Documentation

LS-DYNA

ES-2 50th - Version 9.1

ES-2re 50th - Version 9.1

User's Manual
Manual Release 0.0 for Model 9.1
July 3rd, 2023

DYNAmore GmbH
www.dynamore.de
Germany

Authors:
Sebastian Stahlschmidt
Yupeng Huang
Alexander Schif

Contact Address:
Sebastian Stahlschmidt
DYNAmore GmbH
Industriestr. 2
70565 Stuttgart
Germany
Tel: +49-(0)711-459600-0
support@dynamore.de

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	Date	Revision Nr.
R9.3 dm MPP	03/13/2021	618
R11 MPP	06/09/2020	148584
R12 MPP	02/01/2022	3688

Table 1: LS-DYNA versions.

With the version 9.1 of the Euro-SID 2 50th model the following keyword files are delivered:

File name	Content
es2_v9.1_mm_ms_kg.key	Dummy model, the file name might vary depending on the system of units
es2_v9.1_nullshells.key	Optional contact shells
es2_v9.1_all_units_load_curves_work.key	Dummy curves for working on the model with a pre-processor
es2_v9.1_all_units_server.asc	Encrypted curve file including the table and curves of the model. This can only be used with valid vendor license
es2_v9.1_X-RAI.key	Optional include to track load paths through the dummy
X-RAI_DUMMY2BARRIER_FORCE_TRANSDUCERS.key	Example file for extra force transducer contacts to environment for X-RAI evaluation
psg_vx.x_DYNAMORE_Dummys	Positioning generator to generate positions by using pre-simulations
Lic_*Dummy_customername_issuedate_expirationdate*	Vendor License file

Table 2: Files delivered.

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

Component	Min ID	Max ID	Total number
Nodes	10000	375953	365167
Solids	11000	457627	446628
Beams	10000	11500	476
Shells	11000	225602	214603
Discrete elements	10500	10517	16
Mass elements	10518	10549	30

Accelerometer	1001	1022	11
Set nodes	1005	2042	54
Set beams	2000	2043	25
Set parts	1001	2028	61
Parts	1	740	614
Materials	1001	1230	206
Sections	1001	1740	617
Hourglass	1001	1007	7
Interpolation	10000	10018	4
Joint stiffness	1001	1018	17
Contacts	1001	1172	99
Cross sections	10900	10929	30
Local coordinate systems	1001	1045	45
Load curves / tables	1001	1249	188
Time history nodes	10001	10920	36
Time history elements	10000	10517	22

Table 3: Model numbering scheme.

2. Keywords used

The following control and database keywords are used:

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

Table 4: Used Control cards.

The following database cards are defined:

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

Table 5: Used Database cards.

The following material models are used:

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

Table 6: Used Material models.

The following other keywords are used:

*CONSTRAINED_EXTRA_NODES_SET *CONSTRAINED_INTERPOLATION *CONSTRAINED_JOINT_CYLINDRICAL_ID *CONSTRAINED_JOINT_SPHERICAL_ID *CONSTRAINED_JOINT_STIFFNESS_ GENERALIZED	*ELEMENT_SEATBELT_ ACCELEROMETER *ELEMENT_SHELL *ELEMENT_SOLID *ELEMENT_MASS

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

Table 7: Other keywords used in the model.

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

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

Table 8: Used Primer keywords.

3. Extraction of occupant injury criteria

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

3.1 Rib accelerations

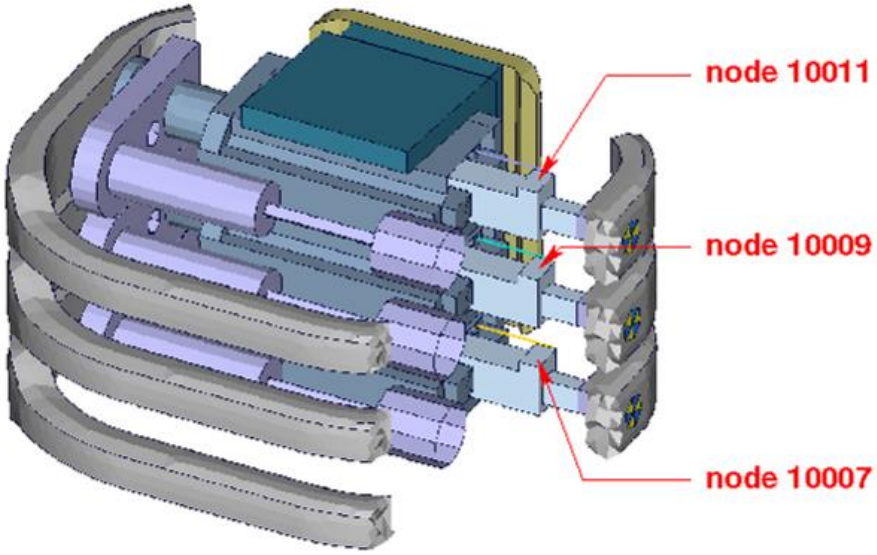


Figure 1: Nodes for extracting rib accelerations

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

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

Table 9: Rib acceleration nodes

3.2 Rib intrusion

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

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

Table 10: Rib intrusion elements from deforc

3.3 Spine accelerations

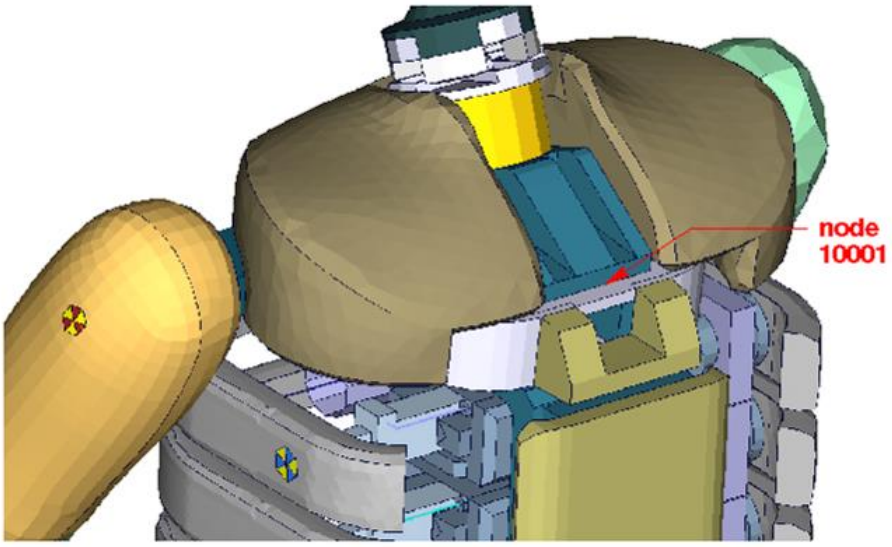


Figure 2: Node for extracting upper spine acceleration

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

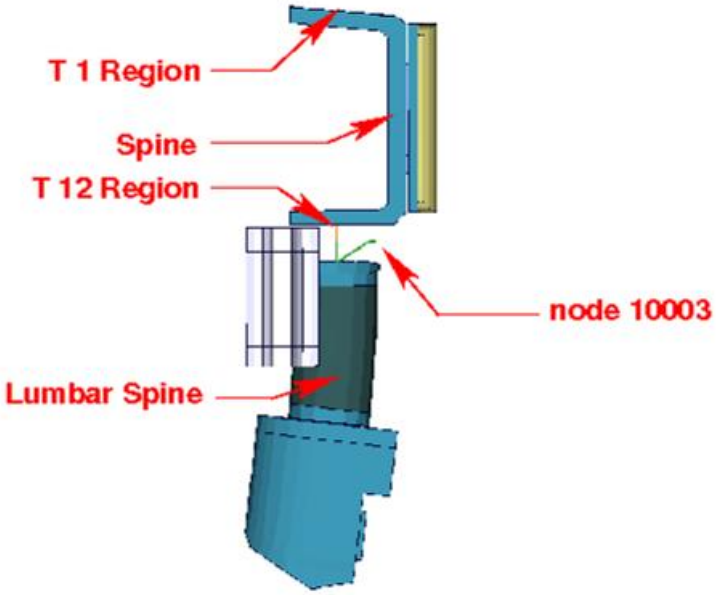


Figure 3: Node for extracting lower spine acceleration

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

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

Table 11: Spine acceleration nodes

3.4 Pelvis acceleration

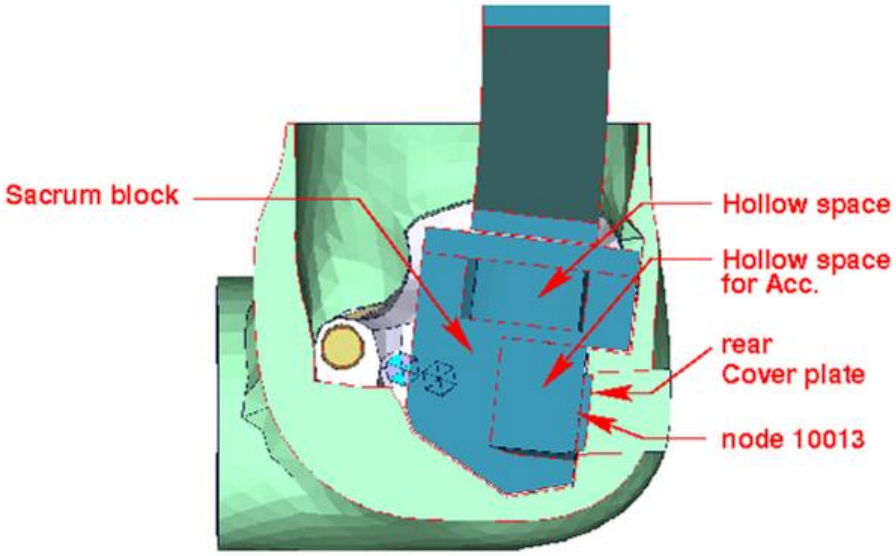


Figure 4: Node for extracting pelvis acceleration

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

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

Table 12: Pelvis accelerometer node.

3.5 Head acceleration

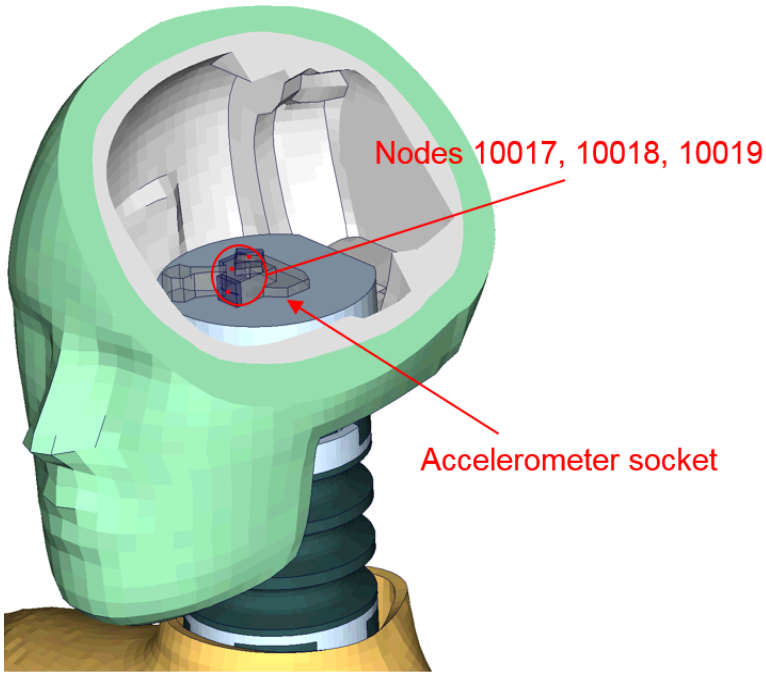


Figure 5: Nodes for extracting head acceleration

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

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

Table 13: Head accelerometer nodes

3.6 Pubic Symphysis force

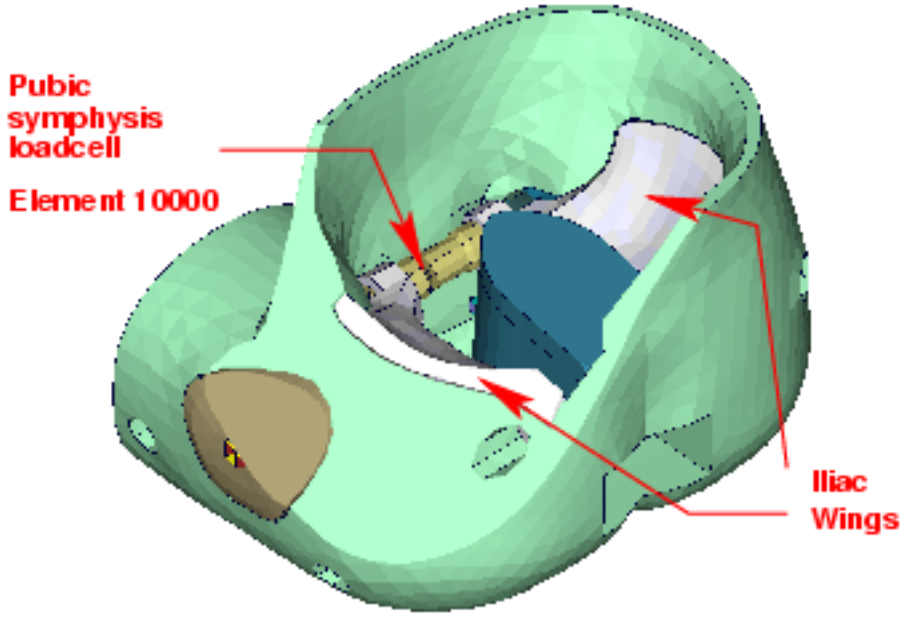


Figure 6: location for extracting signals of pubic symphysis load cell

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

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

Table 14: Pubic force beam

3.7 Shoulder force

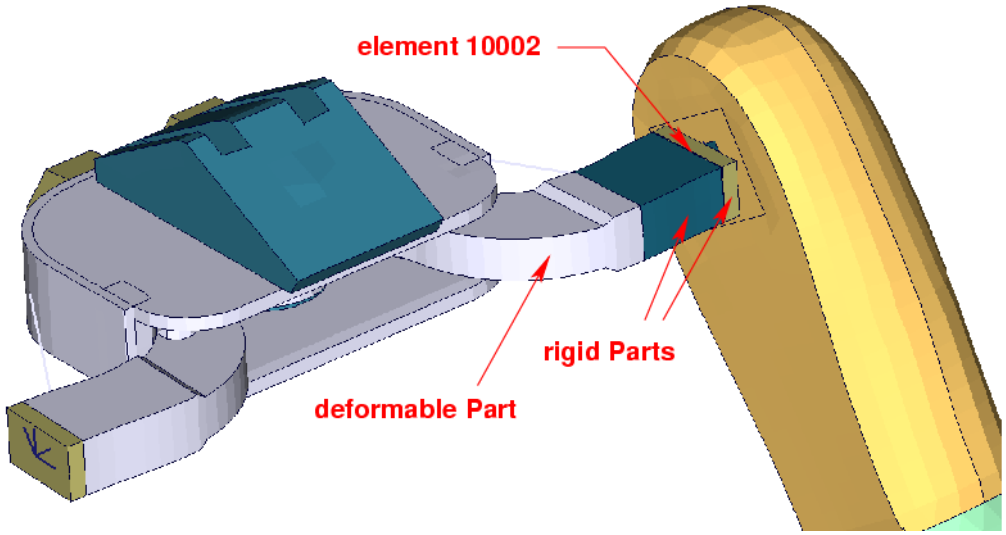


Figure 7: clavicle box with adapted clavicle to measure shoulder forces

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

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

Table 15: Shoulder force beam

3.8 Back plate load cell

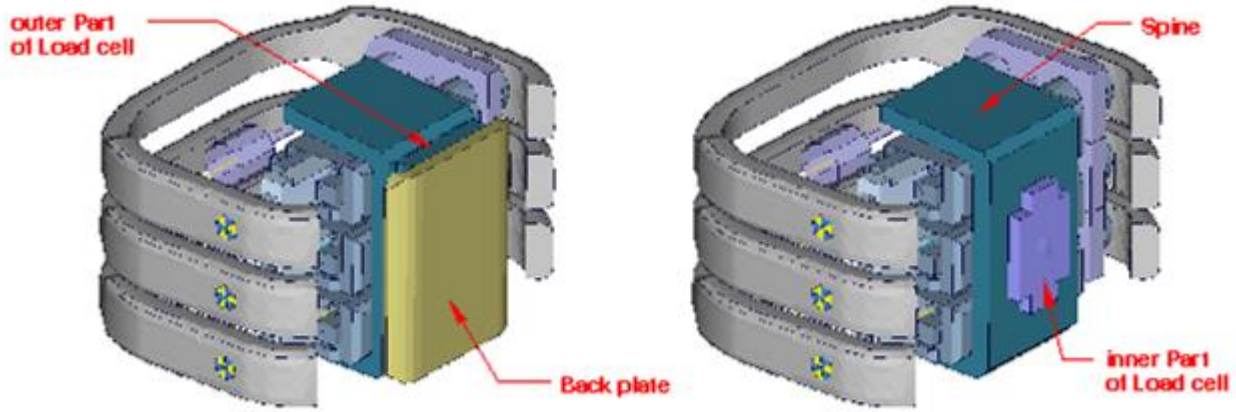


Figure 8: spine box with back plate

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

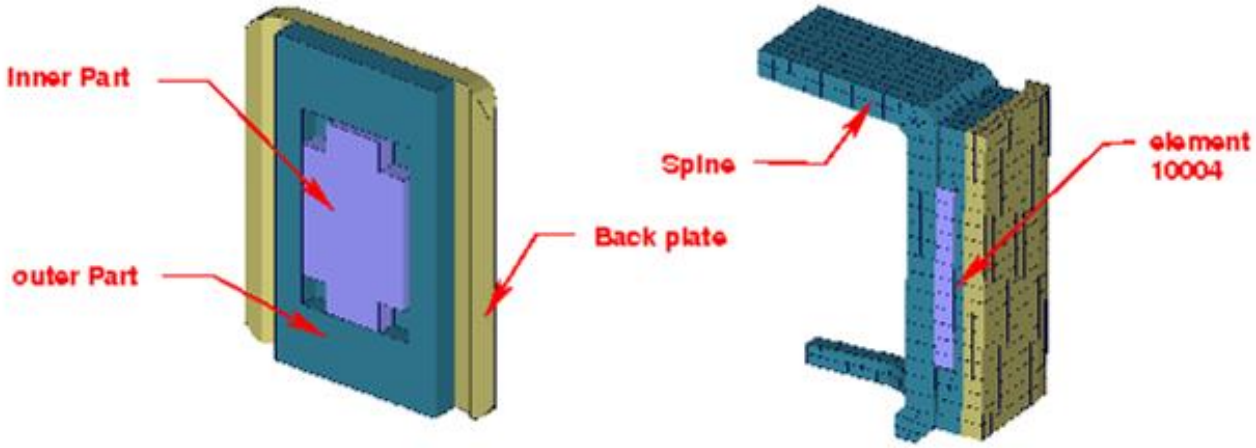


Figure 9: model of back plate load cell

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

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

Table 16: Back plate forces and moment beam

3.9 Neck load cells

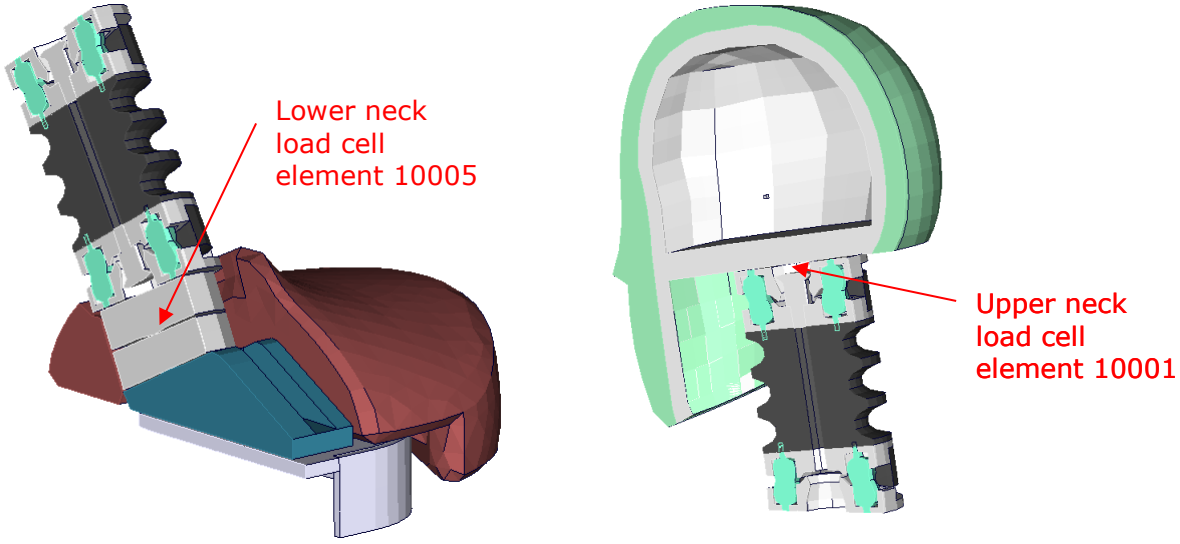


Figure 10: models of lower and upper neck load cell

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	NECKUP00ER	force shear-S
Upper neck moment About x-direction	10001	NECKUP00ER	moment torsion
Lower neck force y-direction	10005	NECKLO00ER	force shear-S
lower neck moment About x-direction	10005	NECKLO00ER	moment torsion

Table 17: Neck force and moment beams

3.10 T12 load cell (lumbar spine)

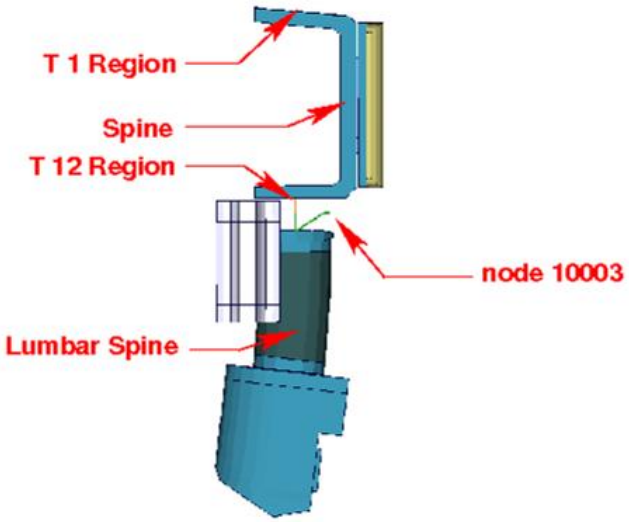


Figure 11: overview spine to sacrum with T12 load cell

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

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

Table 18: T12 force and moment beam

3.11 Lower lumbar load cell

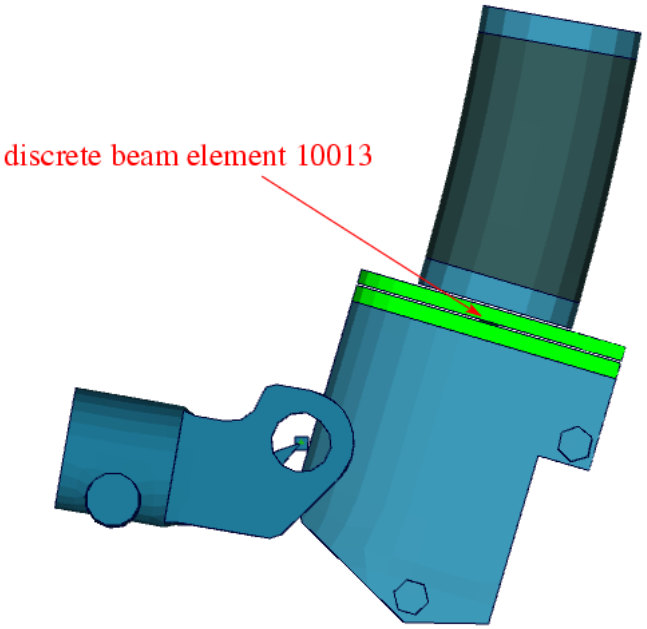


Figure 12: lower lumbar load cell

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

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

Table 19: Lower lumbar force and moment beam

3.12 Abdominal forces

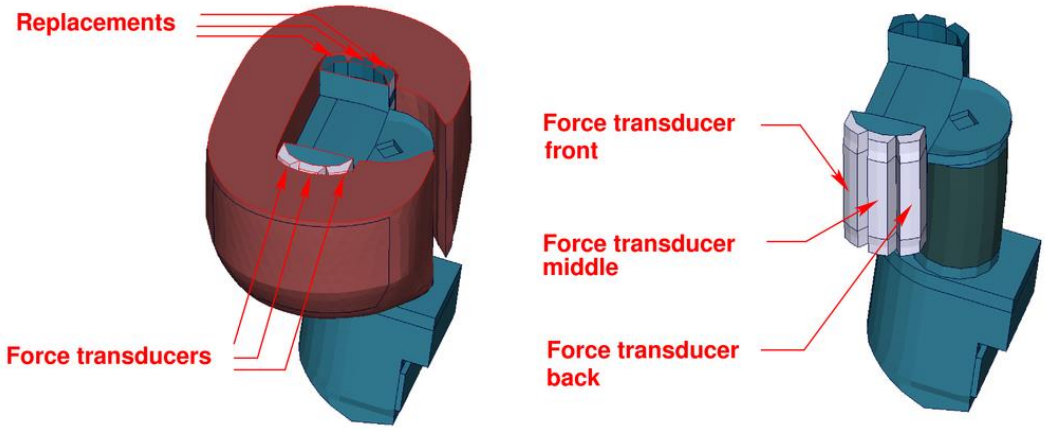


Figure 13: models of abdominal force transducers and replacements

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

Table 20: Abdomen interface forces

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

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

Table 21: Abdomen forces beams

3.13 Femur load cells

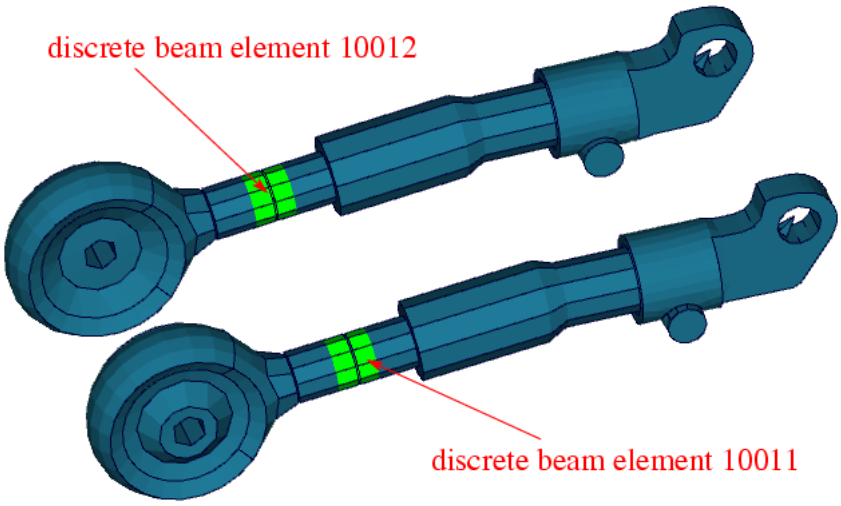


Figure 14: femur load cells

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

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

Table 22: 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.

