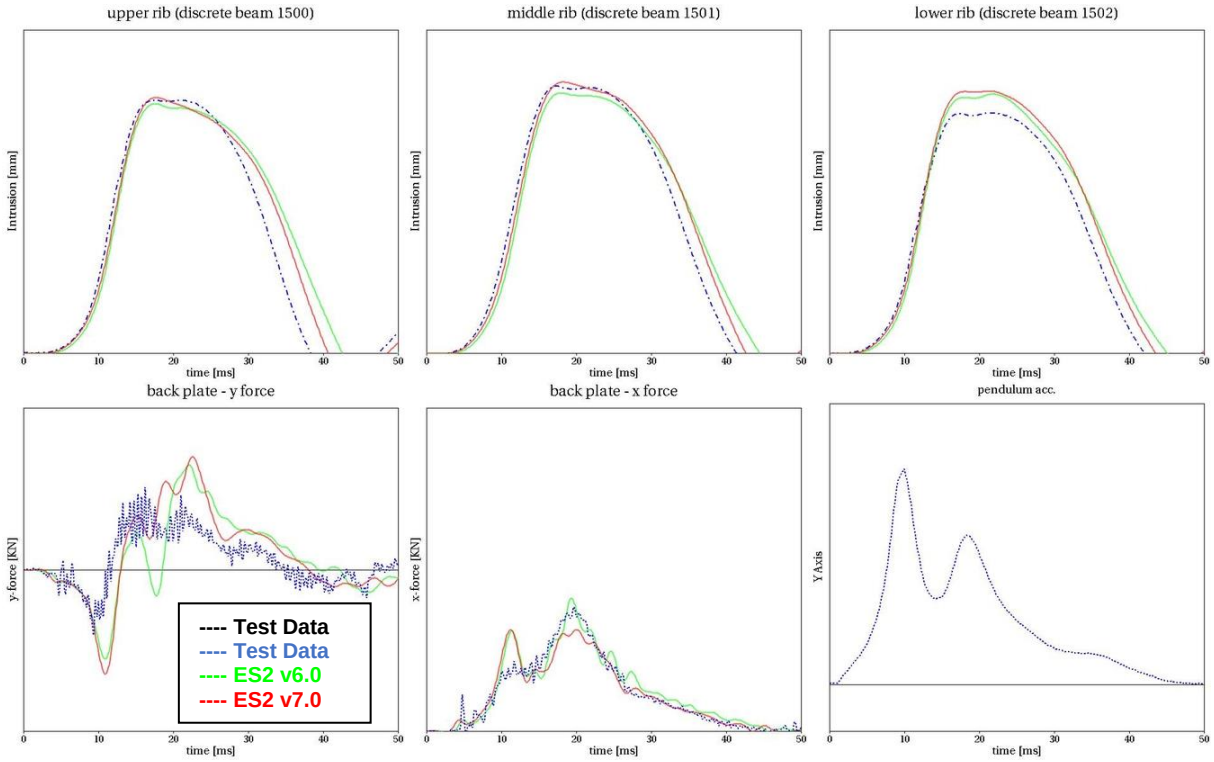


Figure 51: Pendulum impacting the ribs at 45 degrees; with arm and jacket

Results


upper rib (discrete beam 1500)
middle rib (discrete beam 1501)
lower rib (discrete beam 1502)
Intrusion [mm]
time [ms]
back plate - y force
back plate - x force
pendulum acc.
y-force [KN]
x-force [KN]
Y Axis
---- Test Data
---- Test Data
---- ES2 v6.0
---- ES2 v7.0

14. List of Figures