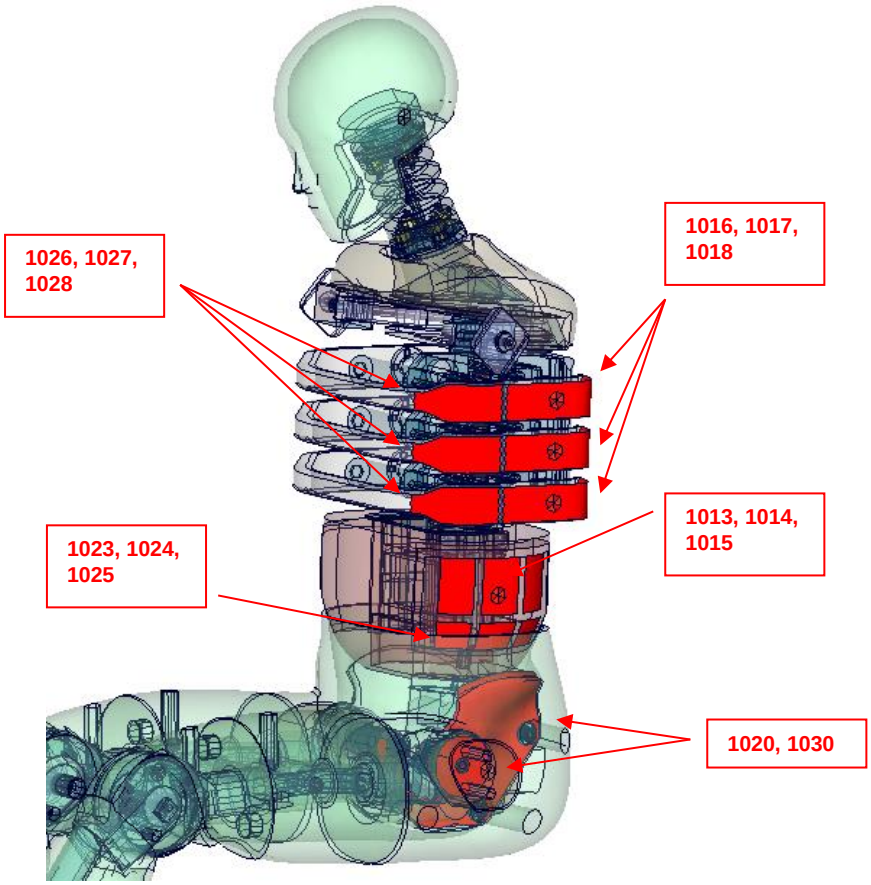


Figure 15: force transducer contacts

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

Table 23: Additional force transducer contacts

3.15 ES-2re extension forces

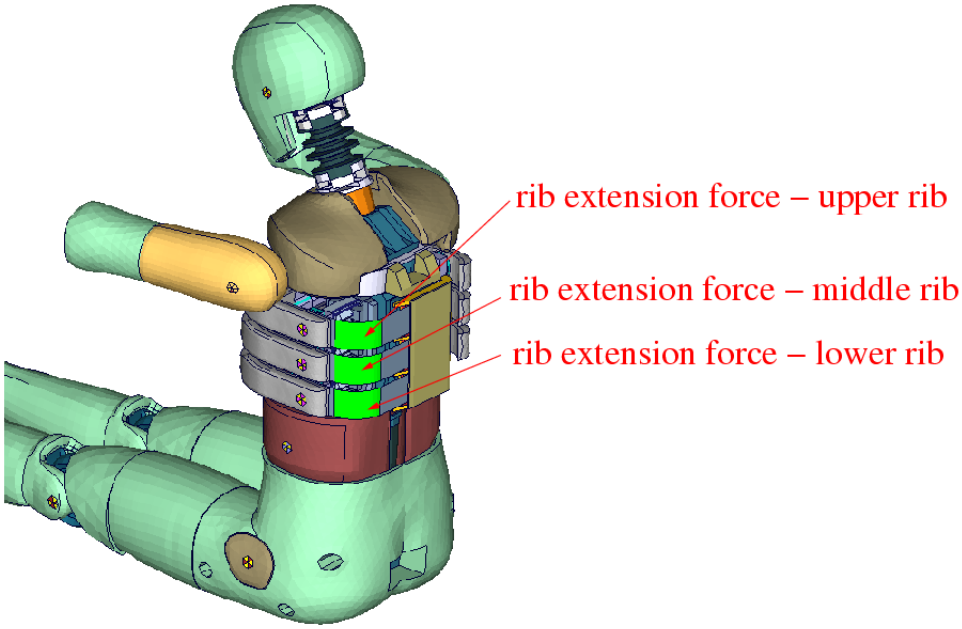


Figure 16: force transducer contacts of rib extension

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

Table 24: rib extension interface forces

4. Accelerometers

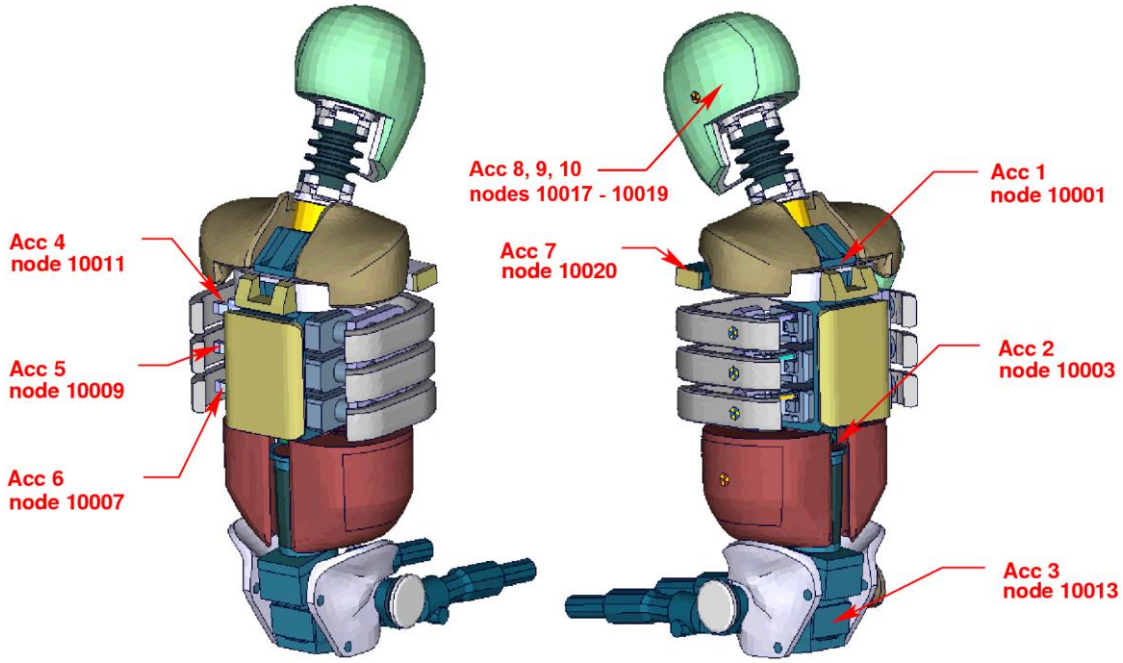


Figure 17: location of the accelerometers

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

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

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

Table 25: ES-2 accelerometers

5. Local coordinate systems

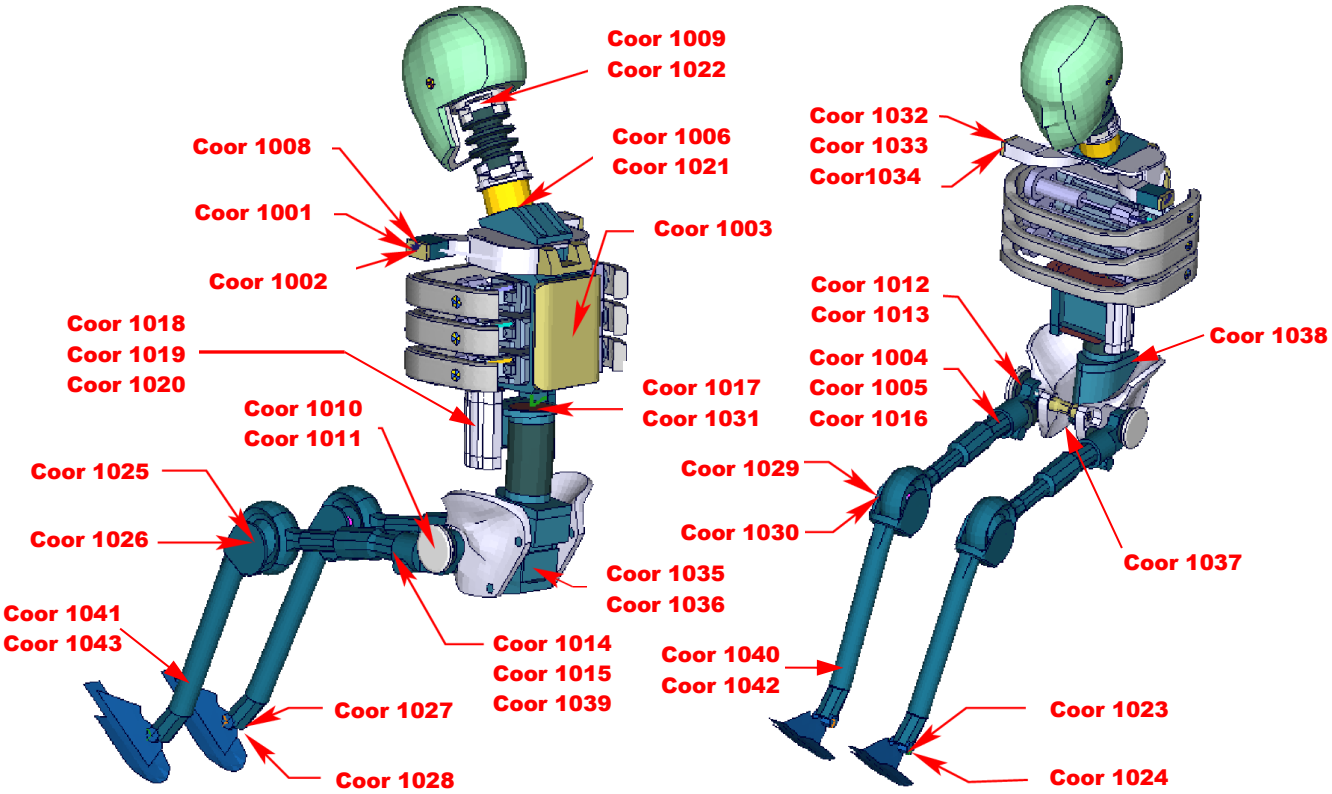


Figure 18: ES-2 skeleton with local coordinate systems

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 is a parameter (sloff) defined which can be used to offset the numbering of the load curves. The load curves can be scaled by using parameters. The names of the parameters refer to the table or load curve ID of each material. So if the y-values of the table ID 1002 are to be scaled then the parameter so1002 must be used. Accordingly sox1002 has to be used for x-scaling.

The principle structure is as follows:

Input data of the ES-2 file:

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

$ Load Curve scale values
R soTABID        1.0
R soxTABID       1.0
          .
          .
          .
*PARAMETER_EXPRESSION
I swTABID    TABID + &sloff
R szTABID    &unso1 * &soTABID

*DEFINE_CURVE
&swTABID         0&soxTABID &soTABID        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_v9.1_all_units_load_curves_work.key

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

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

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

7. Incorporating the dummy in vehicle models

7.1 Positioning, tree file

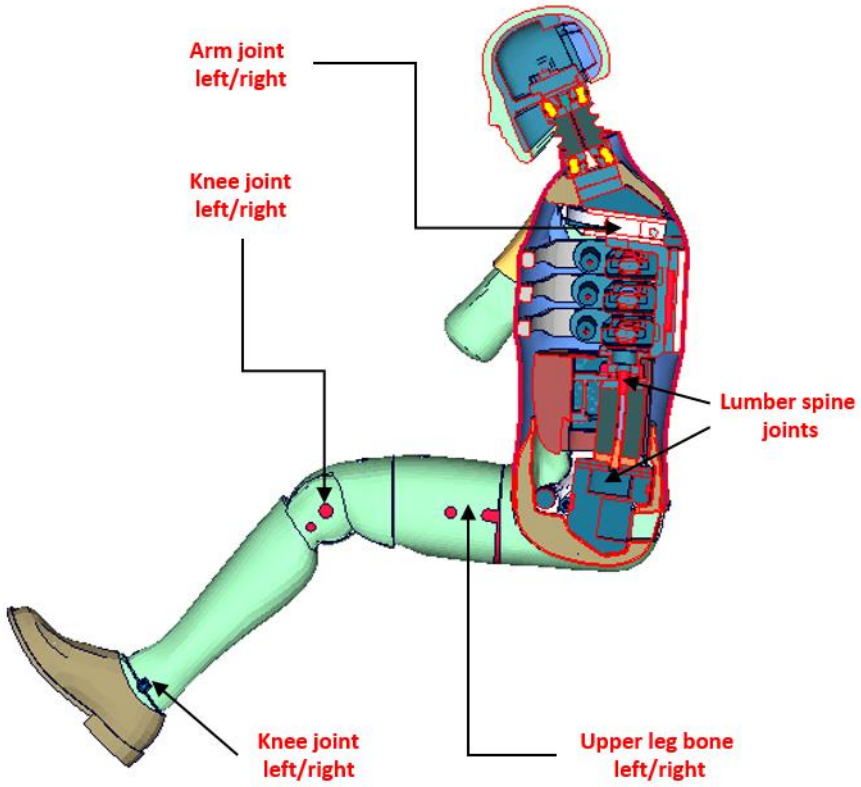


Figure 19: cut through the model with joints

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

Movable parts and revolute joints are:

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

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

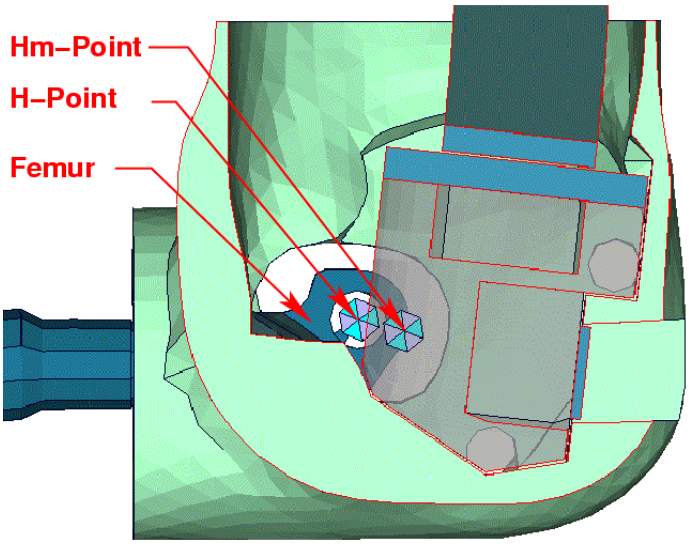


Figure 20: location of H- and Hm-point

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

Following nodes are used:

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

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

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

Table 26: 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 positioning script for the pre-simulation of the ES-2/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 ES-2/re model by using a preprocessor of your choice. Set the desired h-point and pelvis angle for the dummy and write out the model as the initial position model. Include your license file into the new model. In the second step set the desired angles for legs, arms, etc. Don't worry about the penetrations and highly distorted elements. Save this positioned ES-2/re model as the target position 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 initial and the target position of the dummy.

Run:

```
psg_vx.x_DYNAMORE_Dummys –d dummy_pos_initial.key –t dummy_pos_target.key
```

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

7.3 Measuring of pelvis and torso angle

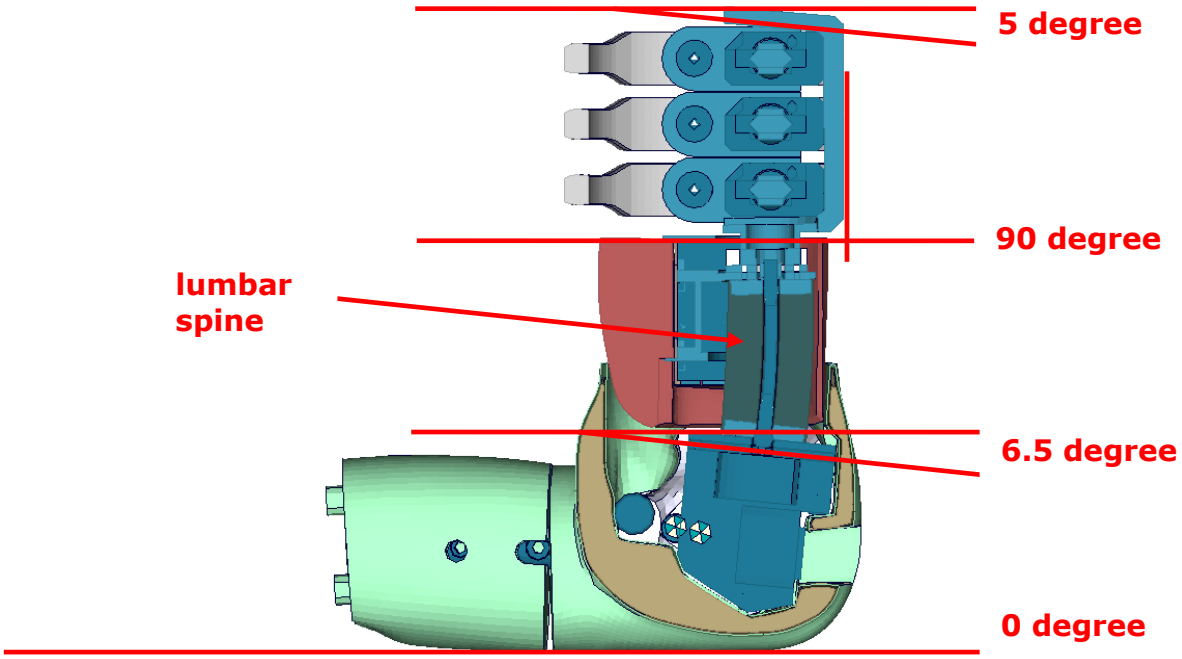


Figure 21: angles of important edges of the ES-2 dummy

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

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

Table 27: dummy angles

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

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

Table 28: dummy model angles

7.4 Parameterized ribs

Parameterized ribs are available since version 9 of the dummy. Four different settings for rib stiffness are available.

- Setting 0: basic rib as version 8.0.2
- Setting 1: minimum deformation rib
- Setting 2: medium deformation rib
- Setting 3: maximum deformation rib

Setting 0 is the original rib of version 8.0.2. For settings 1 to 3 the ribs were modified to match the lower (setting 1), middle (setting 2) and upper (setting 3) bound of the rib certification tests. The certification tests for all four rib settings are shown in Figure 22.

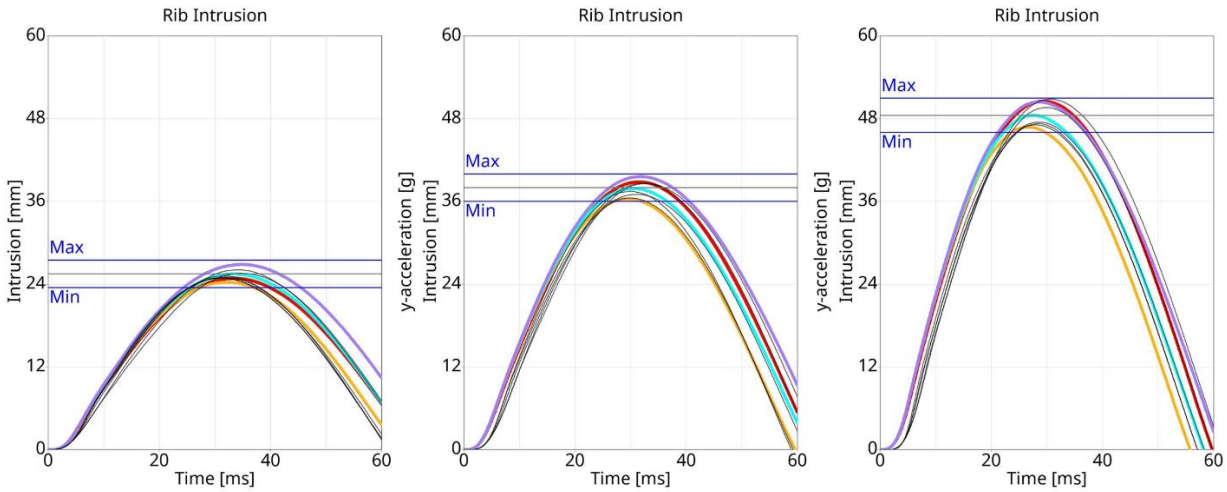


Figure 22: certification tests of parameterized rib settings

In the dummy model it is possible to assign different rib settings to each rib. There is one parameter available for each rib.

- *esuprib* (ES-2) / *eruprib* (ES-2re)
- *esmidrib* (ES-2) / *ermidrib* (ES-2re)
- *eslowrib* (ES-2) / *erlowrib* (ES-2re)

In the delivery model the setting is 0 for each rib. All the performance tests of chapter 11 and 13 were performed with this setting.
Only for the certification tests all four rib settings are available in chapter 12.

7.5 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.

7.6 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:

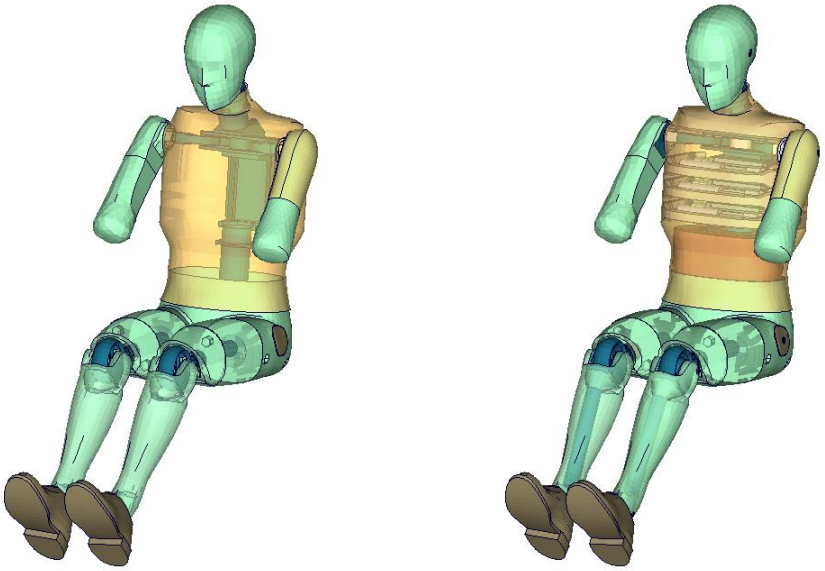


Figure 23: parts used in contact definition

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_v9.1_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.

7.7 Additional remarks

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

8. X-RAI system

Since version 9 the X-RAI system (exterior rigid assembly investigation) to evaluate load paths through the dummy is available. The X-RAI comes as a separate include and can easily be included or excluded from the dummy. The X-RAI has no influence on the performance of the dummy. There are 21 assemblies defined for the X-RAI system to be evaluated:

head	lumbar spine	knee right
neck	abdomen	lower leg left
spine box	pelvis bone	lower leg right
upper rib	pelvis	foot left
middle rib	upper leg left	foot right
lower rib	upper leg right	arm left
thorax	knee left	arm right

Table 29: X-RAI assemblies

8.1 Validation process

To match the defined assemblies several parts needed to be split. In addition several *CONTACT_FORCE_TRANSDUCERs, *DATABASE_HISTORY_DISCRETEs, *DATABSE_HISTORY_NODEs and *DATABASE_CROSS_SECTIONs were added to track forces.
For the X-RAI to work properly FTALL needs to be set to 1 in *CONTROL_CONTACT. Otherwise not all contact forces might be tracked by the force transducers.

The X-RAI system was validated with the performance sled tests. The validation report is available as a separate file in the delivery package named "es2_v9.1_X-RAI_validation_report.pdf". In this manual the principle of the validation process is shown.

For the validation of the X-RAI the following equation was considered:

$$m_i * a_{cog_{initial},i} = \sum_{1}^{n} F_{n,i}$$

Meaning the mass m_i of assembly i times the acceleration of the initial center of gravity $a_{cog,i}$ of assembly i needs to be the same as the sum of all forces $F_{n,i}$ acting on assembly i at each time step.

The masses of the assemblies were calculated with the help of *DATABASE_SSSTAT_MASS_PROPERTIES and the assembly part sets.
The X-RAI nodes to track the accelerations of the 21 assemblies are shown in Table 9. Each of these nodes is constrained to a part belonging to the same assembly with *CONTRAINED_EXTRA_NODES or *CONSTRAINED_INTERPOLATION. The nodes are located in the main dummy include.

Item	Node-ID	Label	Component
Head	10900	HEAD X-RAI	x-/y-/z-acceleration
Neck	10901	NECK X-RAI	x-/y-/z-acceleration
Spine box	10902	SPINE BOX X-RAI	x-/y-/z-acceleration
Thorax	10903	THORAX X-RAI	x-/y-/z-acceleration
Abdomen	10904	ABDOMEN X-RAI	x-/y-/z-acceleration

Lumbar spine	10905	LUMBAR SPINE X-RAI	x-/y-/z-acceleration
Pelvis bone	10906	PELVIS BONE X-RAI	x-/y-/z-acceleration
Pelvis	10907	PELVIS X-RAI	x-/y-/z-acceleration
Upper leg left	10908	UPPER LEG LEFT X-RAI	x-/y-/z-acceleration
Upper leg right	10909	UPPER LEG RIGHT X-RAI	x-/y-/z-acceleration
Knee left	10910	KNEE LEFT X-RAI	x-/y-/z-acceleration
Knee right	10911	KNEE RIGHT X-RAI	x-/y-/z-acceleration
Lower leg left	10912	LOWER LEG LEFT X-RAI	x-/y-/z-acceleration
Lower leg right	10913	LOWER LEG RIGHT X-RAI	x-/y-/z-acceleration
Foot left	10914	FOOT LEFT X-RAI	x-/y-/z-acceleration
Foot right	10915	FOOT RIGHT X-RAI	x-/y-/z-acceleration
Arm left	10916	ARM LEFT X-RAI	x-/y-/z-acceleration
Arm right	10917	ARM RIGHT X-RAI	x-/y-/z-acceleration
Upper rib	10918	UPPER RIB X-RAI	x-/y-/z-acceleration
Mid rib	10919	MID RIB X-RAI	x-/y-/z-acceleration
Lower rib	10920	LOWER RIB X-RAI	x-/y-/z-acceleration

Table 30: X-RAI nodes for acceleration

8.2 Forces tracked by X-RAI include

The sum of forces for each assembly consist of *DATABASE_CROSS_SECTION, *DATABASE_HISTORY_DISCRETE, *CONTACT_FORCE_TRANSDUCER_PENALTY. All of the following definitions for the dummy itself are available in the X-RAI include. Contacts to the environment have to be defined by the user on its own. They are later shown in chapter 8.3.

Table 31 shows the available force transducers of the X-RAI include. Each contact is defined between two assemblies which may come into contact. All of the labels begin with "IC_FORCE_TRANSDUCER_". To make it more clear the beginning of the labels is not shown in the table. The rest of the labels consist of the slave of the contact, the number "2" and the master of the contact (for example HEAD2JACKET: slave is head – master is jacket). The interface numbers can be found in the rcforc output.

Interface ID	Label	Component
1100	HEAD2JACKET	Slave/master
1101	HEAD2NECK	Slave/master
1102	HEAD2ARMLEFT	Slave/master
1103	HEAD2ARMRIGHT	Slave/master
1104	NECK2THORAX	Slave/master
1105	NECK2SHOULDERPAD	Slave/master
1106	SPINEBOX2JACKET	Slave/master
1107	SPINEBOX2LUMBARSPINE	Slave/master
1108	SPINEBOX2ABDOMEN	Slave/master
1109	SPINEBOX2ABDOMENCARRIER	Slave/master
1110	SPINEBOX2RIBS	Slave/master
1111	SPINEBOX2UPPERIB	Slave/master
1112	SPINEBOX2MIDRIB	Slave/master
1113	SPINEBOX2LOWERRIB	Slave/master
1114	SPINEBOX2SHOULDERPAD	Slave/master
1115	SPINEBOX2NECK	Slave/master
1116	SPINEBOX2ARMLEFT	Slave/master
1117	SPINEBOX2ARMRIGHT	Slave/master

1118	RIBS2JACKET	Slave/master
1119	ABDOMEN2THORAX	Slave/master
1120	ABDOMEN2LUMBARSPINE	Slave/master
1121	ABDOMEN2PELVISBONE	Slave/master
1122	ABDOMEN2PELVIS	Slave/master
1123	ABDOMEN2LOWERRIB	Slave/master
1124	ABDOMENRUBBER2ABDOMENCARRIER	Slave/master
1125	ABDOMENRUBBER2THORAX	Slave/master
1126	ABDOMENRUBBER2LUMBARSPINE	Slave/master
1127	ABDOMENRUBBER2PELVISBONE	Slave/master
1128	ABDOMENRUBBER2PELVIS	Slave/master
1129	ABDOMENCARRIER2THORAX	Slave/master
1130	ABDOMENCARRIER2LUMBARSPINE	Slave/master
1131	ABDOMENCARRIER2PELVISBONE	Slave/master
1132	ABDOMENCARRIER2PELVIS	Slave/master
1133	LUMBARSPINE2THORAX	Slave/master
1134	LUMBARSPINE2PELVIS	Slave/master
1135	LUMBARSPINE2PELVISBONE	Slave/master
1136	PELVIS2THORAX	Slave/master
1137	PELVIS2UPPERLEGLEFT	Slave/master
1138	PELVIS2UPPERLEGRIGHT	Slave/master
1139	PELVISBONE2UPPERLEGLEFT	Slave/master
1140	PELVISBONE2UPPERLEGRIGHT	Slave/master
1141	PELVISFOAM2PELVISBONE	Slave/master
1142	ARMLEFT2UPPERRIB	Slave/master
1143	ARMLEFT2MIDRIB	Slave/master
1144	ARMLEFT2LOWERRIB	Slave/master
1145	ARMLEFT2THORAX	Slave/master
1146	ARMRIGHT2UPPERRIB	Slave/master
1147	ARMRIGHT2MIDRIB	Slave/master
1148	ARMRIGHT2LOWERRIB	Slave/master
1149	ARMRIGHT2THORAX	Slave/master
1150	UPPERLEGLEFT2THORAX	Slave/master
1151	UPPERLEGLEFT2UPPERLEGRIGHT	Slave/master
1152	UPPERLEGRIGHT2THORAX	Slave/master
1153	KNEELEFT2UPPERLEGLEFT	Slave/master
1154	KNEELEFT2UPPERLEGRIGHT	Slave/master
1155	KNEELEFT2KNEERIGHT	Slave/master
1156	KNEELEFT2LOWERLEGLEFT	Slave/master
1157	KNEELEFT2LOWERLEGRIGHT	Slave/master
1158	KNEERIGHT2UPPERLEGRIGHT	Slave/master
1159	KNEERIGHT2UPPERLEGLEFT	Slave/master
1160	KNEERIGHT2LOWERLEGRIGHT	Slave/master
1161	KNEERIGHT2LOWERLEGLEFT	Slave/master
1162	LOWERLEGLEFT2LOWERLEGRIGHT	Slave/master
1163	FOOTLEFT2LOWERLEGLEFT	Slave/master
1164	FOOTLEFT2LOWERLEGRIGHT	Slave/master
1165	FOOTLEFT2FOOTRIGHT	Slave/master
1166	FOOTRIGHT2LOWERLEGLEFT	Slave/master
1167	FOOTRIGHT2LOWERLEGRIGHT	Slave/master
1168	JACKET2UPPERIB	Slave/master
1169	JACKET2MIDRIB	Slave/master
1170	JACKET2LOWERRIB	Slave/master

1171	SACRUMBLOCK2ILIACWING	Slave/master
1172	SACRUMBLOCK2ILIACWING	Slave/master

Table 31: X-RAI transducer contacts

The cross sections are listed in Table 32. The cross section output can be found in the secforc output.

Section	Label	Component
10900	PUBIC CROSS SECTION X-RAI	x-/y-/z-force
10901	UPPER NECK CROSS SECTION X-RAI	x-/y-/z-force
10902	CLAVICLE LEFT CROSS SECTION X-RAI	x-/y-/z-force
10903	CLAVICLE RIGHT CROSS SECTION X-RAI	x-/y-/z-force
10904	BACK PLATE CROSS SECTION X-RAI	x-/y-/z-force
10905	LOWER NECK CROSS SECTION X-RAI	x-/y-/z-force
10906	T12 CROSS SECTION X-RAI	x-/y-/z-force
10907	FEMUR LEFT CROSS SECTION X-RAI	x-/y-/z-force
10908	FEMUR RIGHT CROSS SECTION X-RAI	x-/y-/z-force
10909	LUMBAR SPINE CROSS SECTION X-RAI	x-/y-/z-force
10910	ABDOMEN FRONT CROSS SECTION X-RAI	x-/y-/z-force
10911	ABDOMEN MID CROSS SECTION X-RAI	x-/y-/z-force
10912	ABDOMEN REAR CROSS SECTION X-RAI	x-/y-/z-force
10913	LAGER BEAM CROSS SECTION X-RAI	x-/y-/z-force
10914	FEMURAL NECK JOINT LEFT CROSS SECTION X-RAI	x-/y-/z-force
10915	FEMURAL NECK JOINT RIGHT CROSS SECTION X-RAI	x-/y-/z-force
10916	FEMUR JOINT LEFT CROSS SECTION X-RAI	x-/y-/z-force
10917	FEMUR JOINT RIGHT CROSS SECTION X-RAI	x-/y-/z-force
10918	KNEE JOINT LEFT CROSS SECTION X-RAI	x-/y-/z-force
10919	KNEE JOINT RIGHT CROSS SECTION X-RAI	x-/y-/z-force
10920	ANKLE JOINT LEFT CROSS SECTION X-RAI	x-/y-/z-force
10921	ANKLE JOINT RIGHT CROSS SECTION X-RAI	x-/y-/z-force
10922	UPPER SPOTWELDS CROSS SECTION X-RAI	x-/y-/z-force
10923	MID SPOTWELDS CROSS SECTION X-RAI	x-/y-/z-force
10924	LOWER SPOTWELDS CROSS SECTION X-RAI	x-/y-/z-force
10925	JACKET2PELVIS CROSS SECTION X-RAI	x-/y-/z-force
10926	LUMBAR SPINE RUBBER CROSS SECTION X-RAI	x-/y-/z-force
10927	UPPER RIB BEAM CROSS SECTION X-RAI	x-/y-/z-force
10928	MID RIB BEAM CROSS SECTION X-RAI	x-/y-/z-force
10929	LOWER RIB BEAM CROSS SECTION X-RAI	x-/y-/z-force

Table 32: X-RAI cross sections

The discrete history outputs are listed in Table 33. The discrete outputs can be found in deforc.

Discrete ID	Label	Component
10503	UPPER RIB DAMPER SPRING X-RAI	x-/y-/z-force
10504	MID RIB DAMPER SPRING X-RAI	x-/y-/z-force
10505	LOWER RIB DAMPER SPRING X-RAI	x-/y-/z-force
10506	UPPER RIB DAMPER X-RAI	x-/y-/z-force
10507	MID RIB DAMPER X-RAI	x-/y-/z-force
10508	LOWER RIB DAMPER X-RAI	x-/y-/z-force

Table 33: X-RAI discrete outputs

8.3 Additional contact force transducers

Only for the internal interactions the force transducer contacts are directly available in the dummy model with the X-RAI include. All the force transducers for the contact with the environment need to be added by the user.
The delivery package contains an example file with predefined force transducers to environment (”X-RAI_DUMMY2BARRIER_FORCE_TRANSDUCERS”). Within this file fourteen additional force transducer contacts to the environment (barrier) are defined. The slave side of these contacts contains the X-RAI assembly part set (f.e. head) coming into contact with the environment, the master side contains the barrier with part set id #10000.
If there is not just one barrier set available which might come into contact with the dummy, additional contact force transducers have to be defined by the user accordingly to this example file.

8.4 Evaluation

The delivery package includes a standard evaluation hypergraph template (es2_v9.1_X-RAI_S*.tpl) for evaluation. This template contains all outputs needed for the validation process described in chapter 8.1. For the dummy to environment interactions the template will use the contacts of the example file introduced in chapter 8.3 “X-RAI_DUMMY2BARRIER_FORCE_TRANSDUCERS”.

9. Release notes from v8.0.2 to v9.1

9.1 Modifications from v9.0.2 to v9.1

- Fixed an issue where it came to instabilities when using the parameterized ribs for settings 1, 2 and 3 in S2 unit system
- Added additional scaling parameters for rib settings 1, 2 and 3 (where only available for setting 0) in S2 and S3 unit system

Remarks:

1. **VERSION 9.1 IS USING A NEW MATERIAL FILE AND LICENSE, IT WILL NOT WORK WITH V9.0!!!**
2. There are no modifications to nodes – there should be no need for new pre-simulations
3. Results for v9.0.2 and v9.1 in S3 unit system should be the same (for all rib settings)
4. Results for v9.0.2 and v9.1 in S2 units system should be slightly different (**only** when using rib settings 1, 2 or 3)

9.2 Modifications from v9.0.1 to v9.0.2

- Fixed dummy tree file for ES-2 dummy (NID#10916 for X-RAI system was in no assembly and therefore not moved)
- Set IGRAV=1 for *ELEMENT_SEATBELT_ACCELEROMETERS to match hardware
- Changed some names of RHD model *SET_NODEs (left/right)

9.3 Modifications from v9.0 to v9.0.1

- Modified name of abdomen foam part to stay deformable during psg-script pre-simulations
- Fixed stop angles of lower leg for RHD models
- Fixed curve parameterization of ES-2re S2 models

9.4 Modifications from v8.0.2 to v9.0

Geometrical dummy model modifications

There are only minor geometrical modifications available in v9.0.

9.4.1 Femur bones and iliac wings

- Radius on femur bones and smoothing of iliac wings to better match hardware geometry
- Results in better pubic force performance and robustness of the model

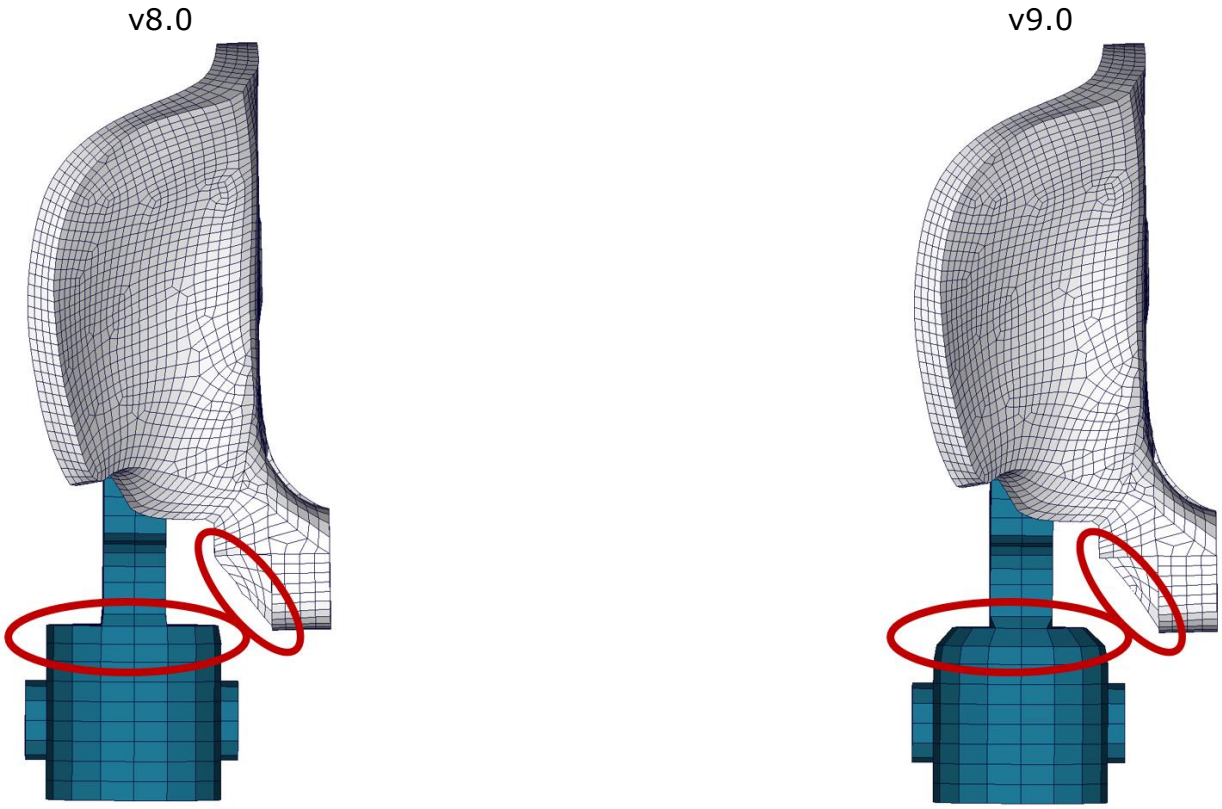


Figure 24: parts used in contact definition

9.4.2 Additional H_m-point marker

There is an additional Hm-point marker available in v9.0 for easier positioning

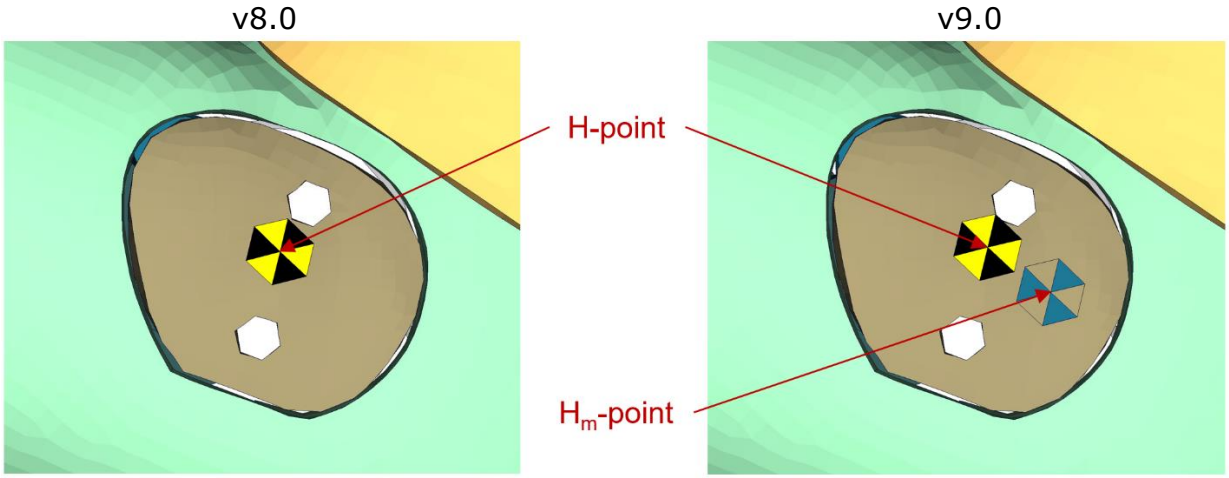


Figure 25: parts used in contact definition

Non-geometric dummy model modifications

9.4.3 Parameterized ribs

Version 9.0 offers the option to choose from four different rib settings which are:

- Setting 0: basic rib as version 8.0.2
- Setting 1: minimum deformation rib
- Setting 2: medium deformation rib
- Setting 3: maximum deformation rib

Each rib can have its own setting. The minimum, medium and maximum ribs where developed in regard of the borders of the rib calibration test.

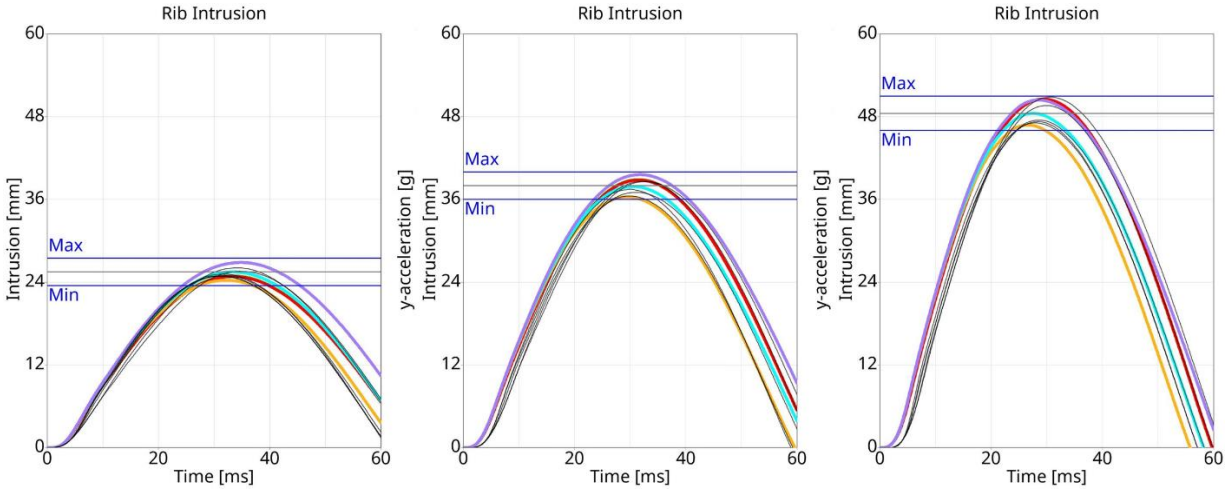


Figure 26: Certification tests of parameterized rib setups

9.4.4 X-RAI system

The X-RAI (exterior rigid assembly investigation) system is introduced to evaluate load paths though the dummy. The X-RAI comes as a separate include and can easily be included or excluded from the dummy. There are 21 assemblies defined for the X-RAI system:

head	lumbar spine	knee right
neck	abdomen	lower leg left
spine box	pelvis bone	lower leg right
upper rib	pelvis	foot left
middle rib	upper leg left	foot right
lower rib	upper leg right	arm left
thorax	knee left	arm right

Table 34: X-RAI assemblies

To match the defined assemblies several parts needed to be split. In addition several *CONTACT_FORCE_TRANSDUCERs, *DATABASE_HISTORY_DISCRETEs, *DATABSE_HISTORY_NODEs and *DATABASE_CROSS_SECTIONs were added to track forces.

The X-RAI system was validated with the performance sled tests. The following equation was considered for the validation process:

$$m_i * a_{cog_{initial},i} = \sum_{1}^{n} F_{n,i}$$

Meaning the mass m_i of assembly i times the acceleration $a_{cog,i}$ of the initial center of gravity of assembly i needs to be the same as the sum of all forces $F_{n,i}$ acting on assembly i.

Additional information about the X-RAI system can be found in the X-RAI chapter 8.

9.4.5 Additional remarks

- Released lumbar cable spine spherical joint
- IGRAV=0 to match hardware sensors
- Set-Part for pre-simulation script extended to prevent penetrations in leg ankle region
- Removed _MPP option from self-contact
- Edge-Contact (SOFT=2) also with PART_CONTACT friction values
- Minor changes to match identical assemblies of ES-2 and ES-2re
- Several minor material/section/part/joint/friction/contact optimization
- CORA ratings are now available in the manual

10. Limitations and further work

Chapter 11 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 v9.1 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

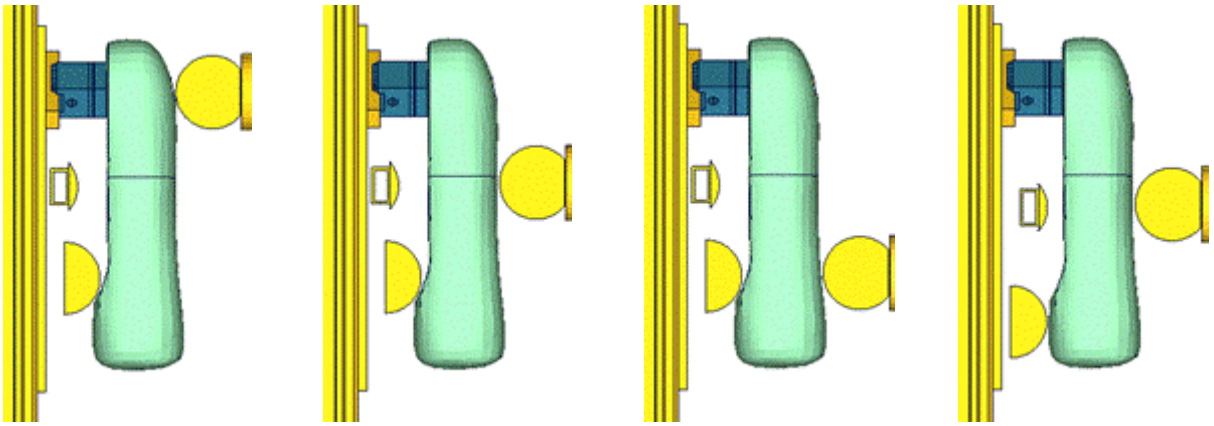
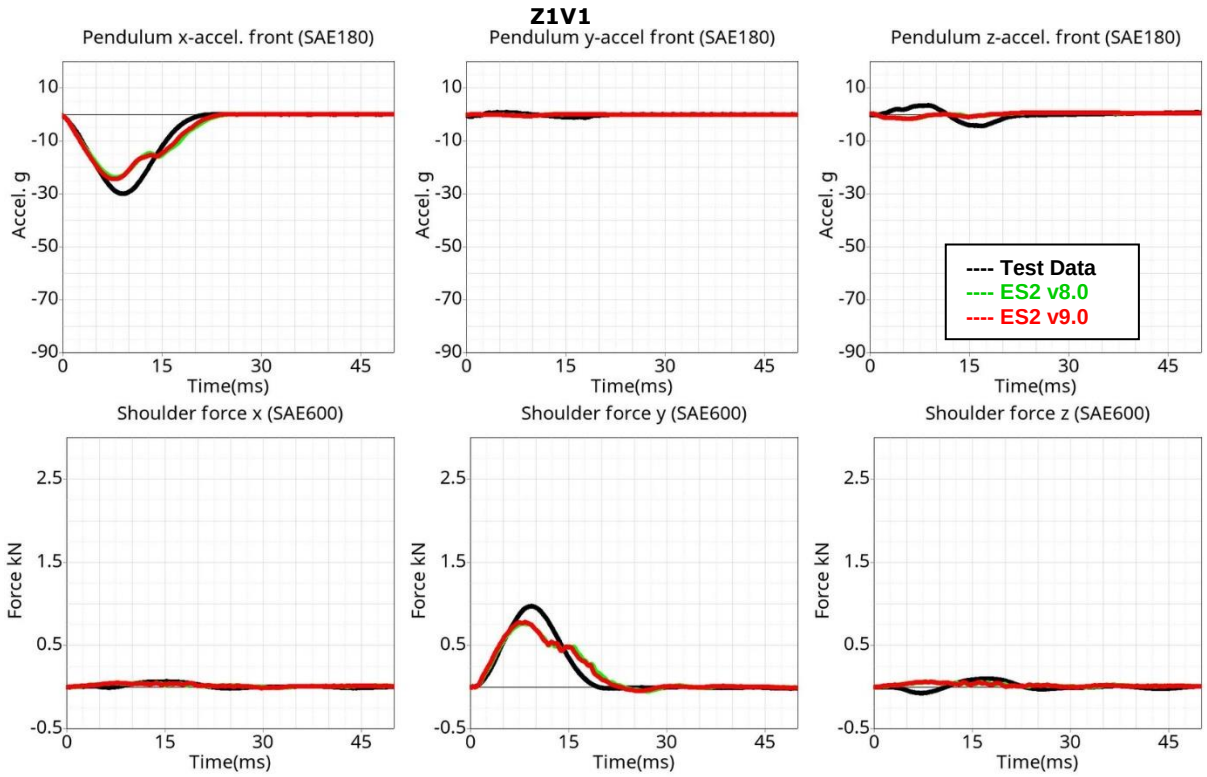


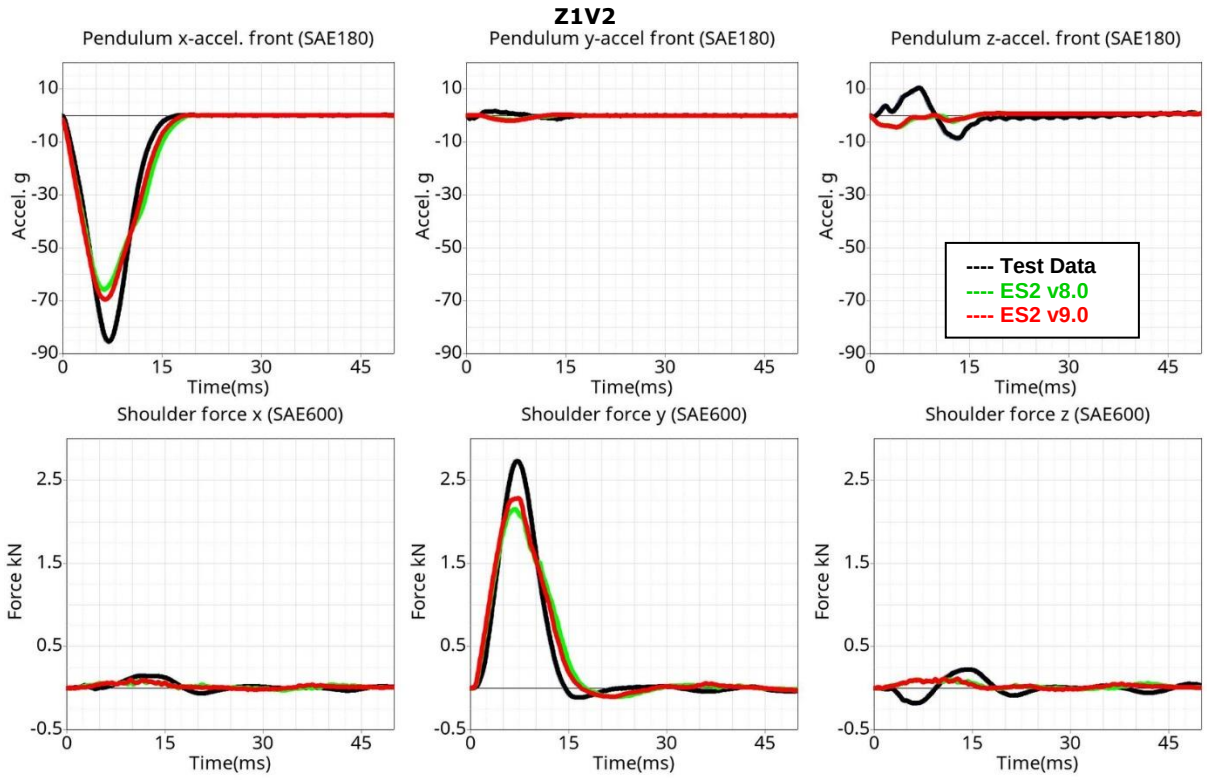
Figure 27: Test setups for Arm test

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

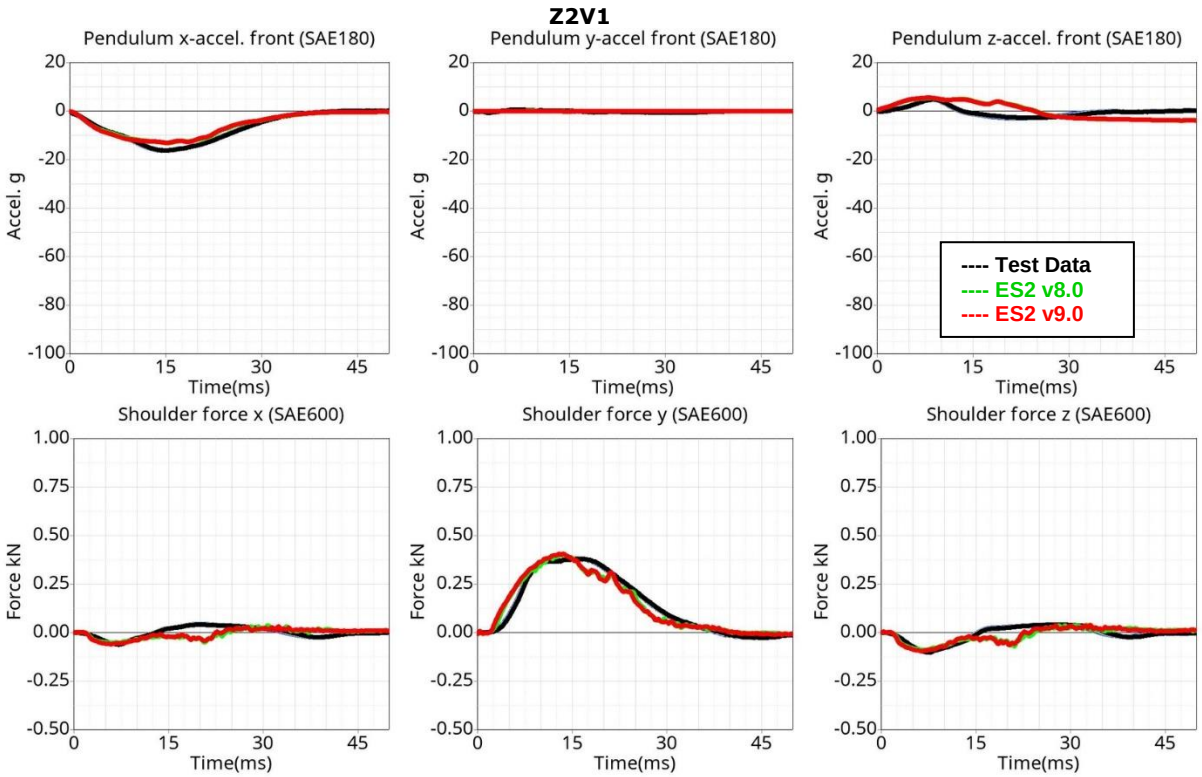
Results for top impact, low velocity



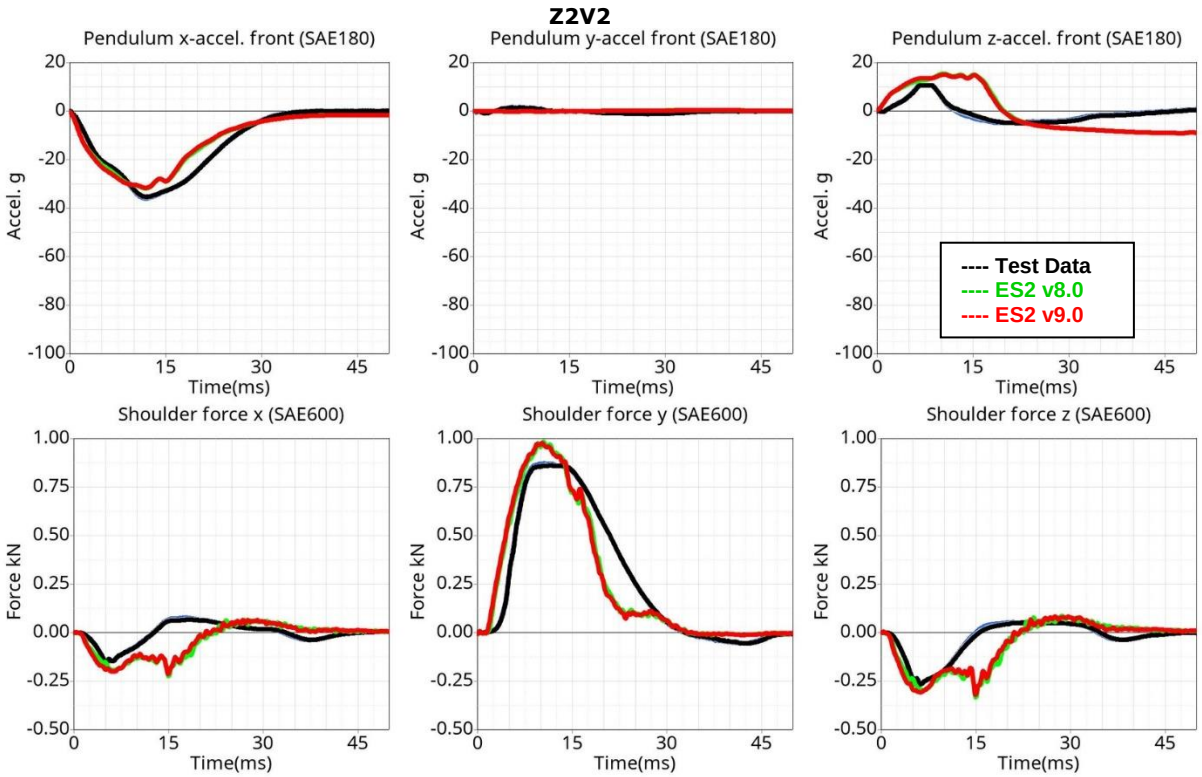
Results for top impact, high velocity



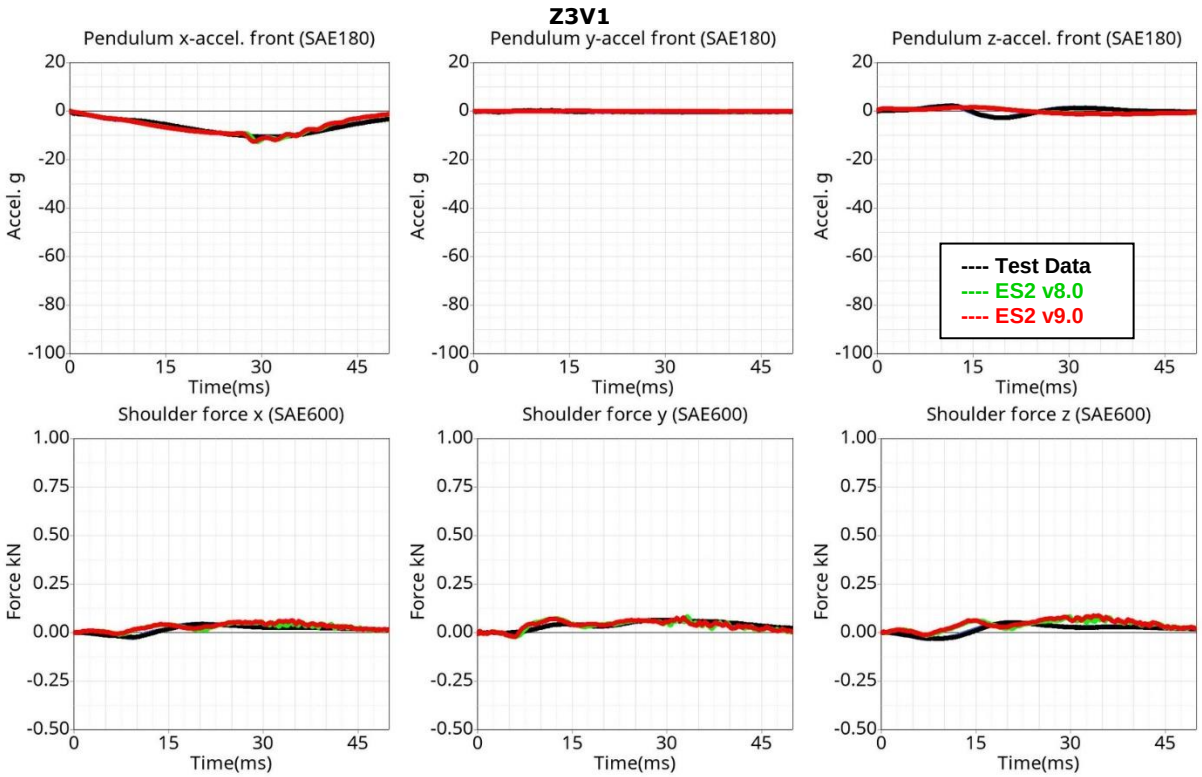
Results for mid-position impact, low velocity



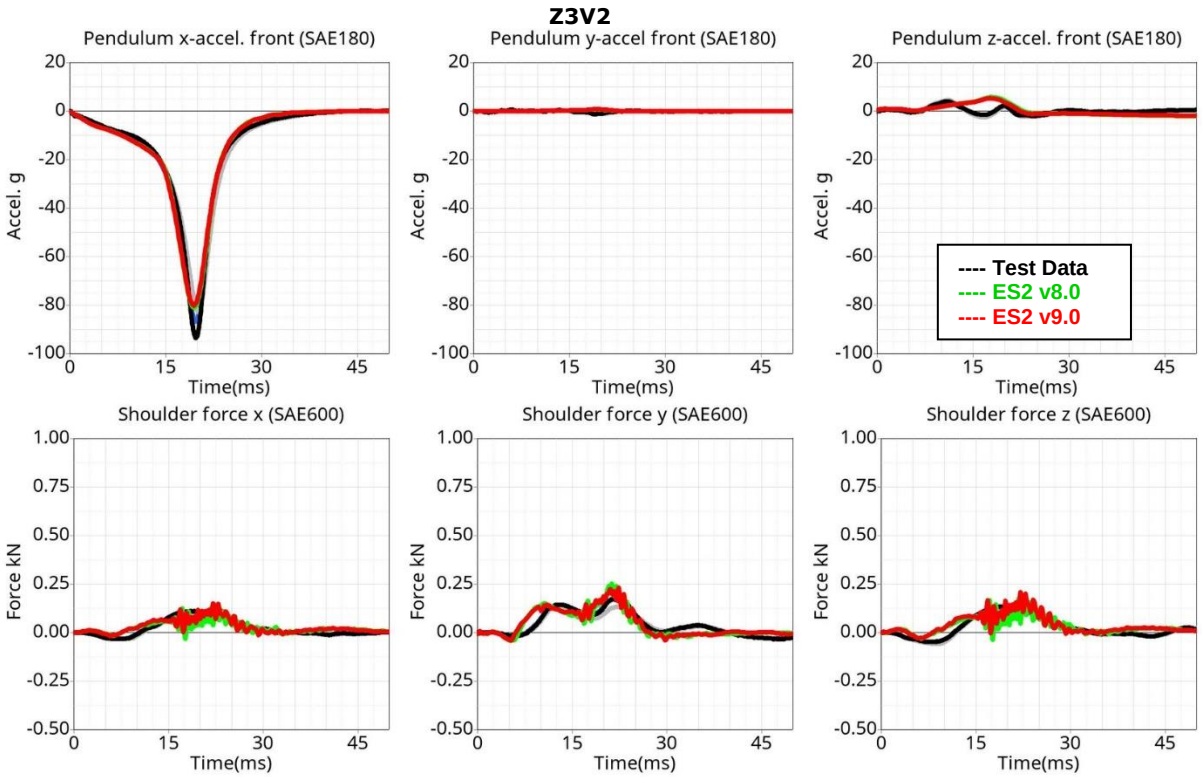
Results for mid-position impact, high velocity



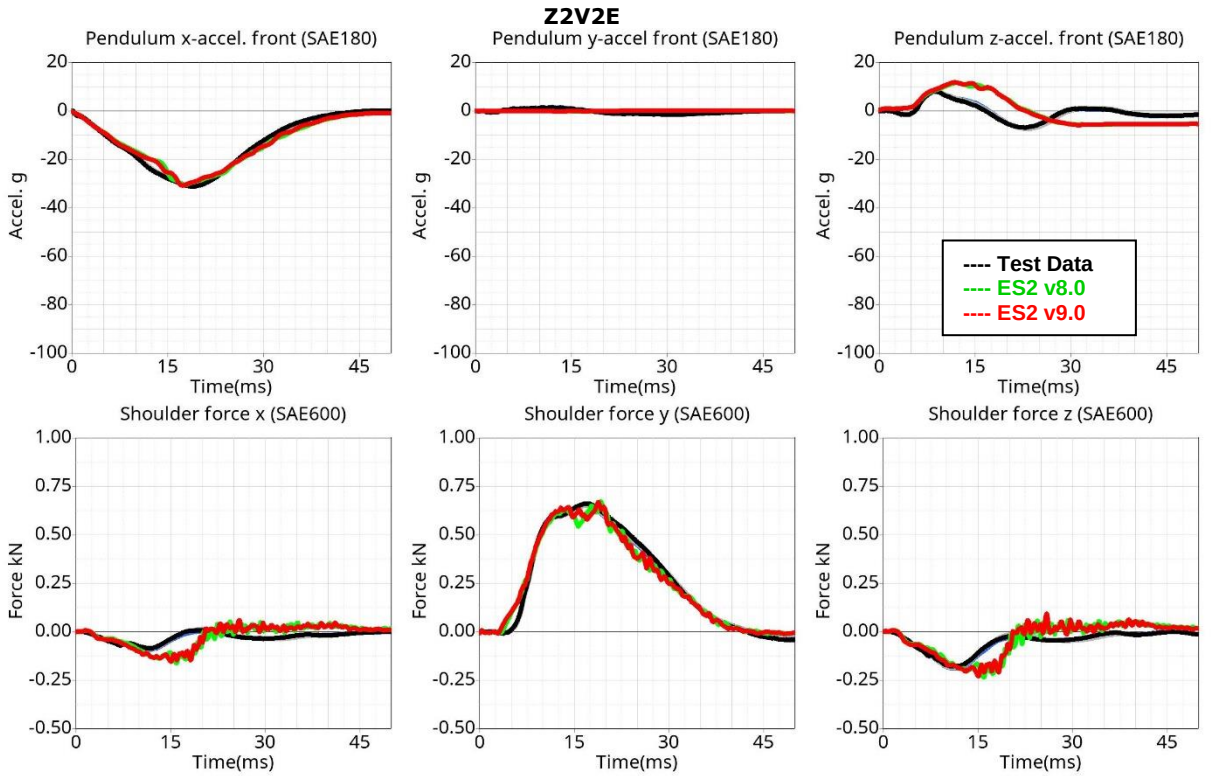
Results for bottom impact, low velocity



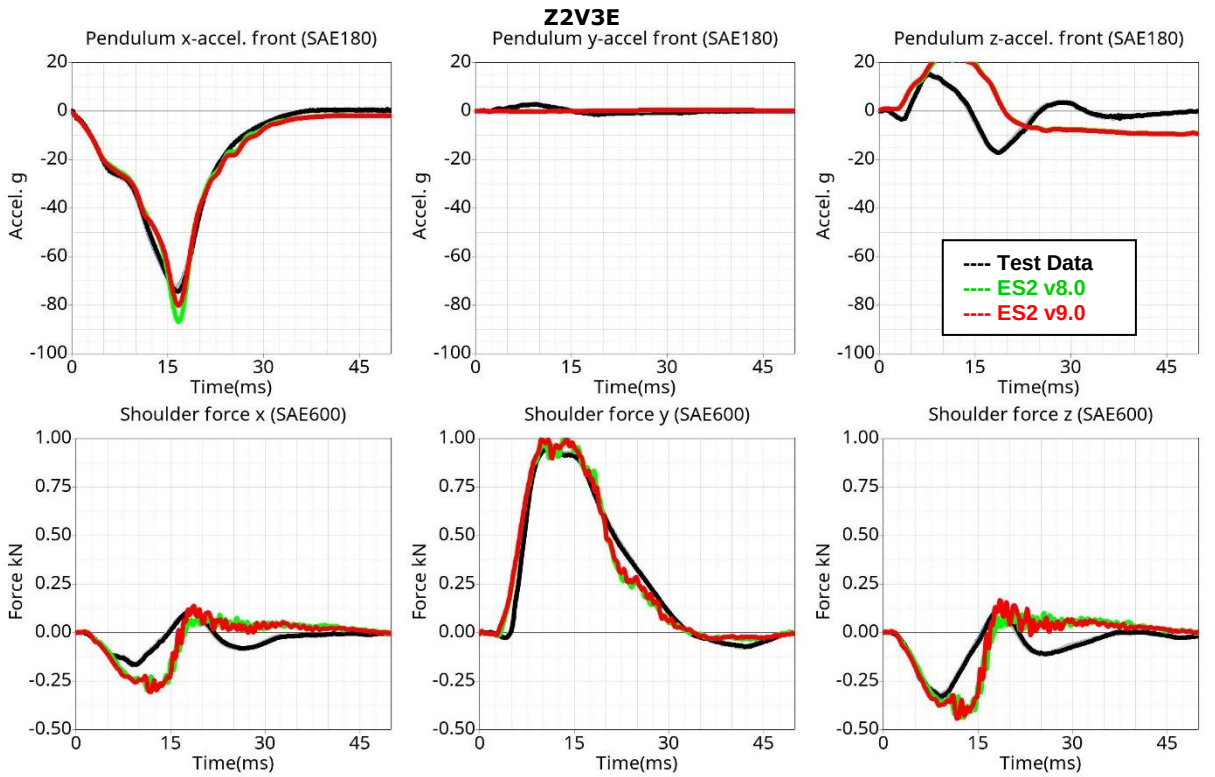
Results for bottom impact, high velocity



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



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



11.1.2 Clavicle test

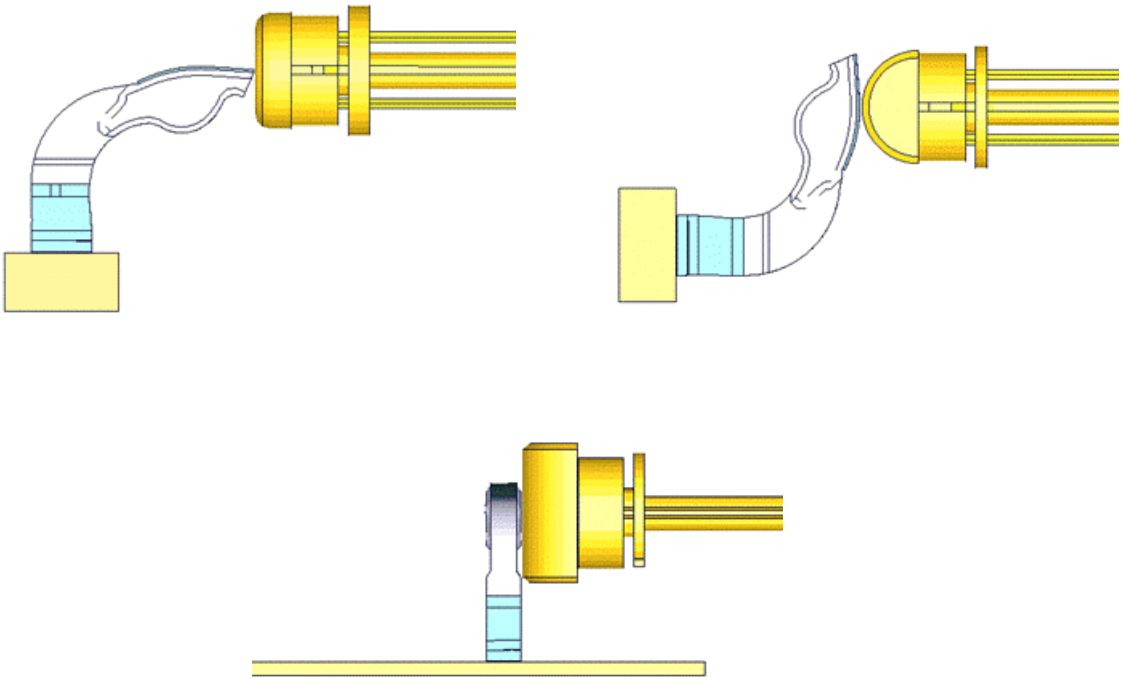
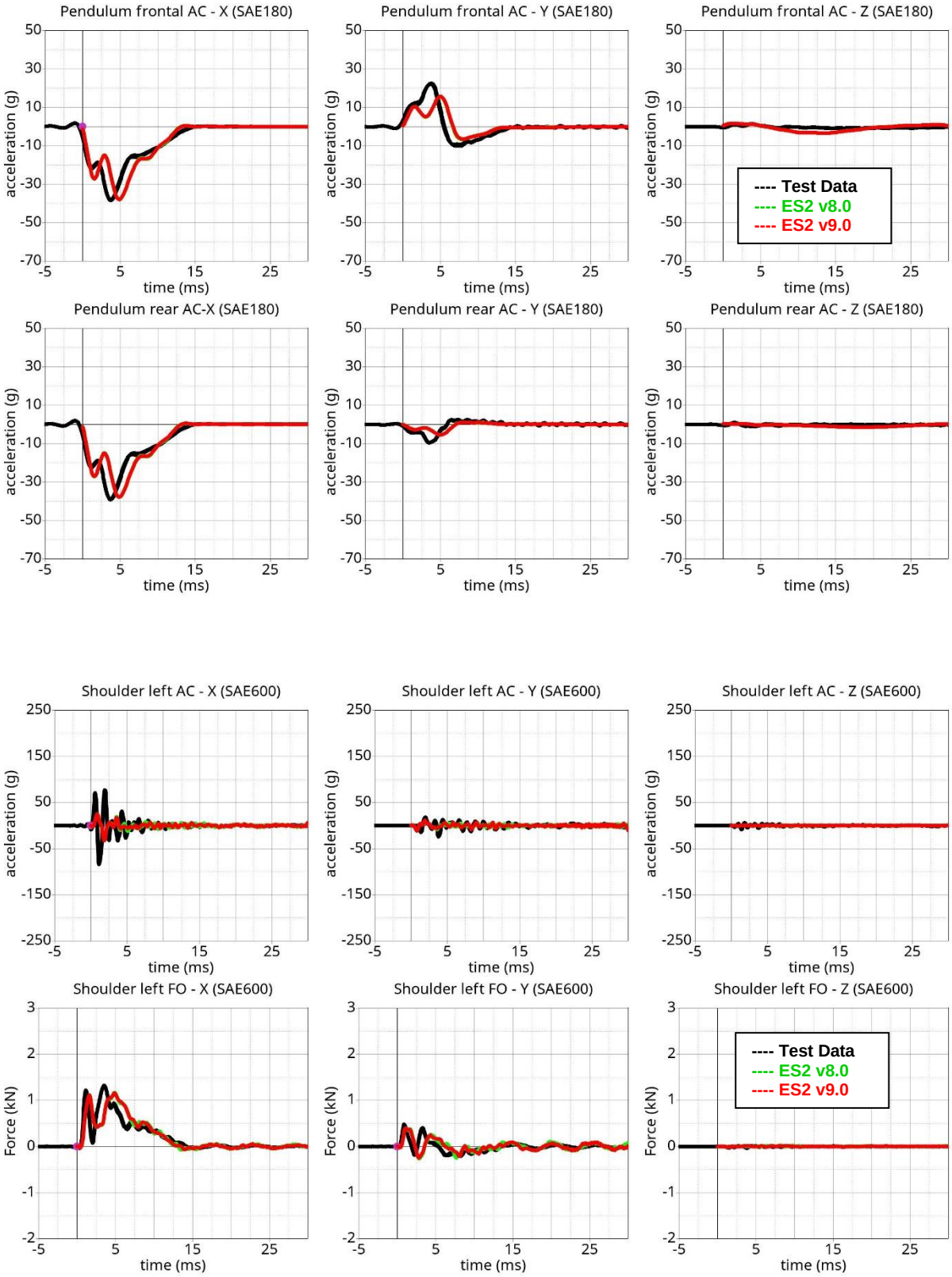


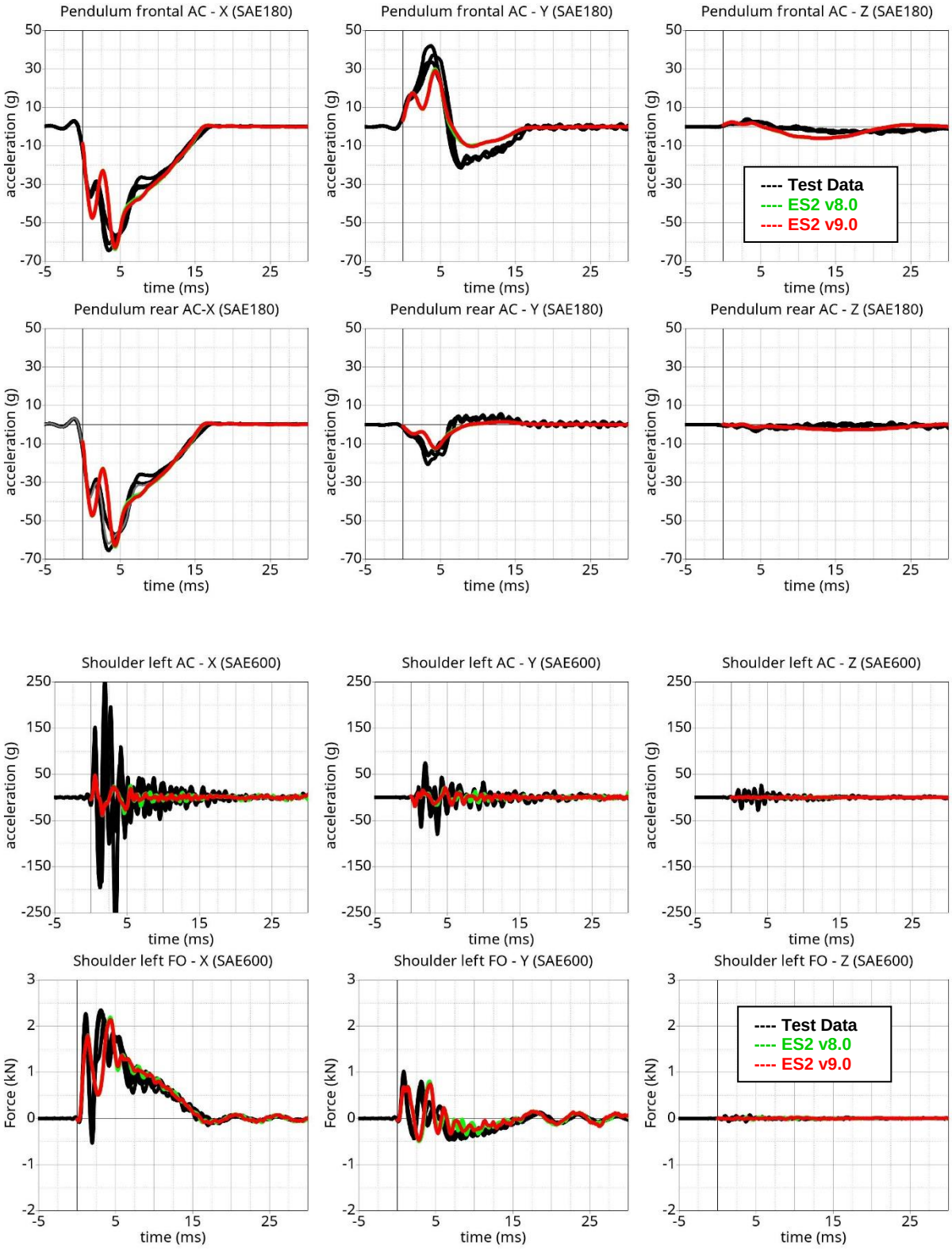
Figure 28: Clavicle test: Pendulum impact on Clavicle in x- , y- and z-direction respectively

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

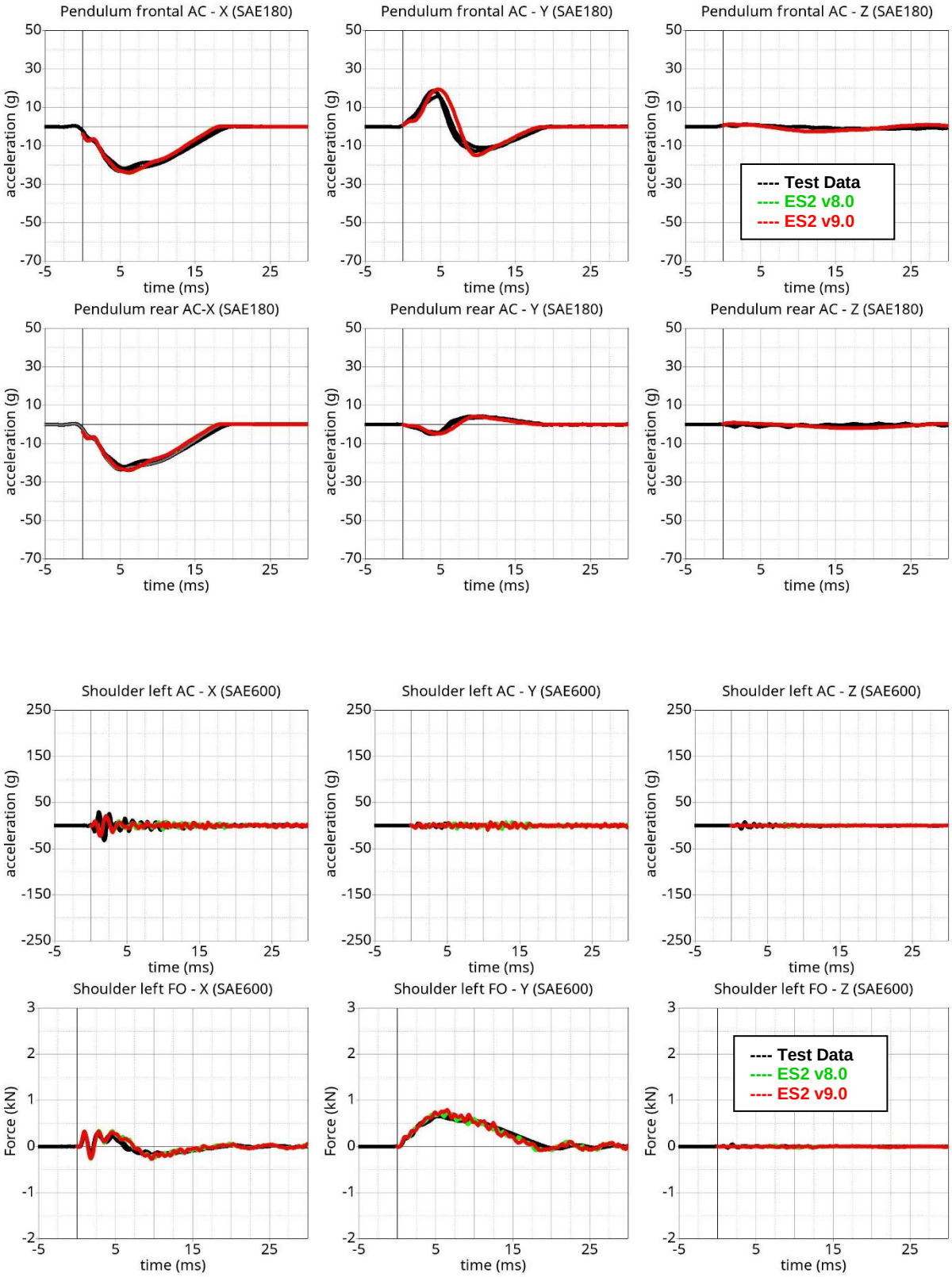
Results for X-direction impact, low velocity



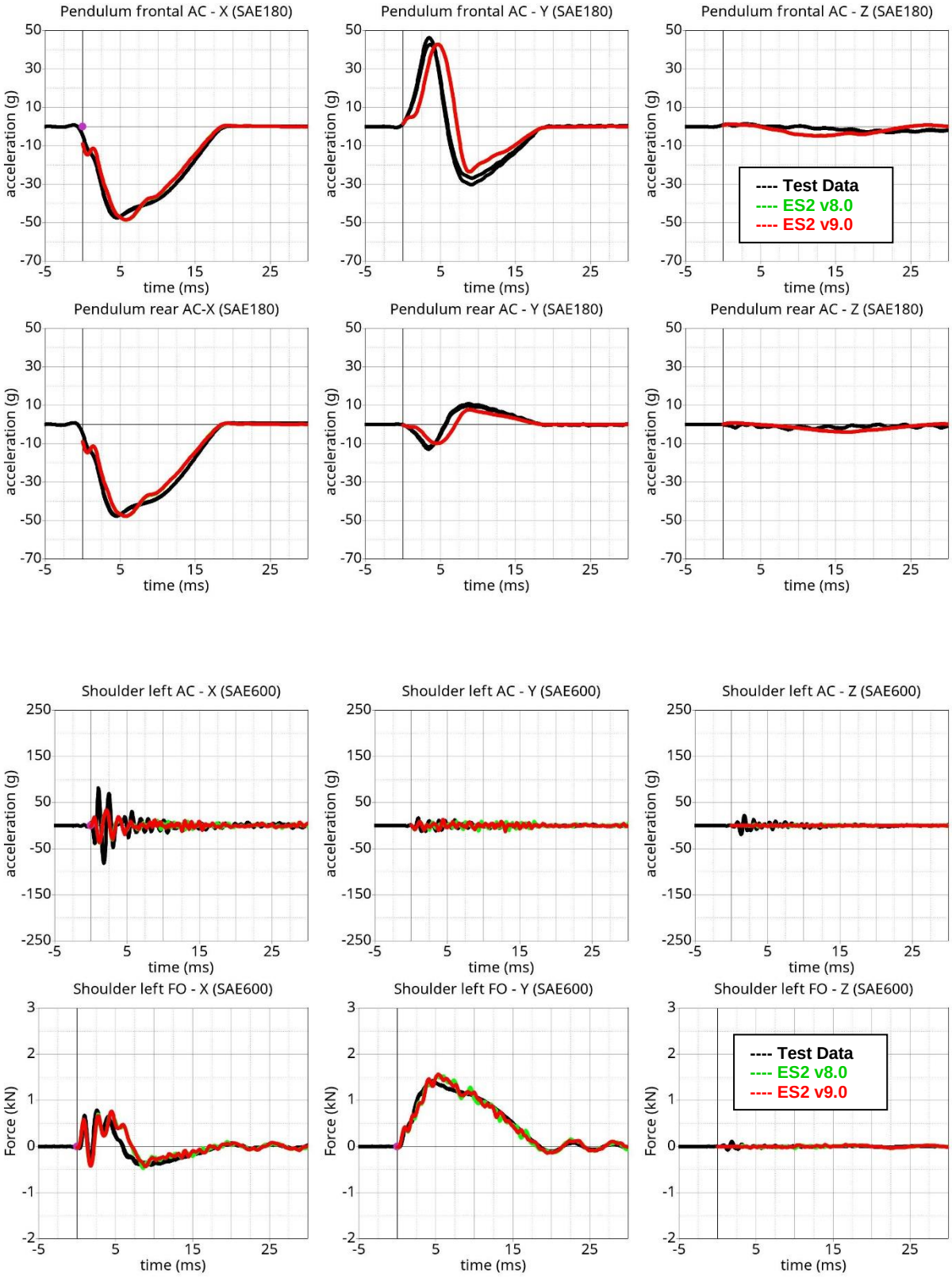
Results for X-direction impact, high velocity



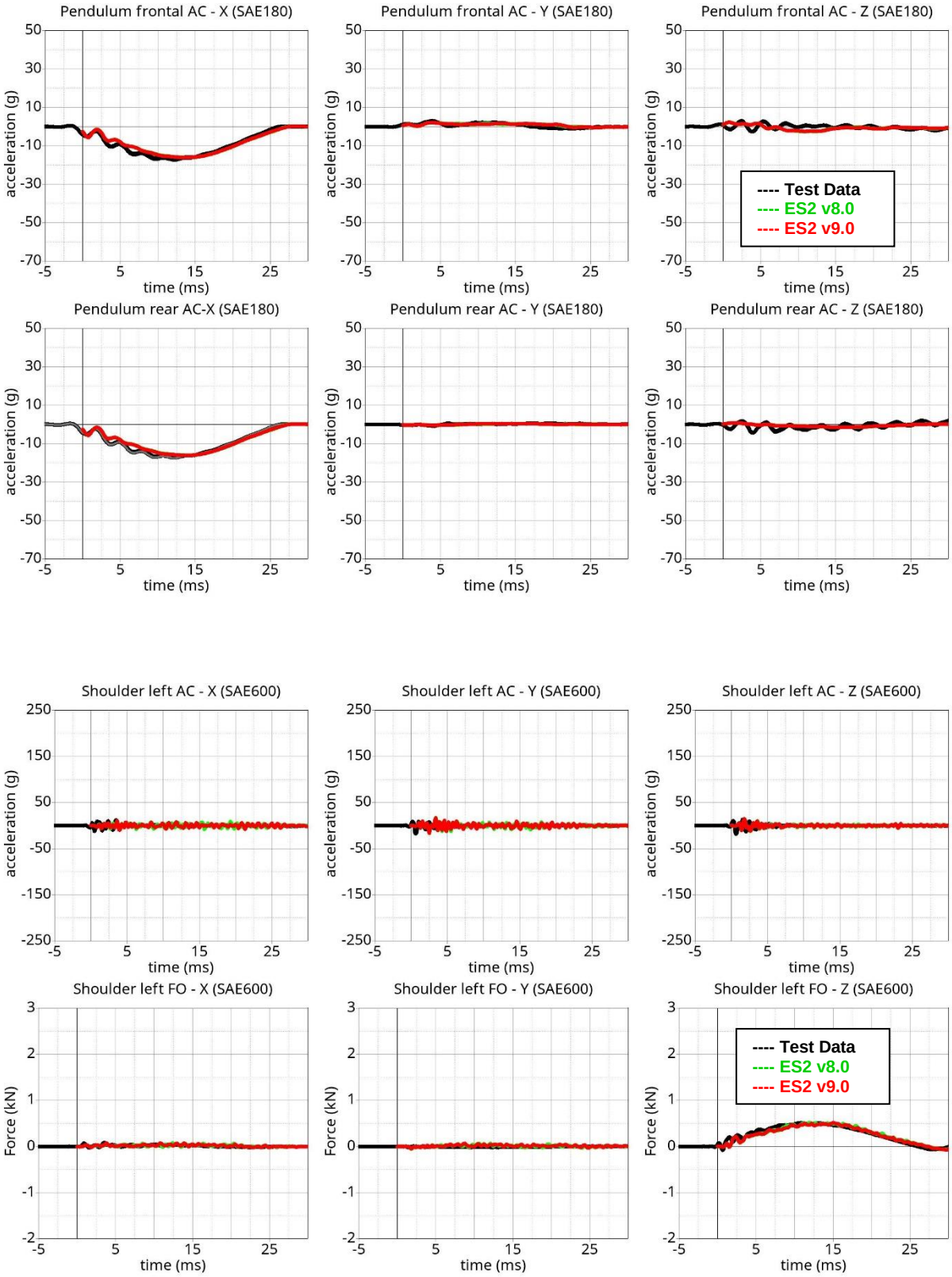
Results for Y-direction impact, low velocity



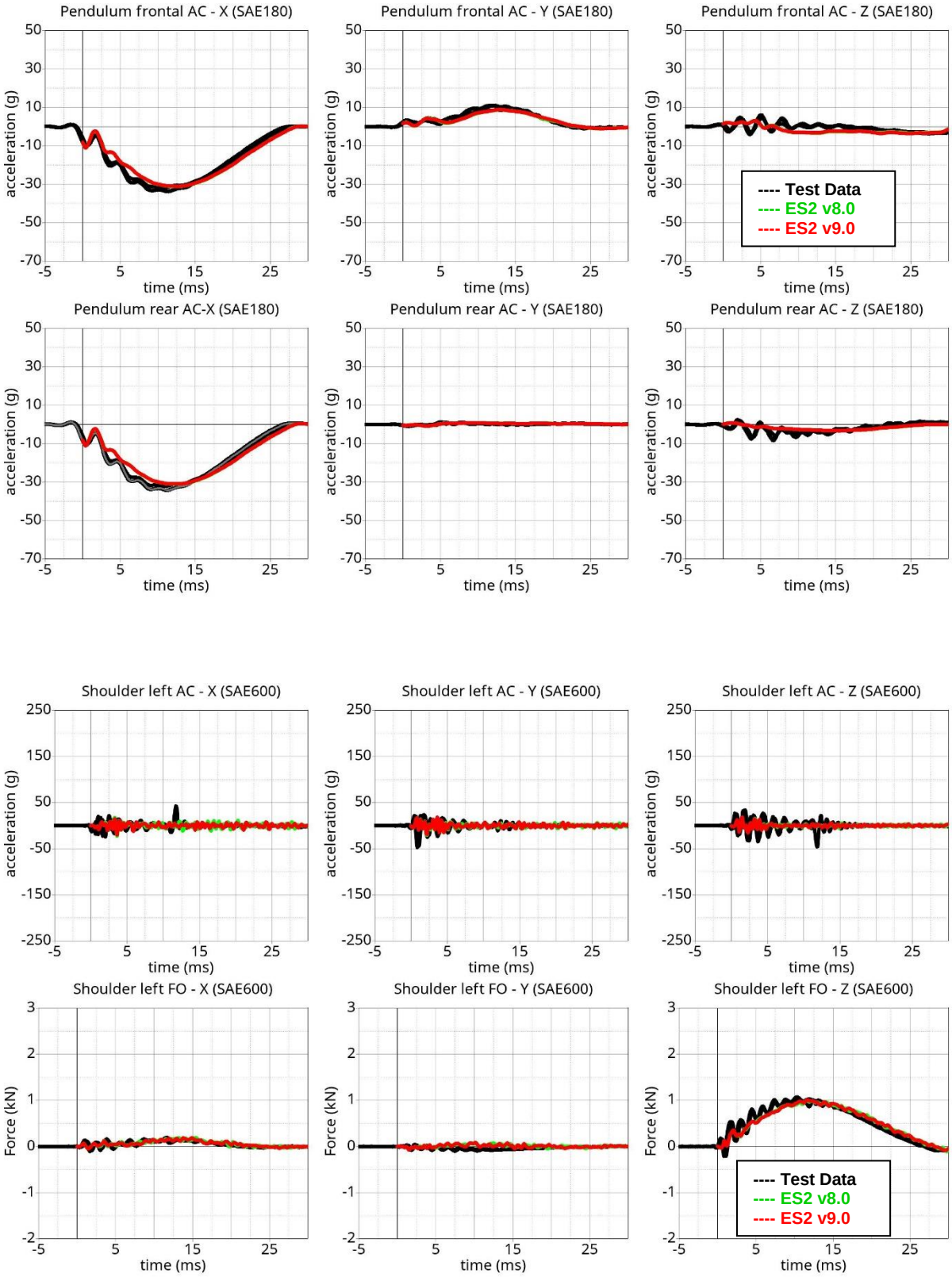
Results for Y-direction impact, high velocity



Results for Z-direction impact, low velocity



Results for Z-direction impact, high velocity



11.1.3 Clavicle Box test

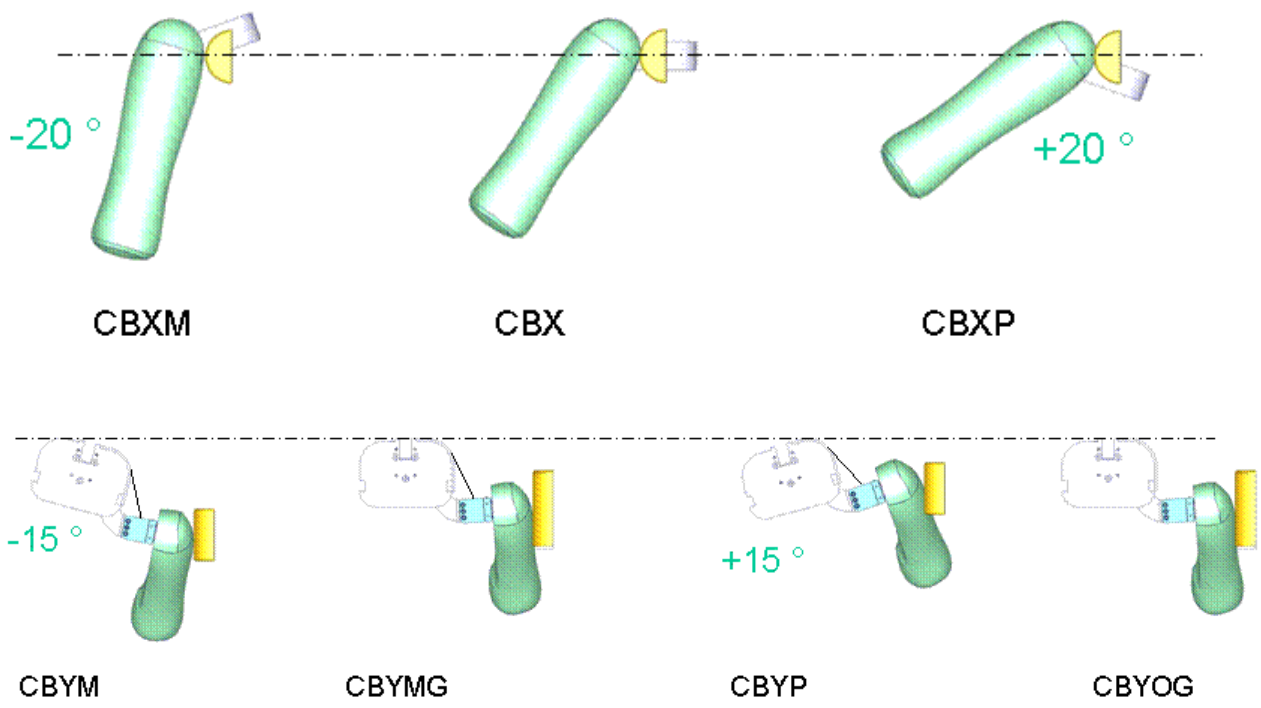
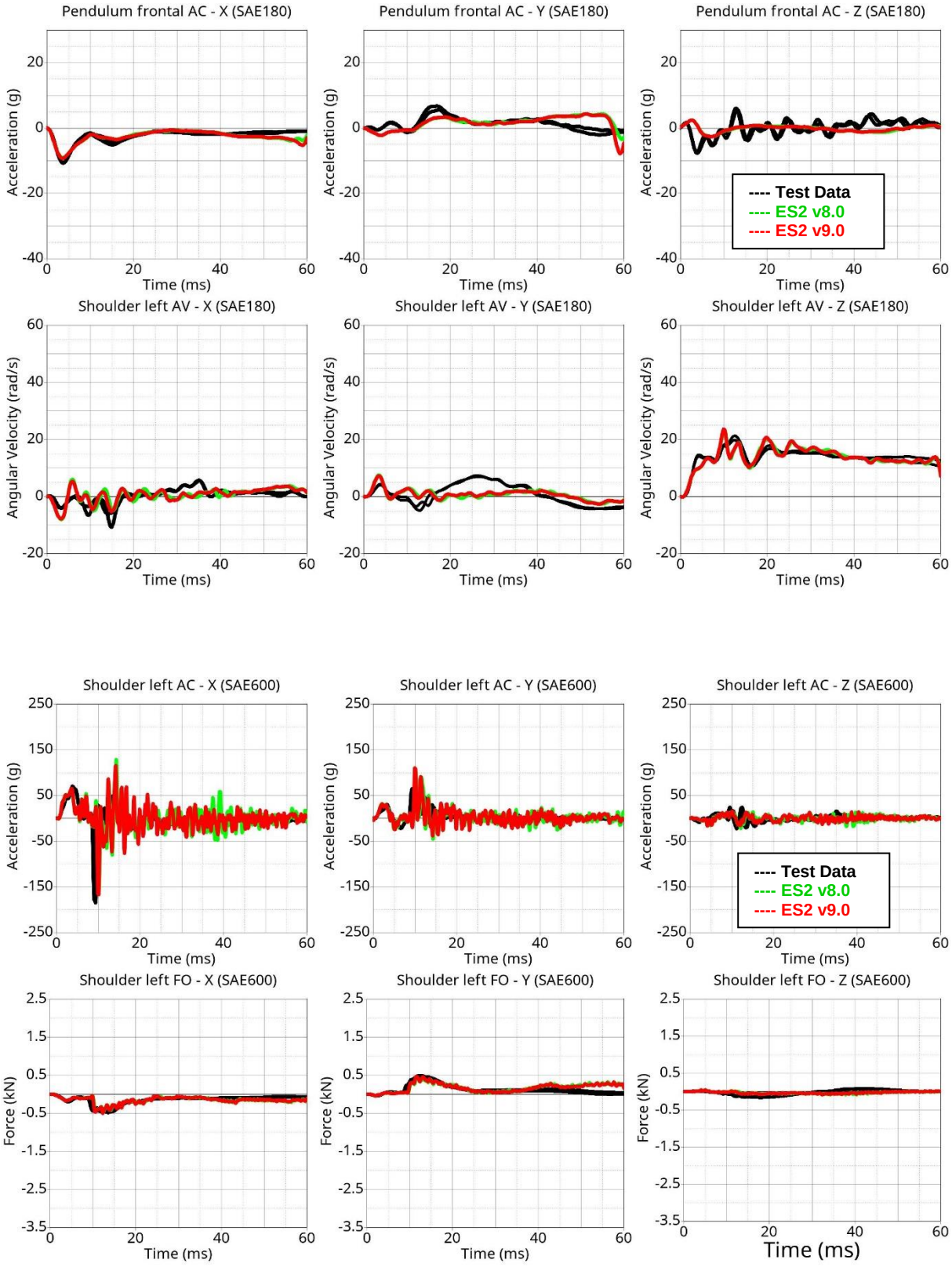
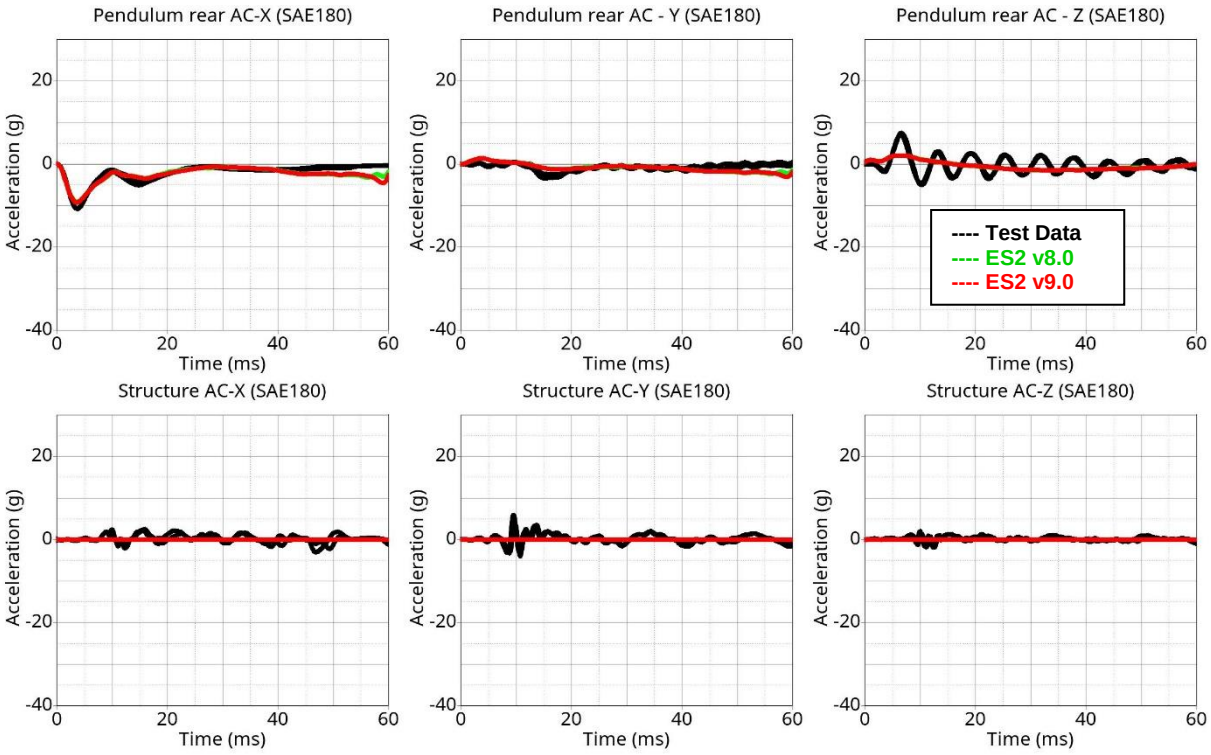


Figure 29: Test configurations for Clavicle Box test

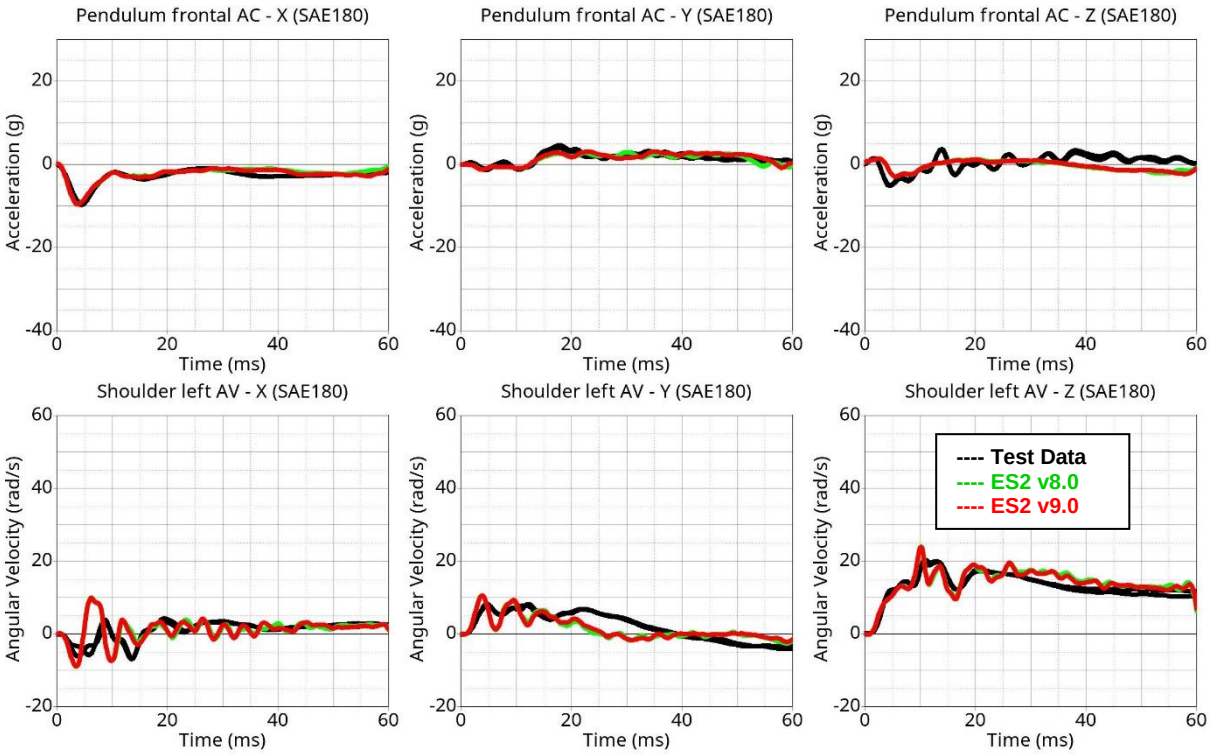
The various test configurations for the clavicle box test are shown in the figure above. The pendulum impacts the arm and clavicle box assembly in x- and y-directions. For the impact in y-direction, tests are carried out with low and high velocities of the pendulum. An additional set of tests is carried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

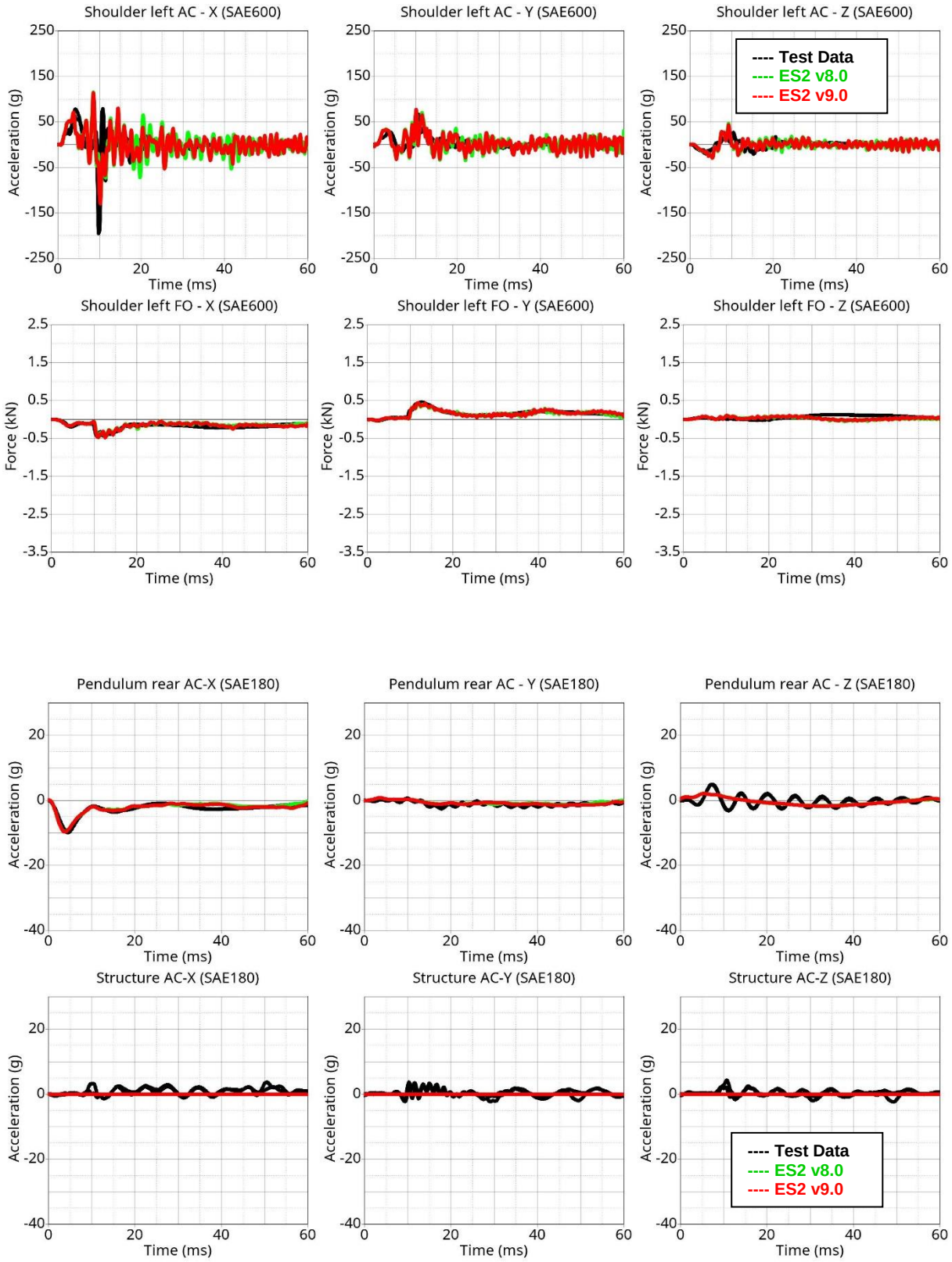
Results for X-direction impact, low velocity (CBX)



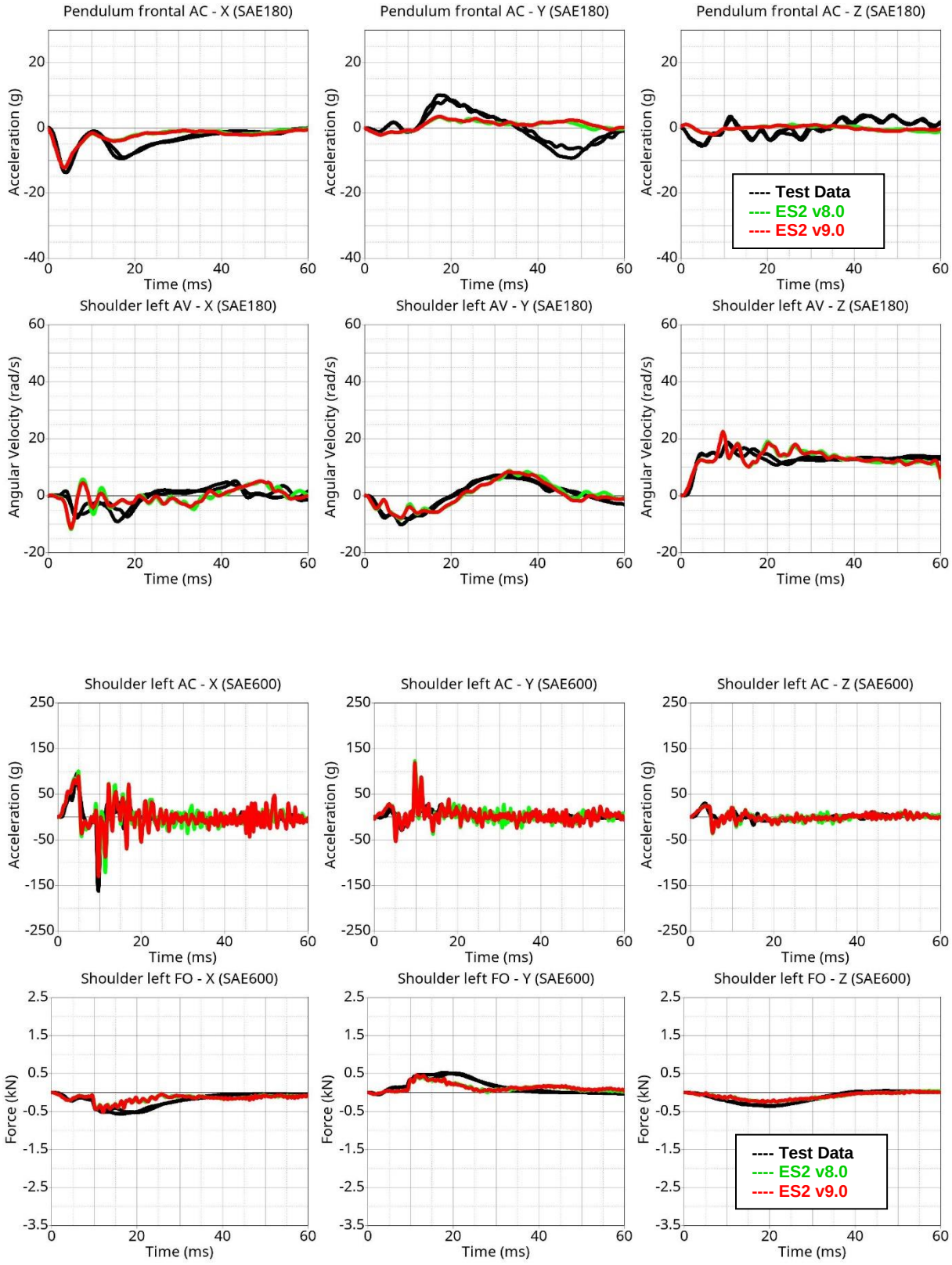


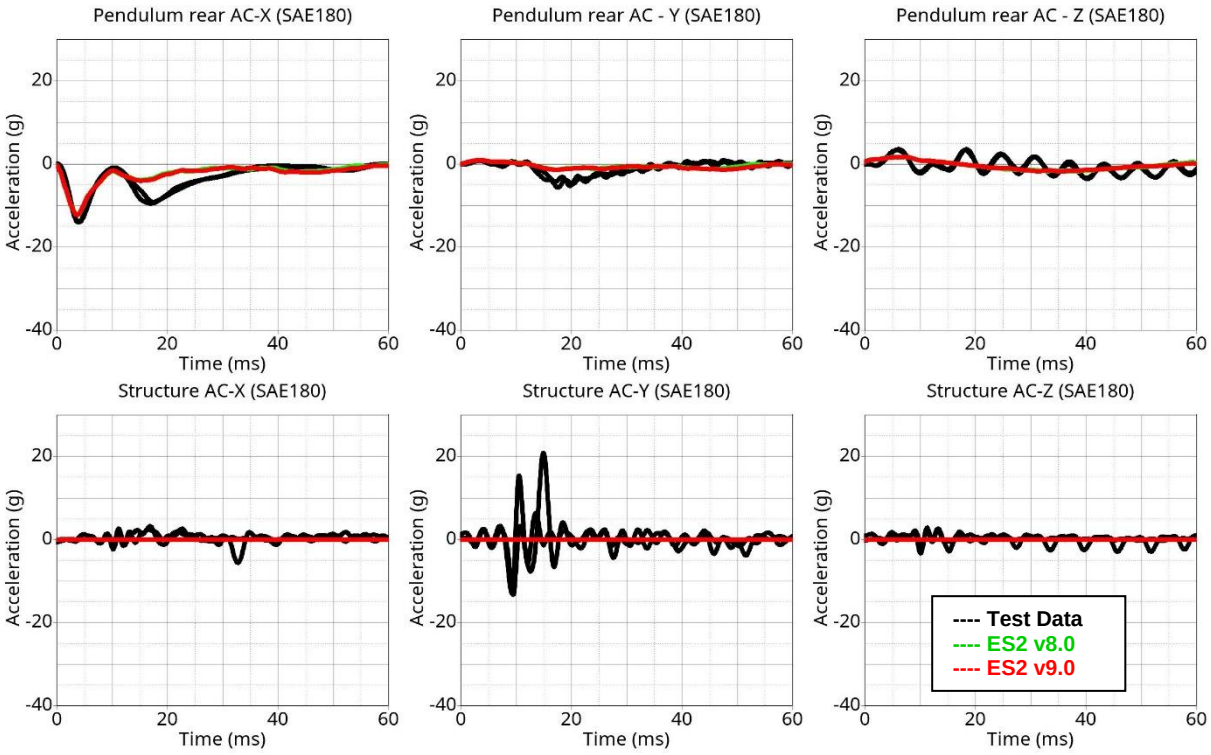
Results for X-direction impact, low velocity (CBXM)



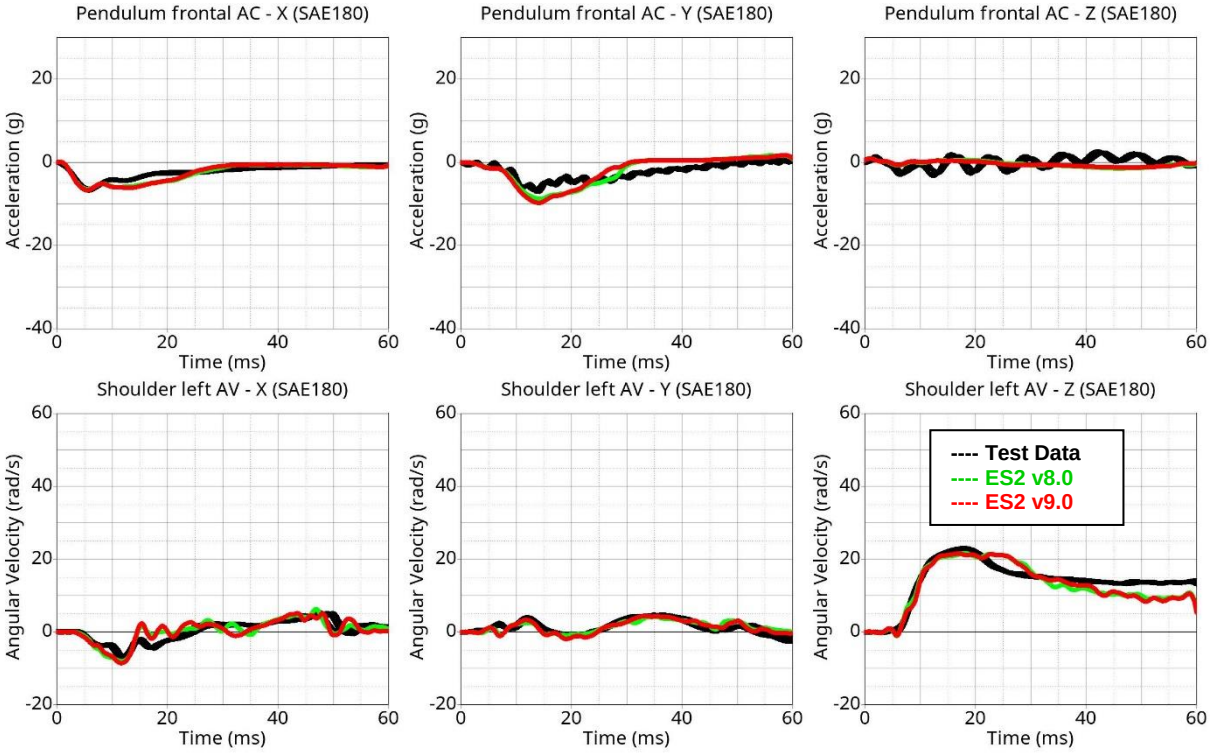

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
Acceleration (g)
Time (ms)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Force (kN)
Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)

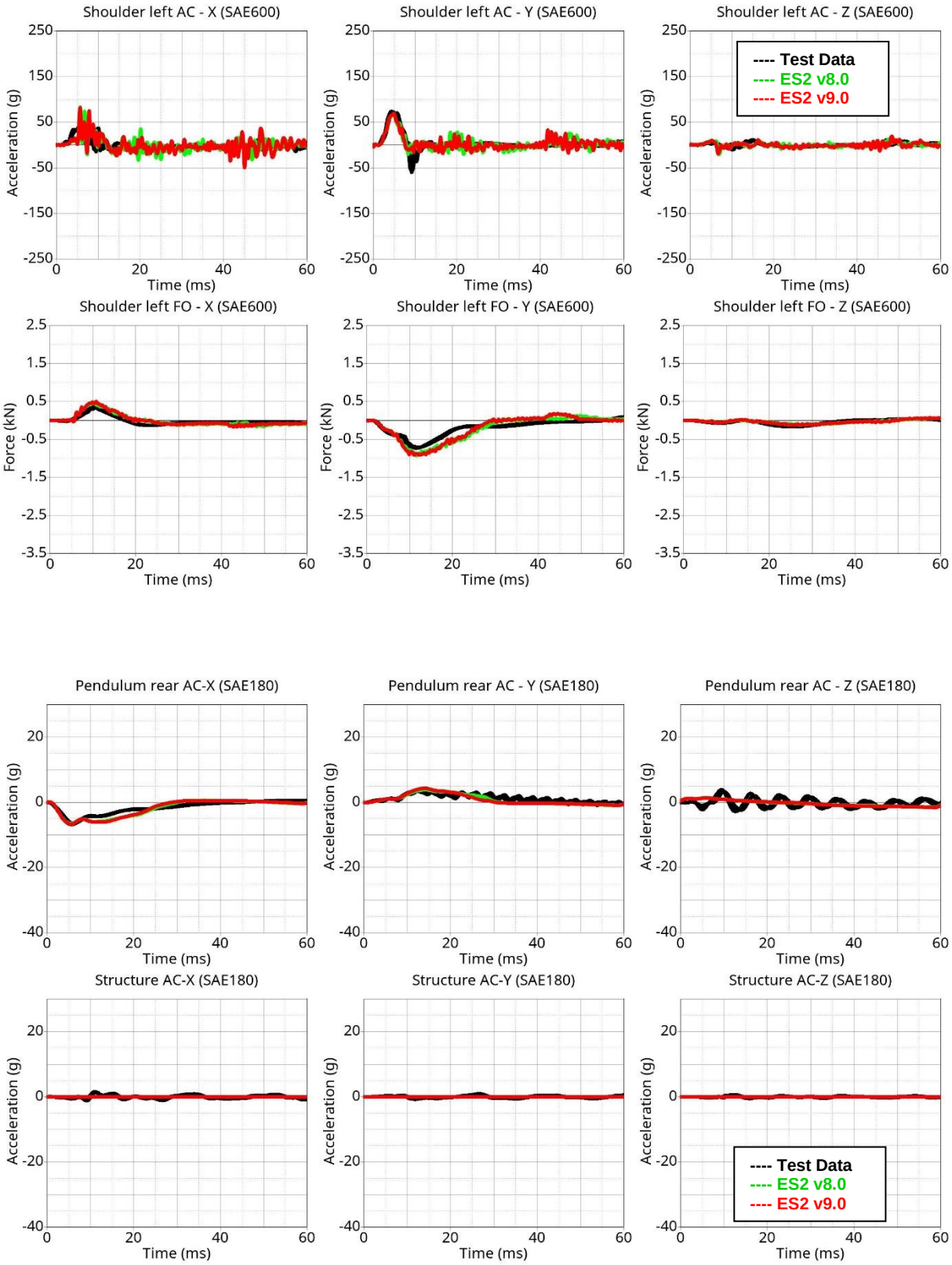
Results for X-direction impact, low velocity (CBXP)



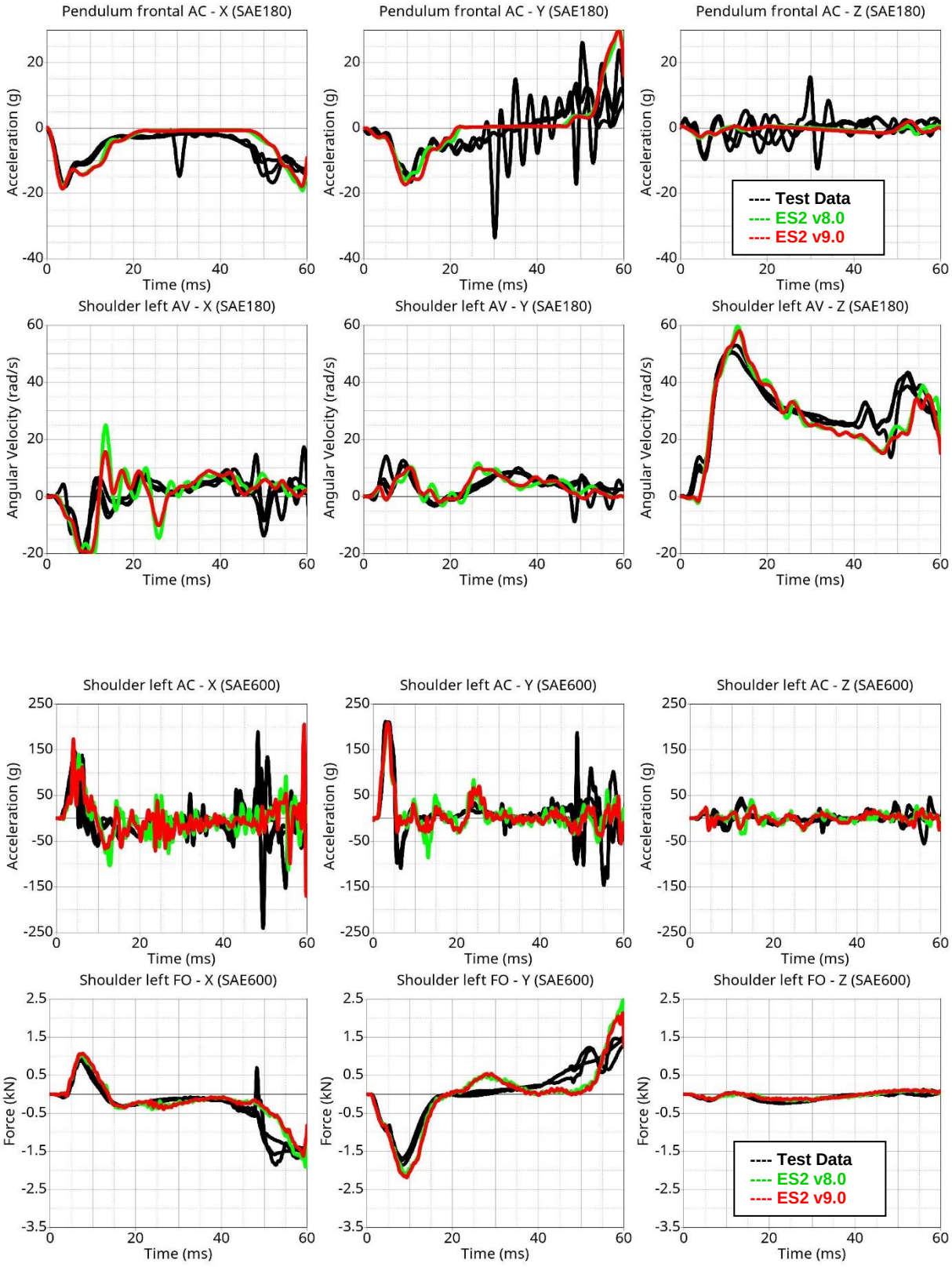


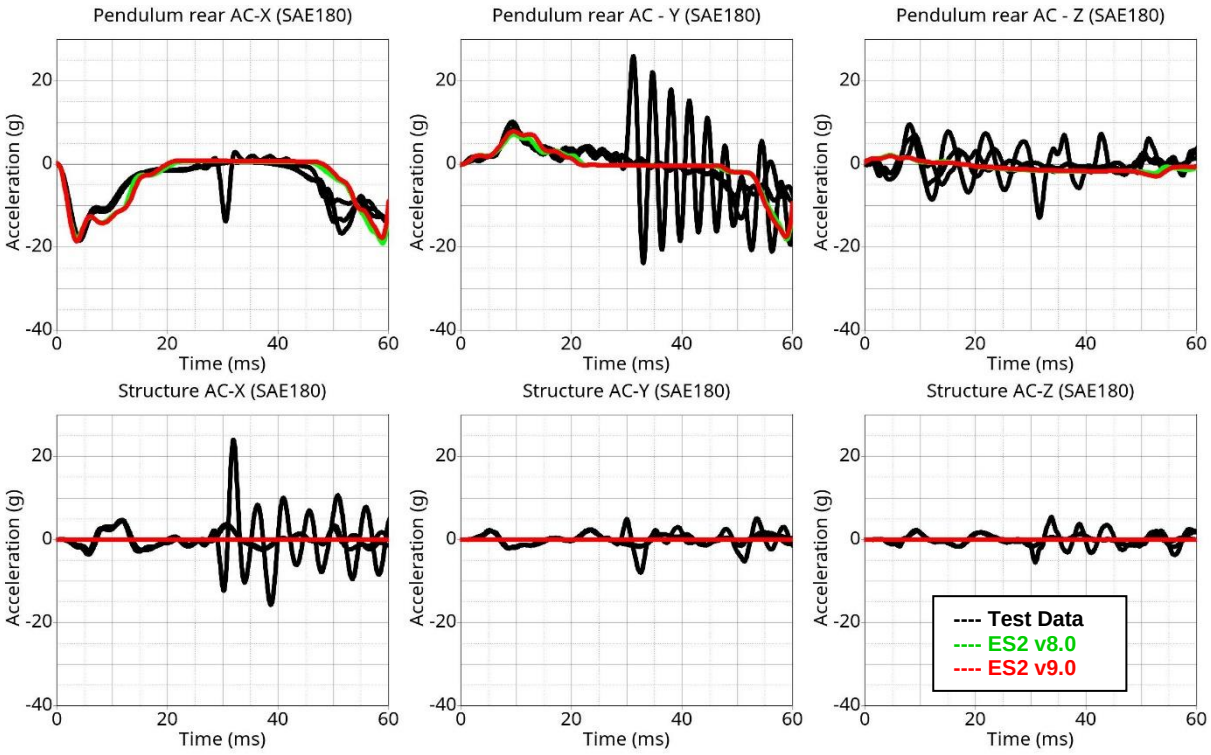
Results for Y-direction impact, low velocity (CBYM3)



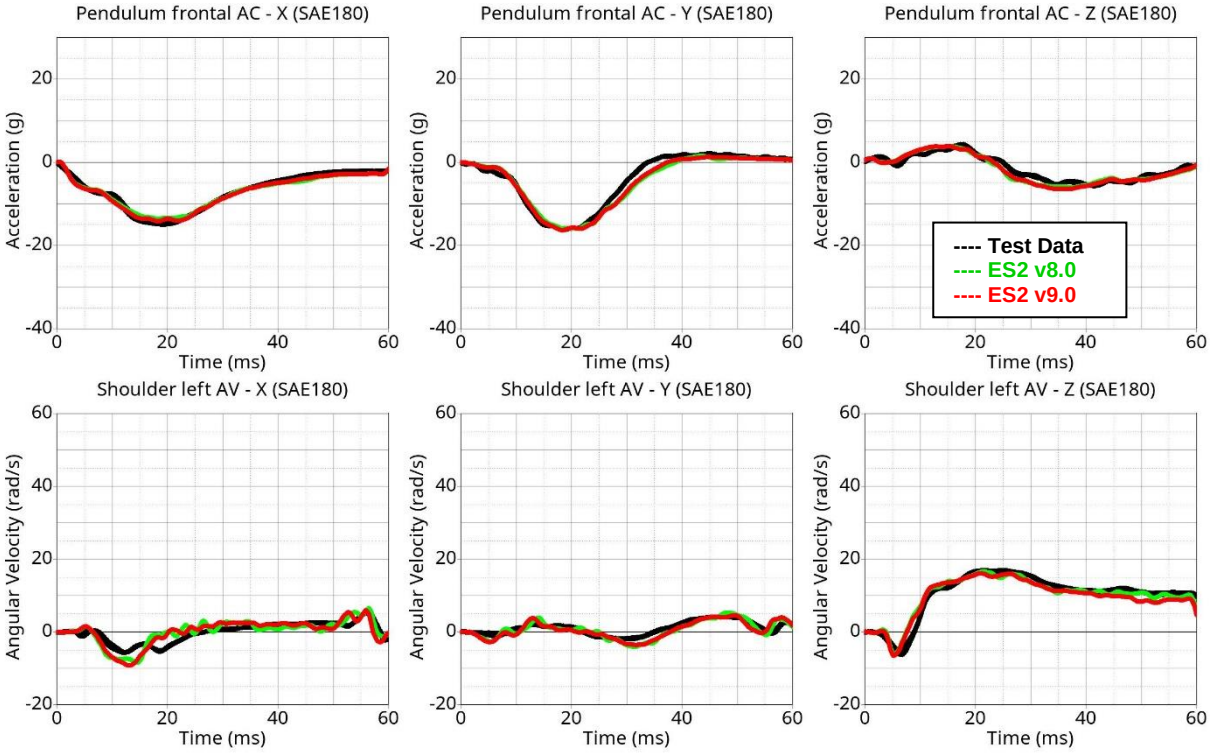

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
Acceleration (g)
Time (ms)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Force (kN)
Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)

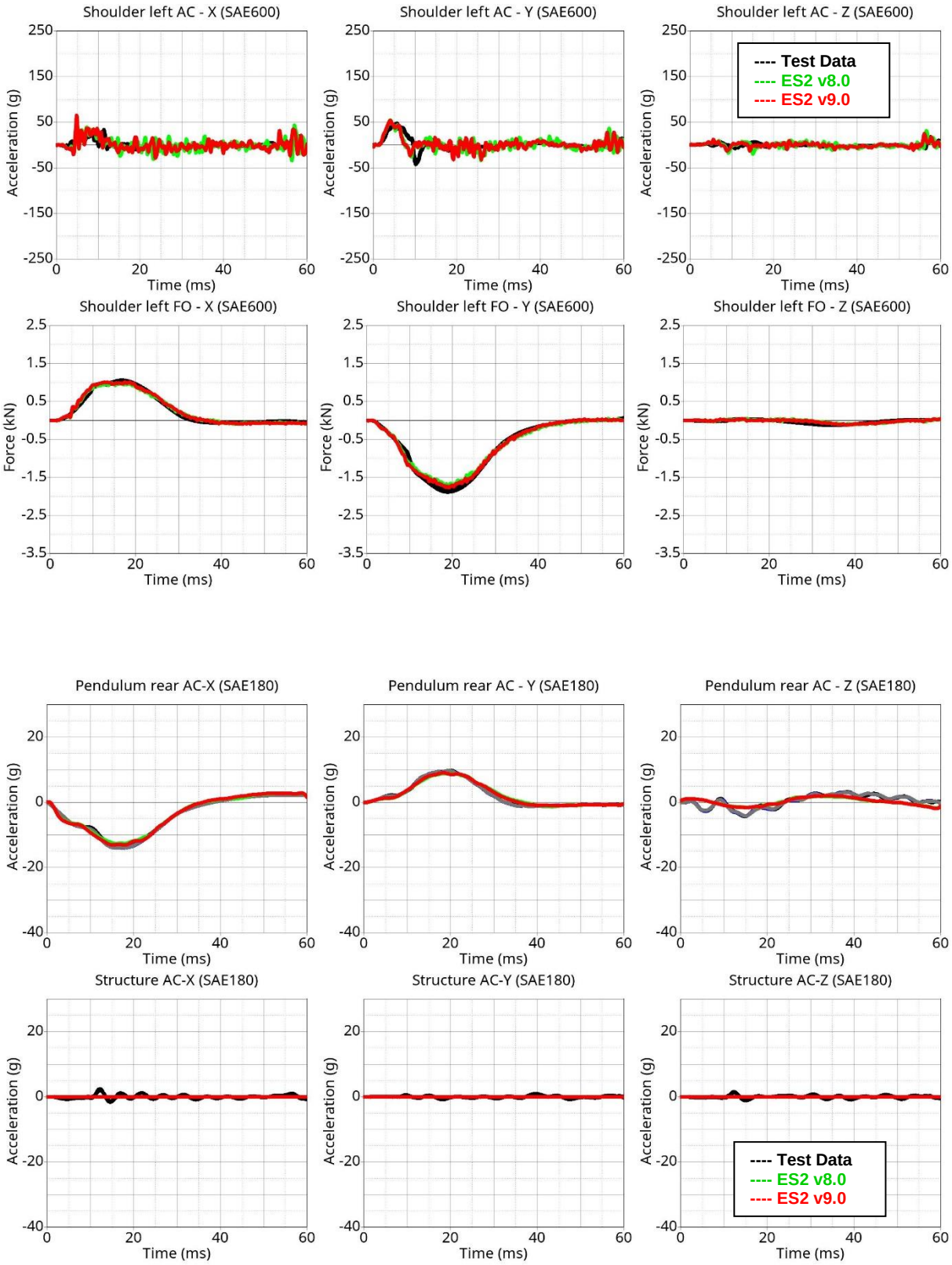
Results for Y-direction impact, high velocity (CBYM6)



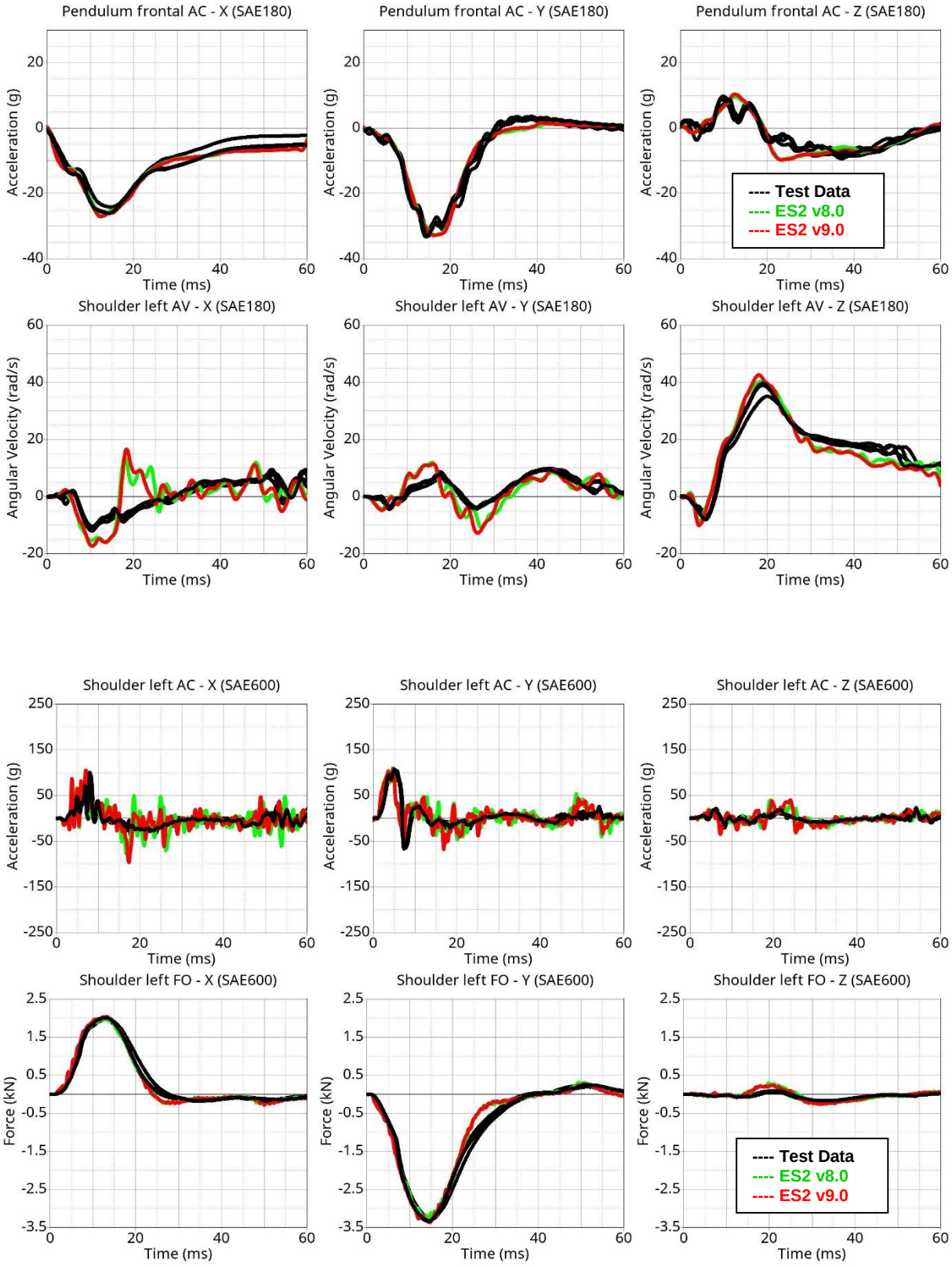


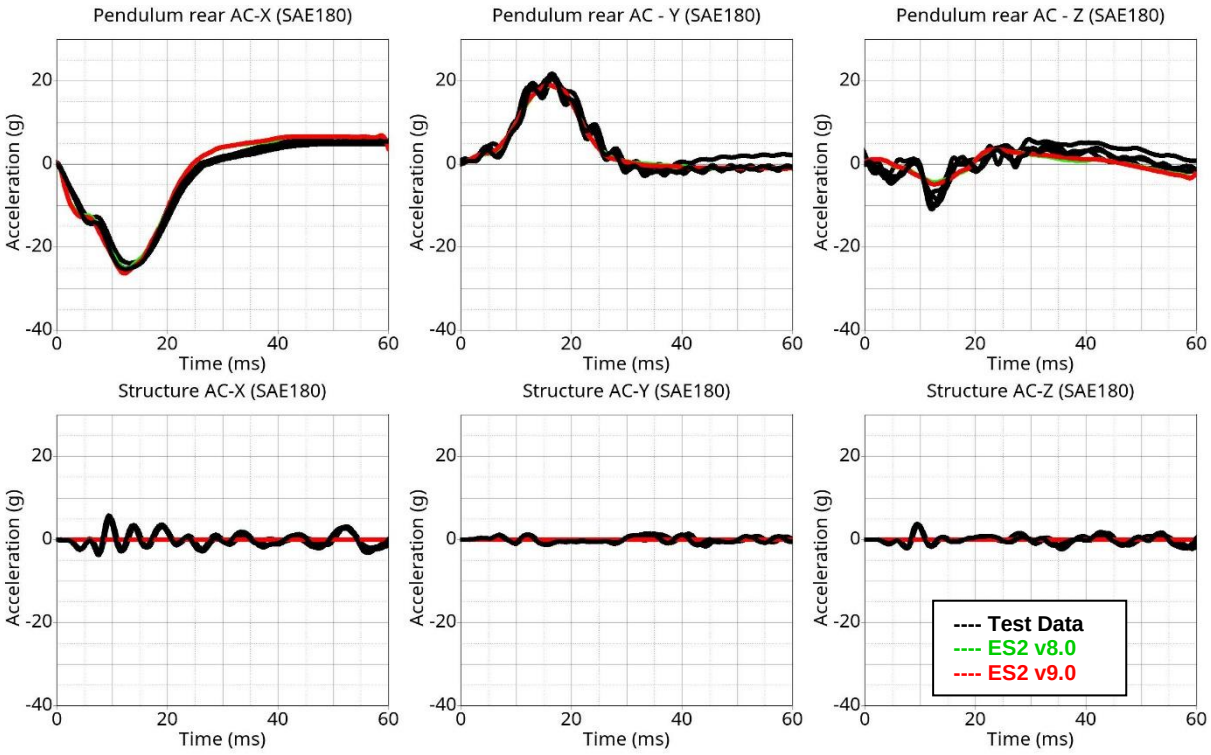
Results for Y-direction impact, low velocity (CBYP3)



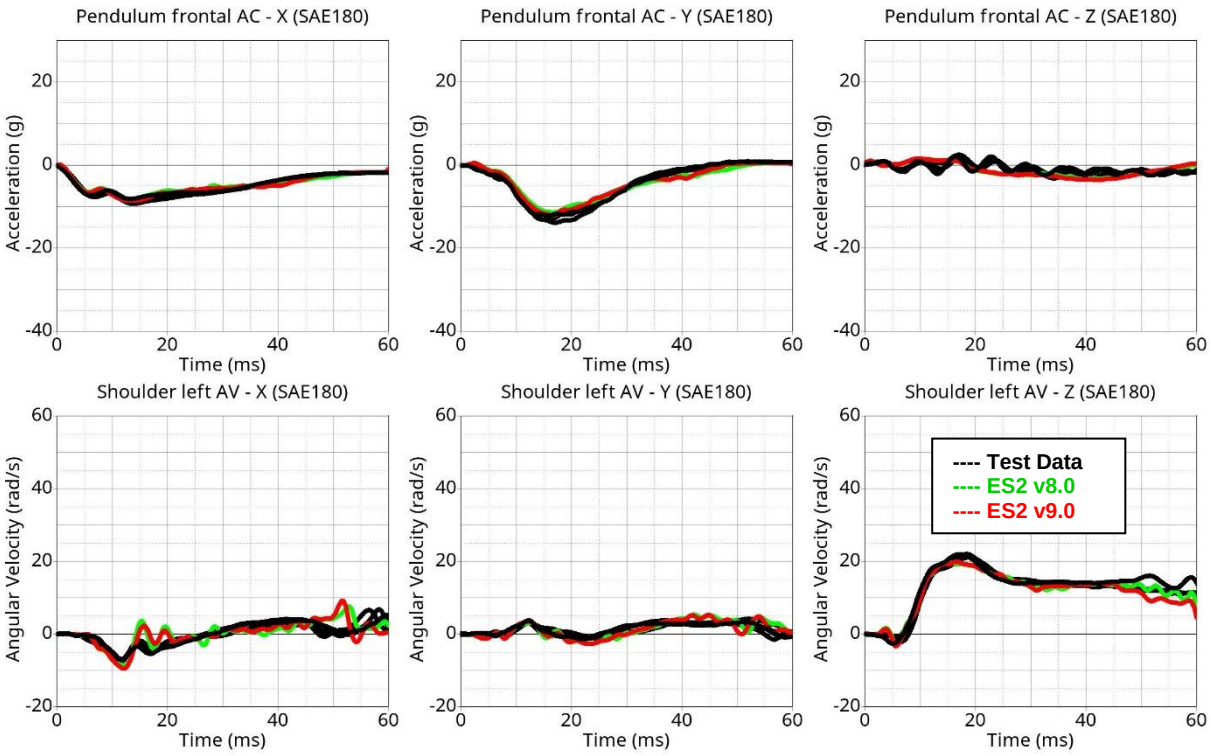

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
Acceleration (g)
Time (ms)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Force (kN)
Time (ms)
Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)

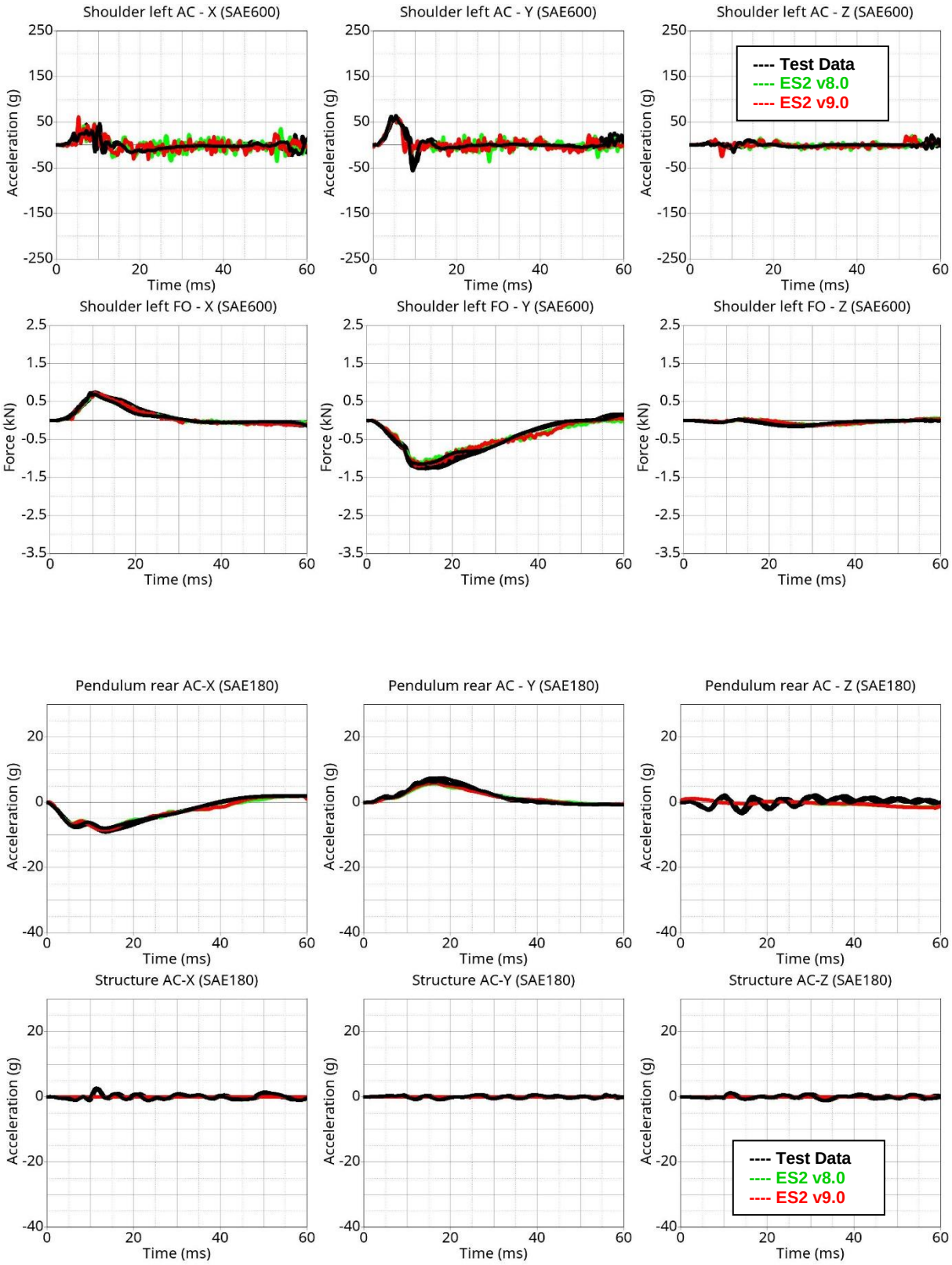
Results for Y-direction impact, high velocity (CBYP5)



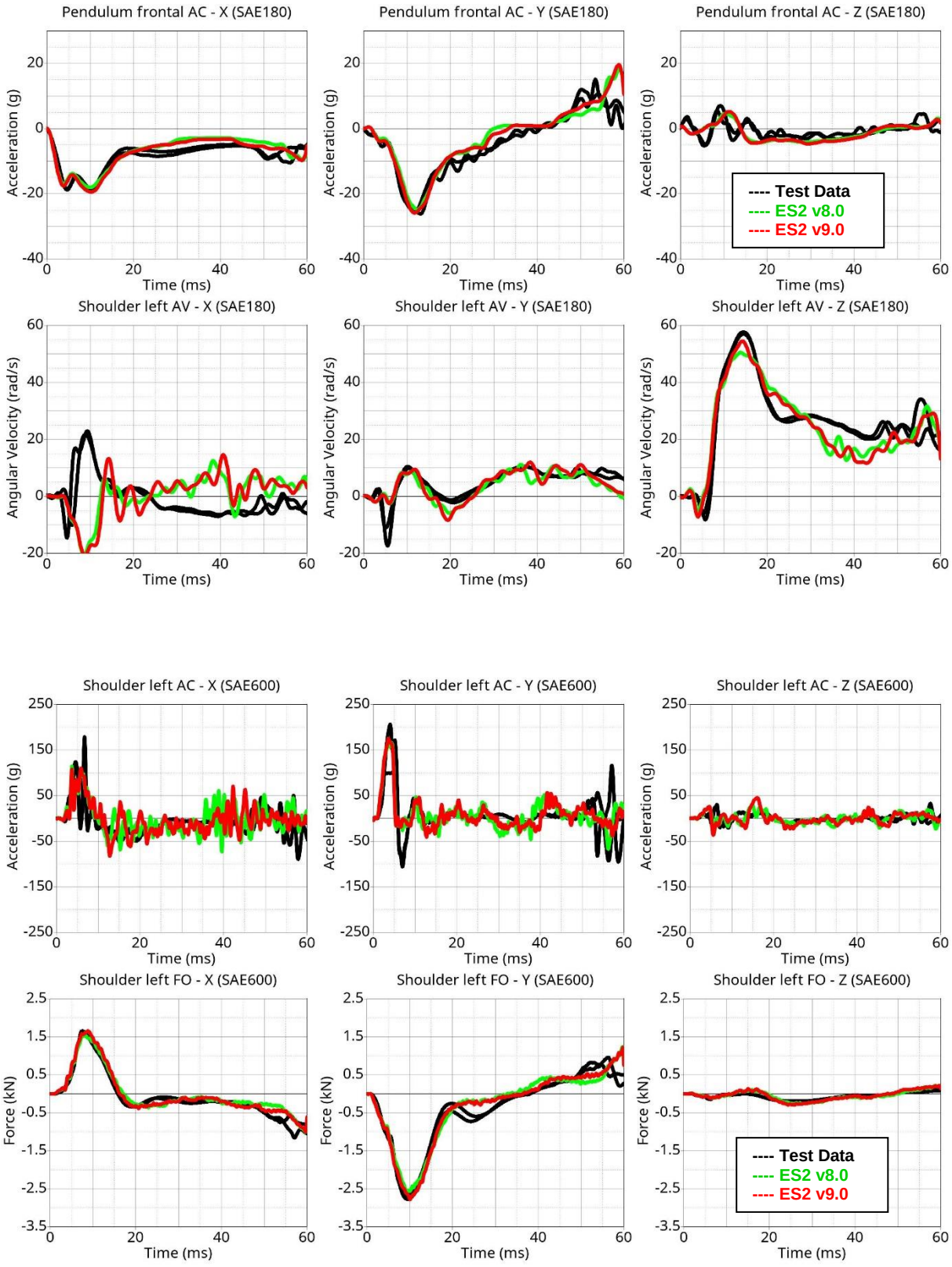


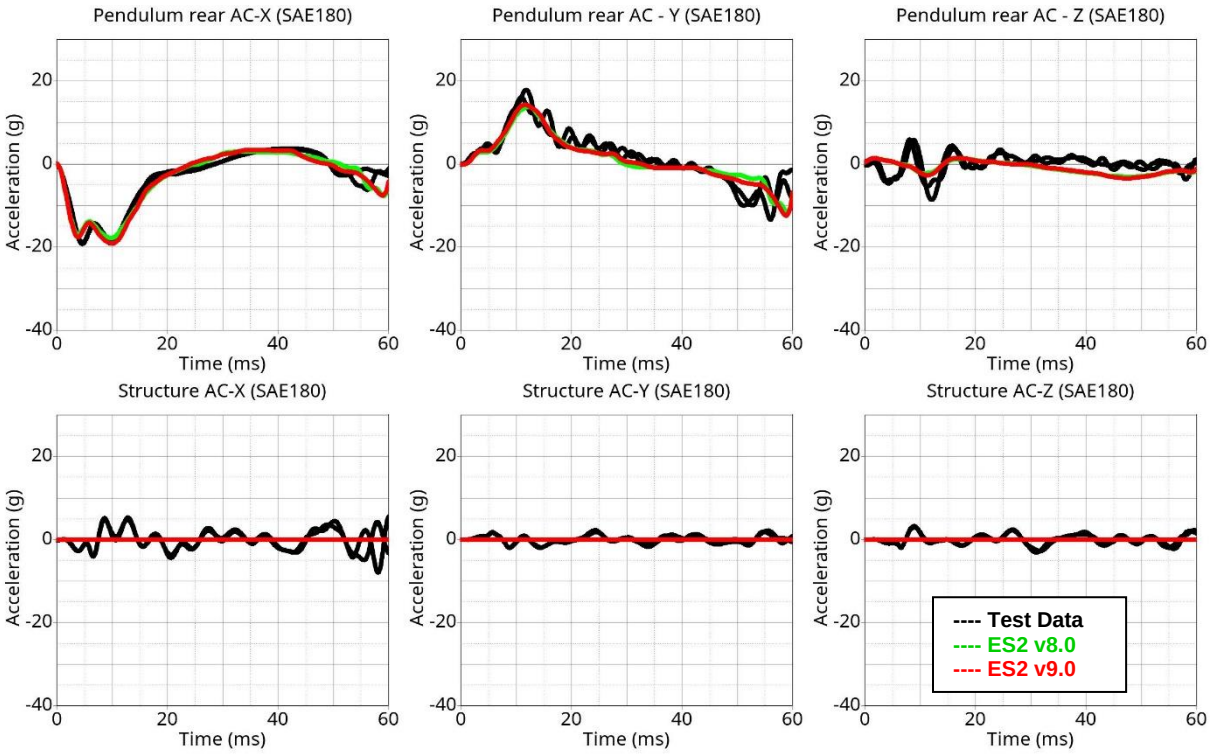
Results for Y-direction impact, low velocity, with clavicle strap (CBYMG3)



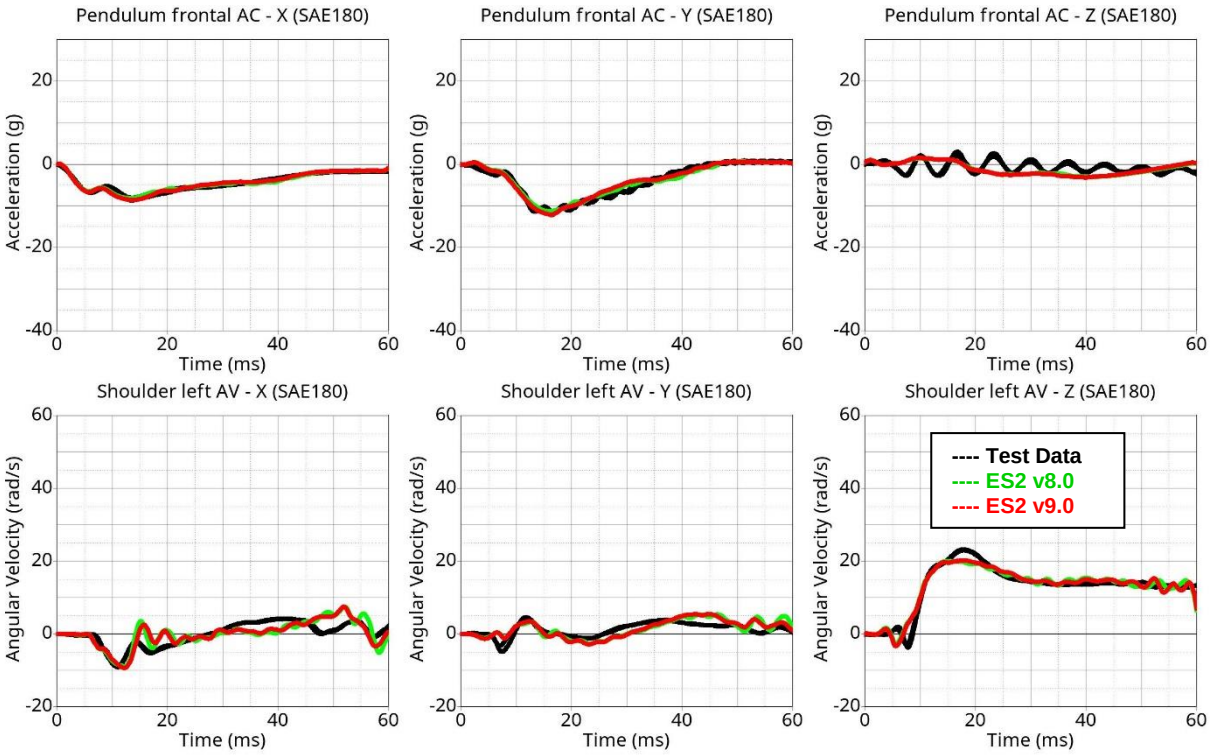

Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
Acceleration (g)
Time (ms)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Force (kN)
Time (ms)
Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)

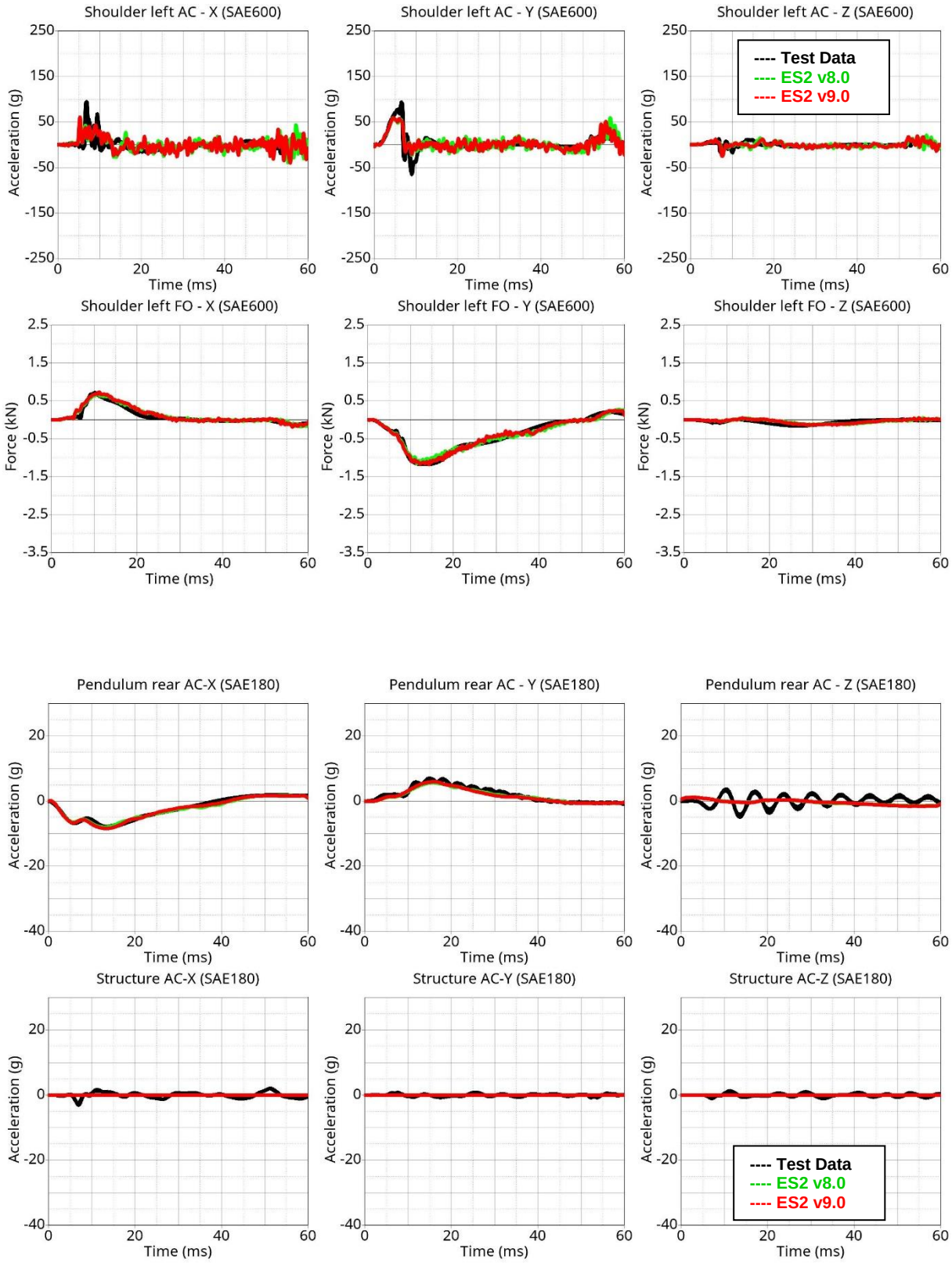
Results for Y-direction impact, high velocity, with clavicle strap (CBYMG6)





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




Shoulder left AC - X (SAE600)
Shoulder left AC - Y (SAE600)
Shoulder left AC - Z (SAE600)
Acceleration (g)
Time (ms)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
Shoulder left FO - X (SAE600)
Shoulder left FO - Y (SAE600)
Shoulder left FO - Z (SAE600)
Force (kN)
Pendulum rear AC-X (SAE180)
Pendulum rear AC - Y (SAE180)
Pendulum rear AC - Z (SAE180)
Structure AC-X (SAE180)
Structure AC-Y (SAE180)
Structure AC-Z (SAE180)

11.1.4 Abdomen slab test

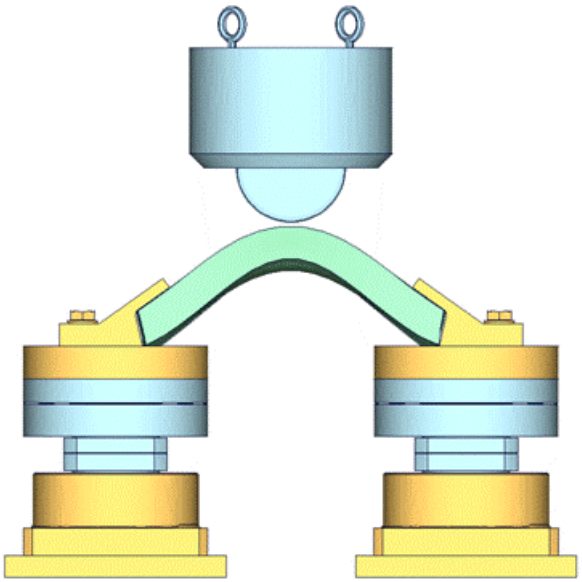
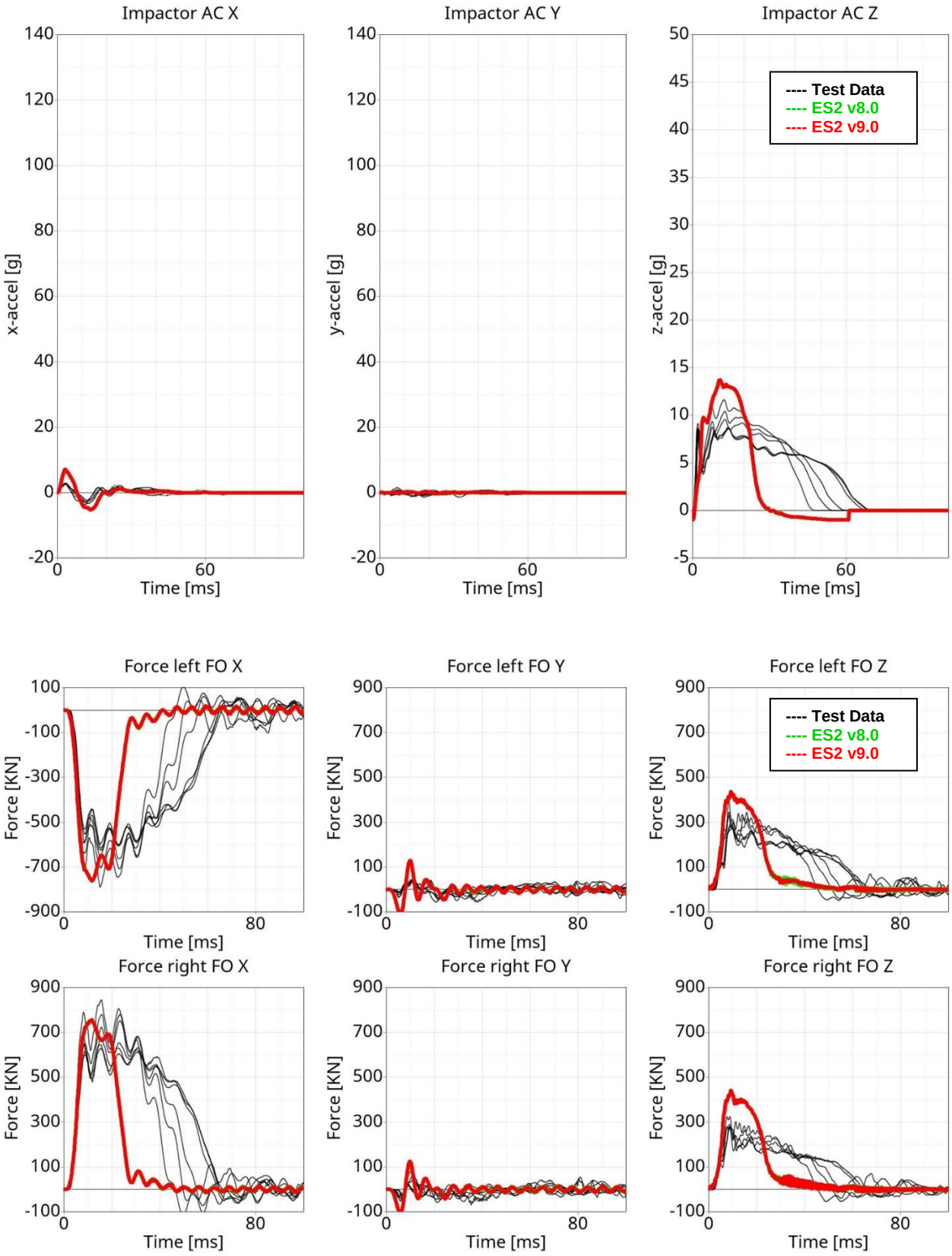


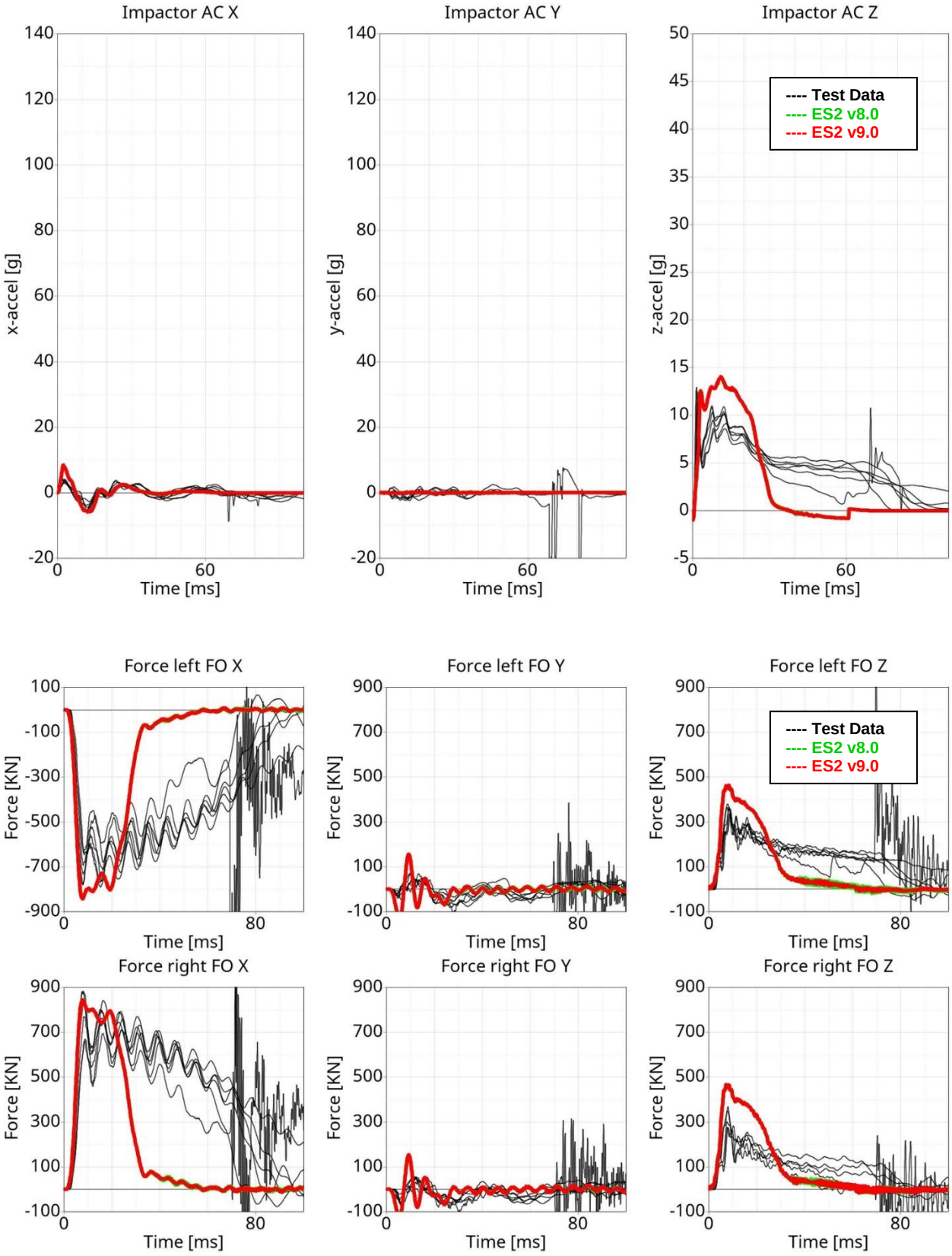
Figure 30: Test setup for Abdomen slab test

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

Results for low velocity impact



Results for high velocity impact



11.1.5 Abdomen test

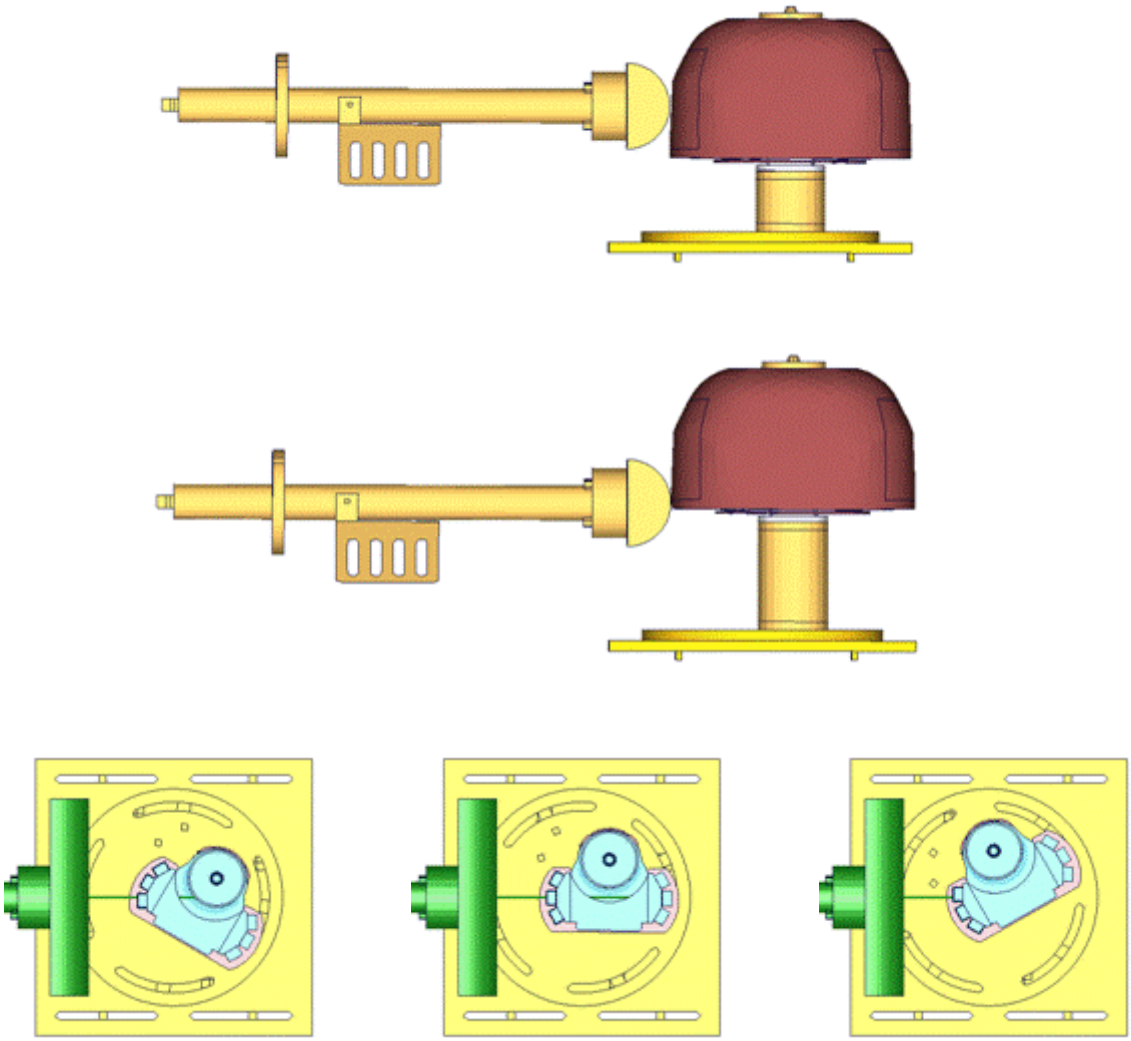
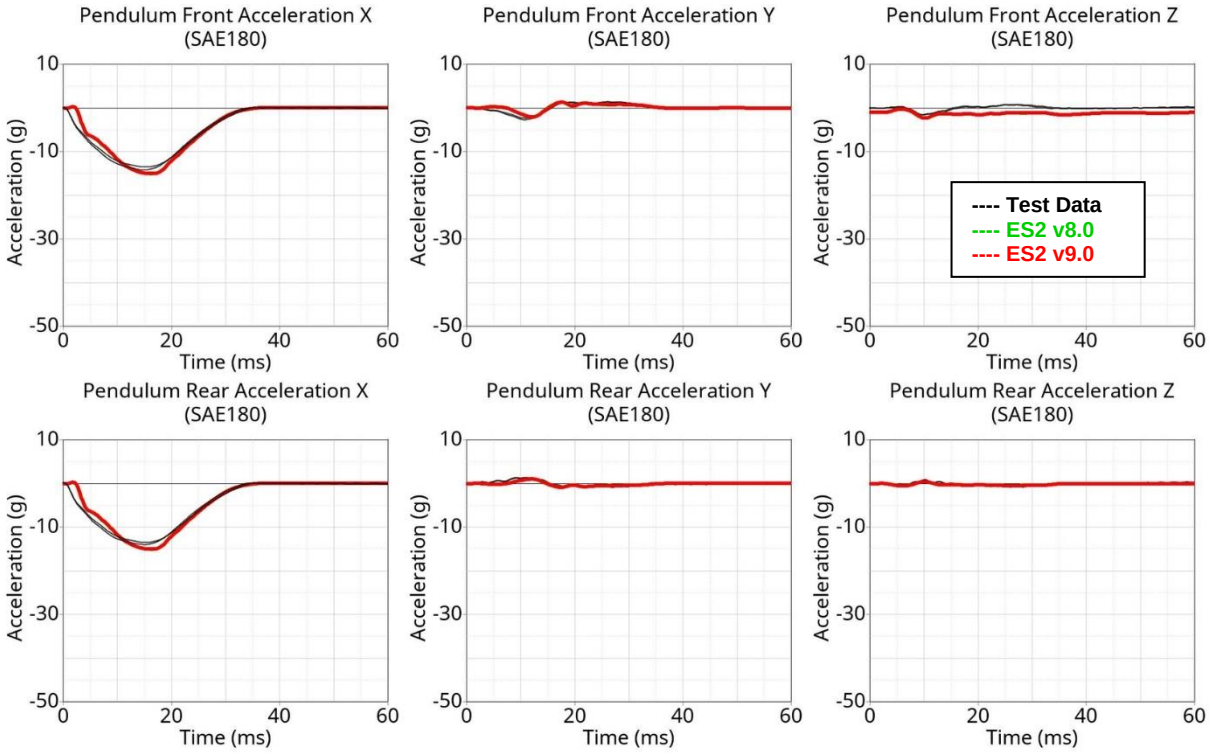
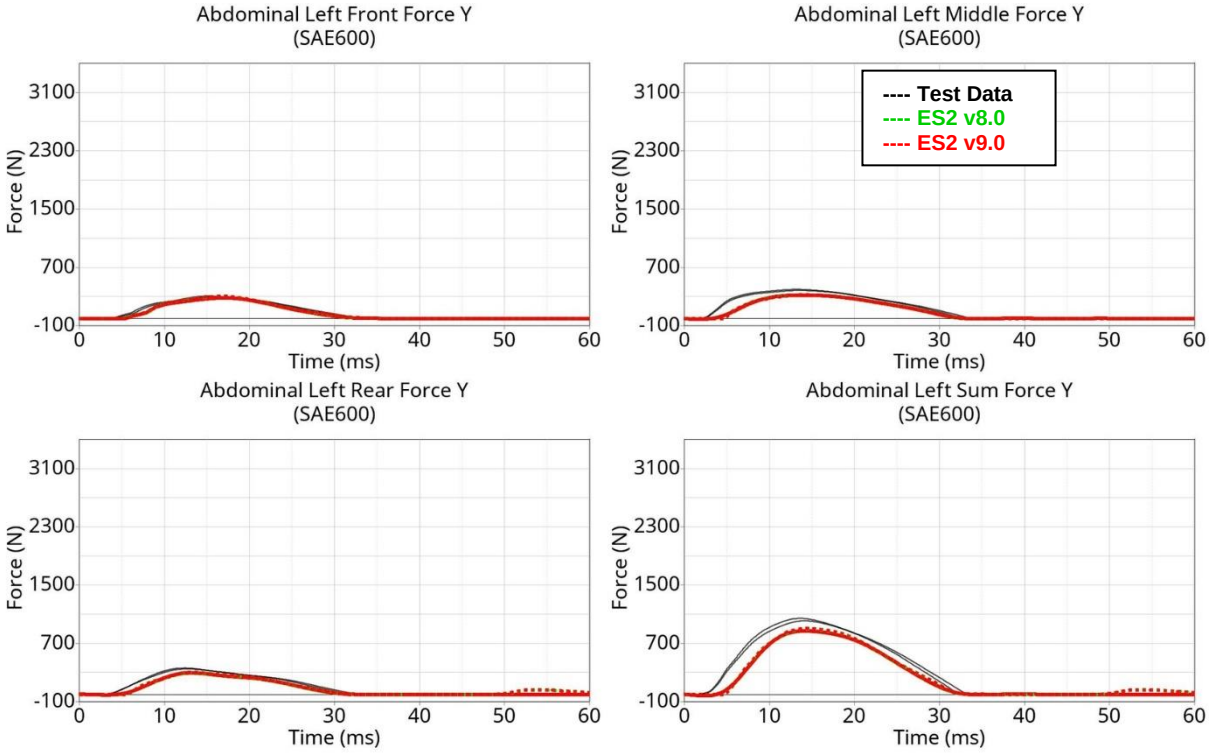


Figure 31: Test setup for Abdomen test

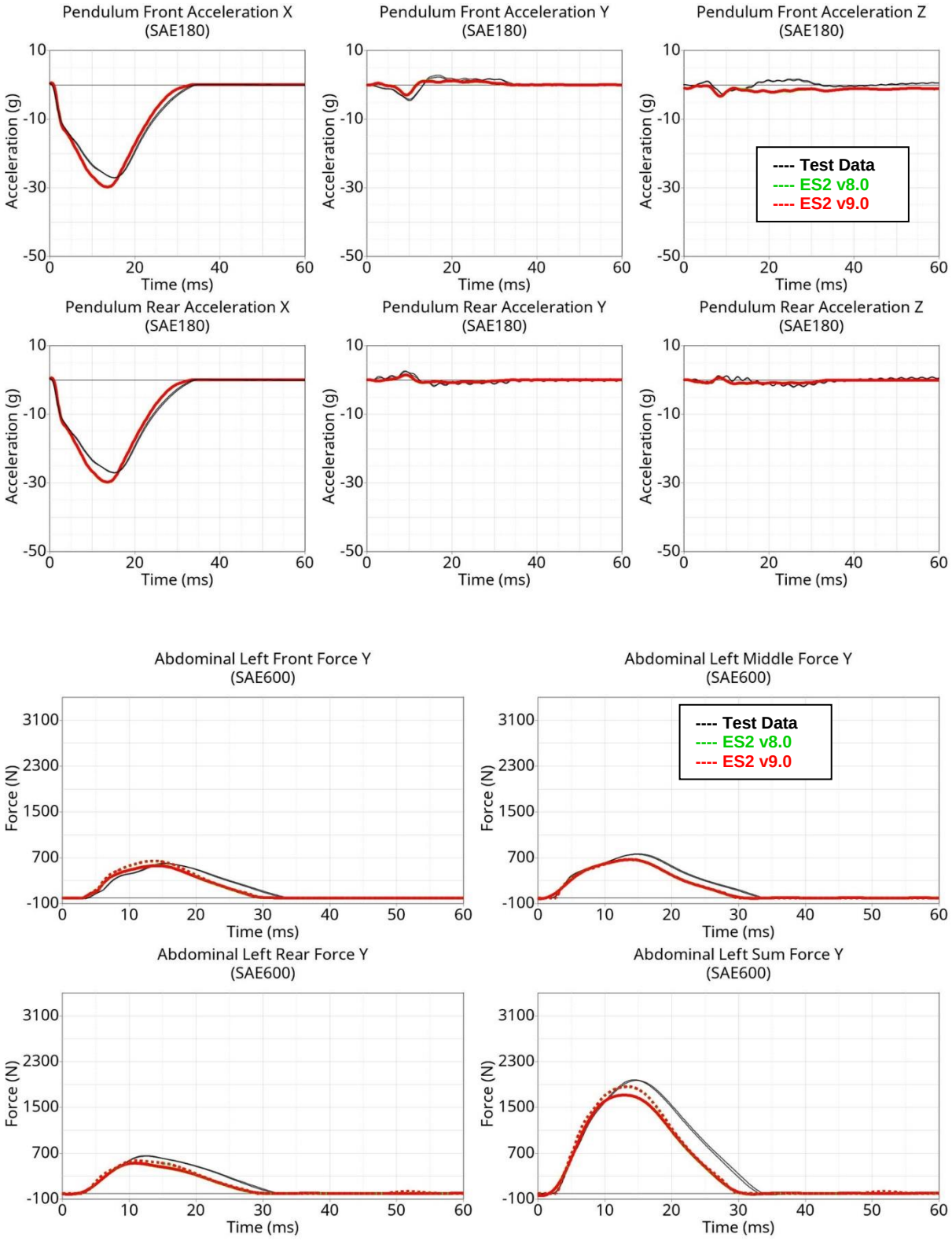
The test setup for the abdomen test is shown in the figure above. The Abdomen assembly is impacted by a pendulum at two different heights with three different velocities and three different abdomen assembly orientations each. The different abdomen assembly orientations are achieved by rotating the abdomen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

Results for 90° orientation, middle impact, low velocity

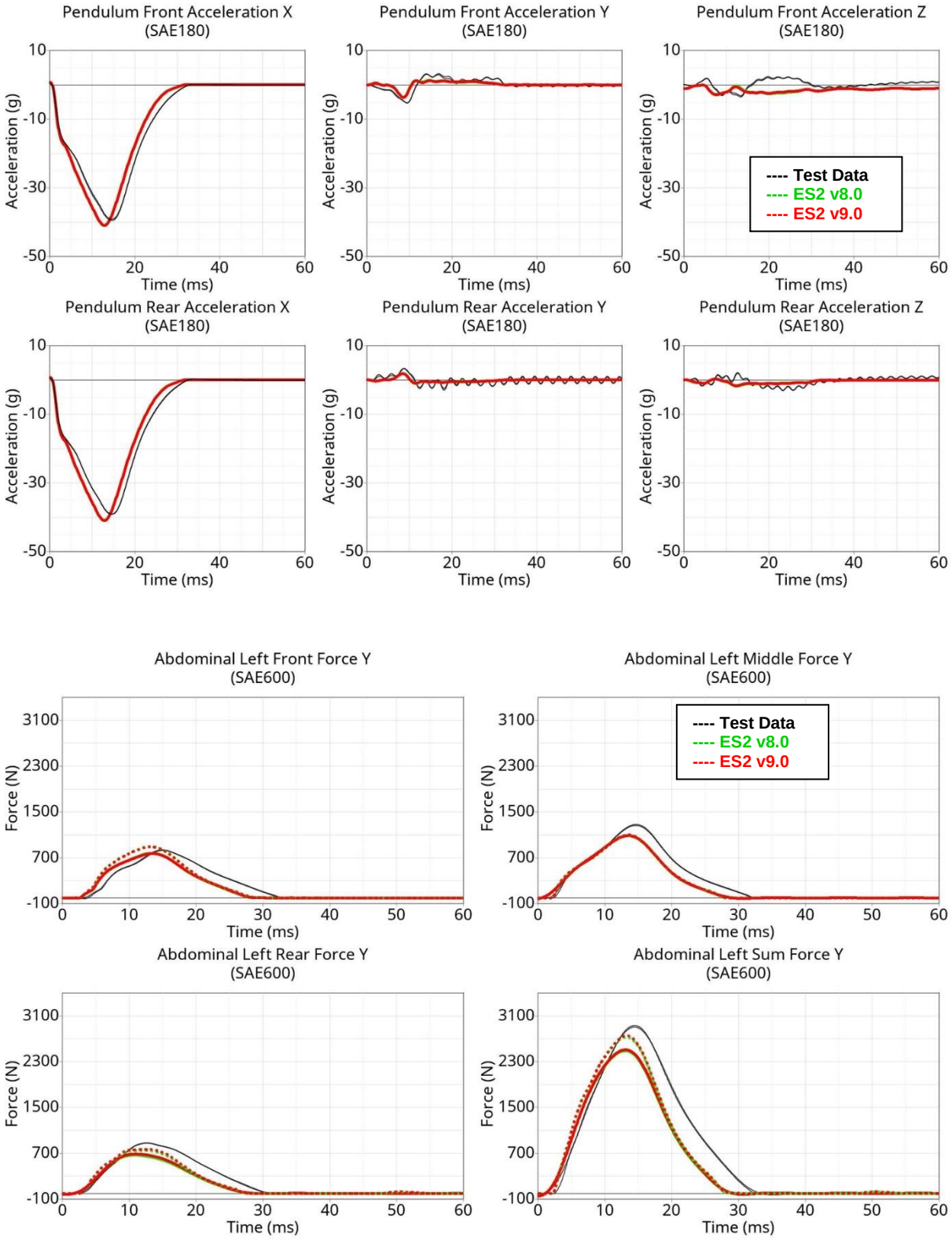




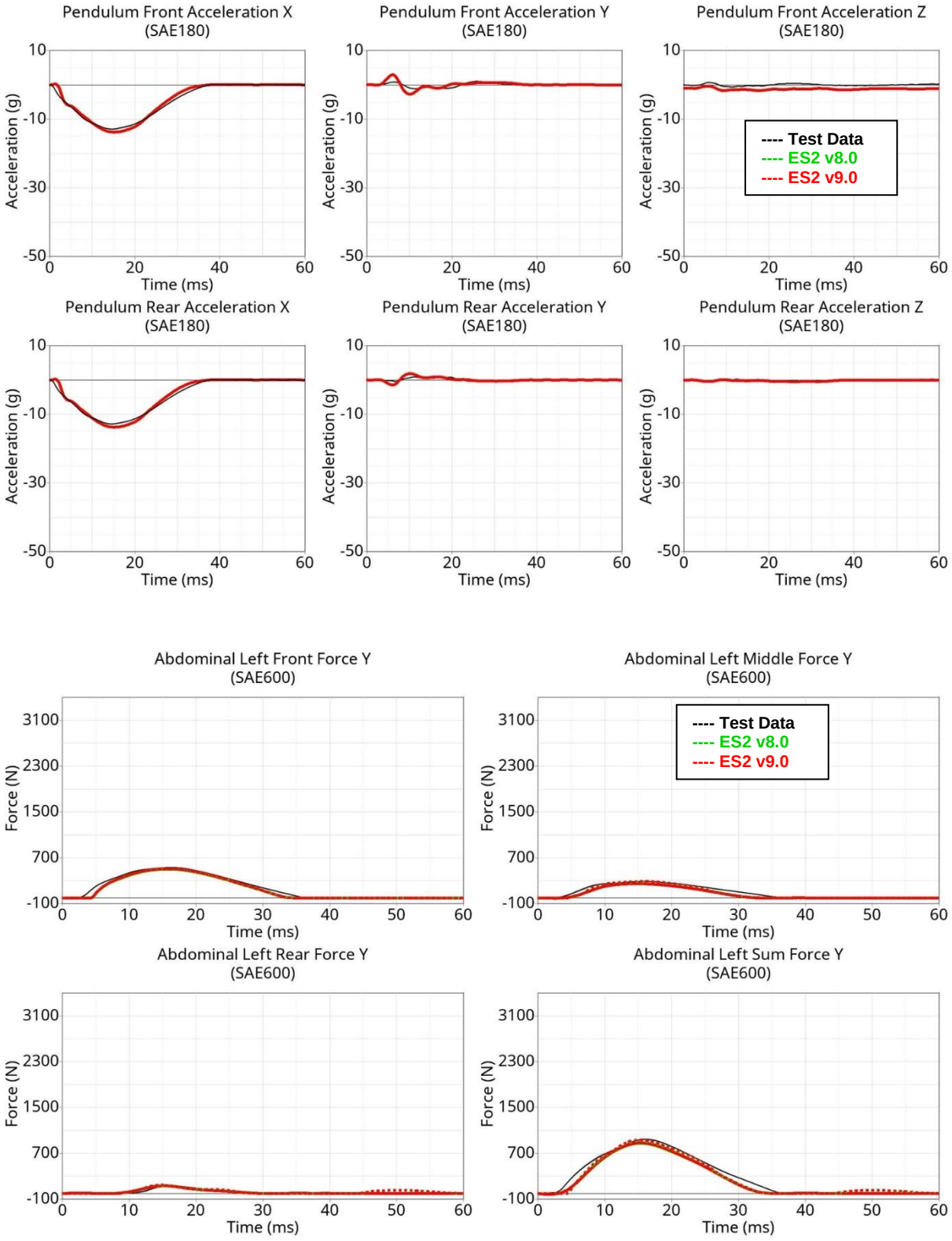
Results for 90° orientation, middle impact, medium velocity



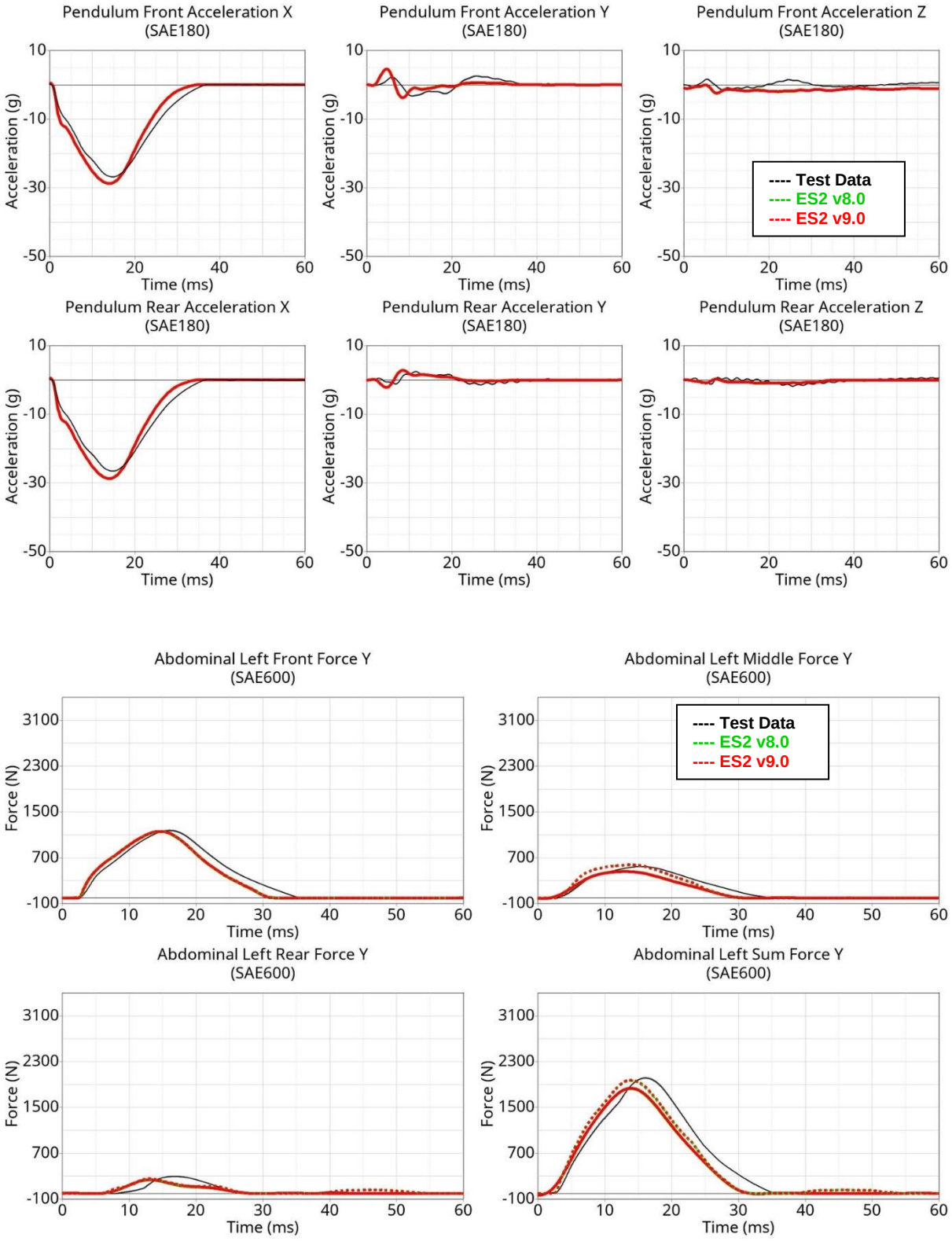
Results for 90° orientation, middle impact, high velocity



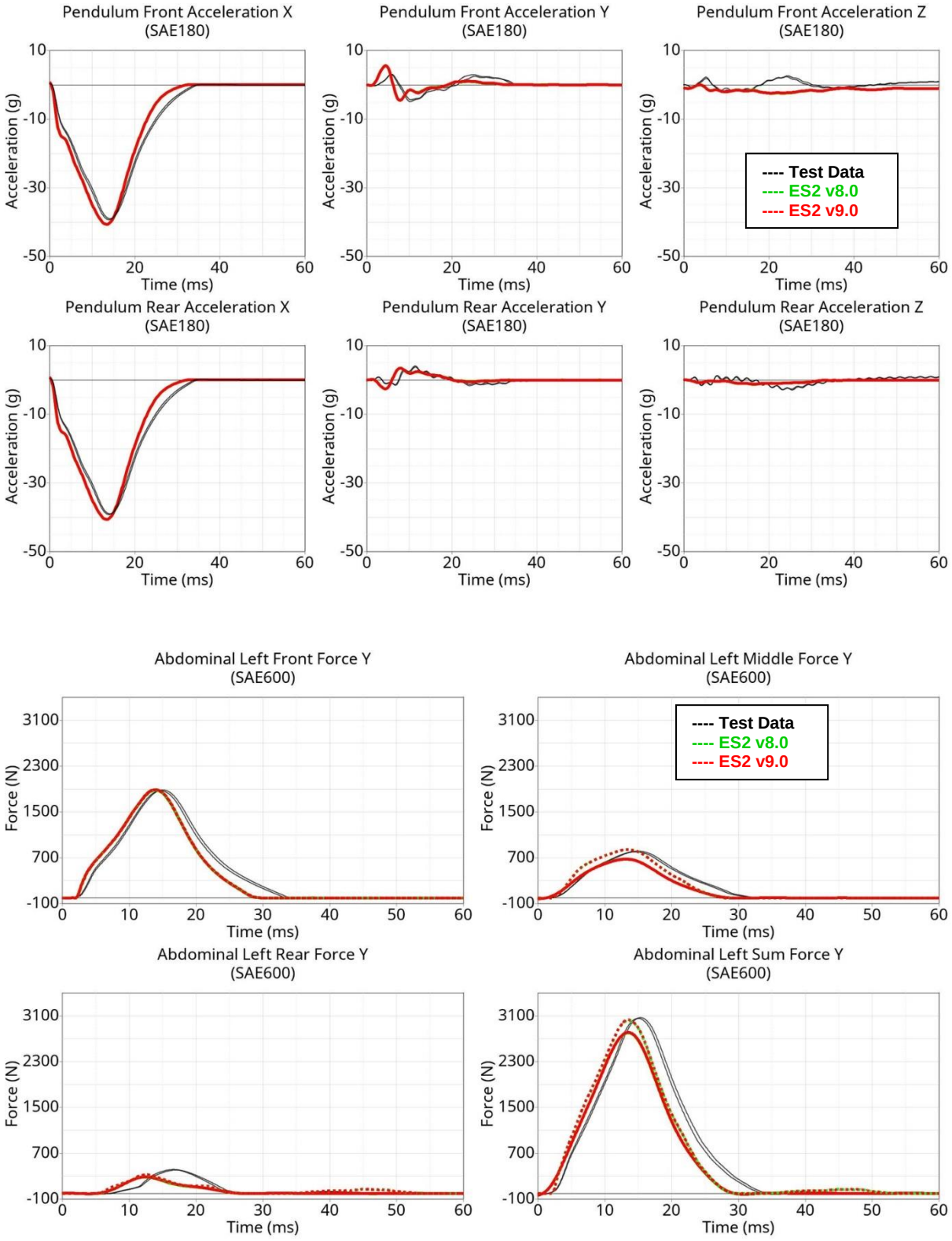
Results for 60° orientation, middle impact, low velocity



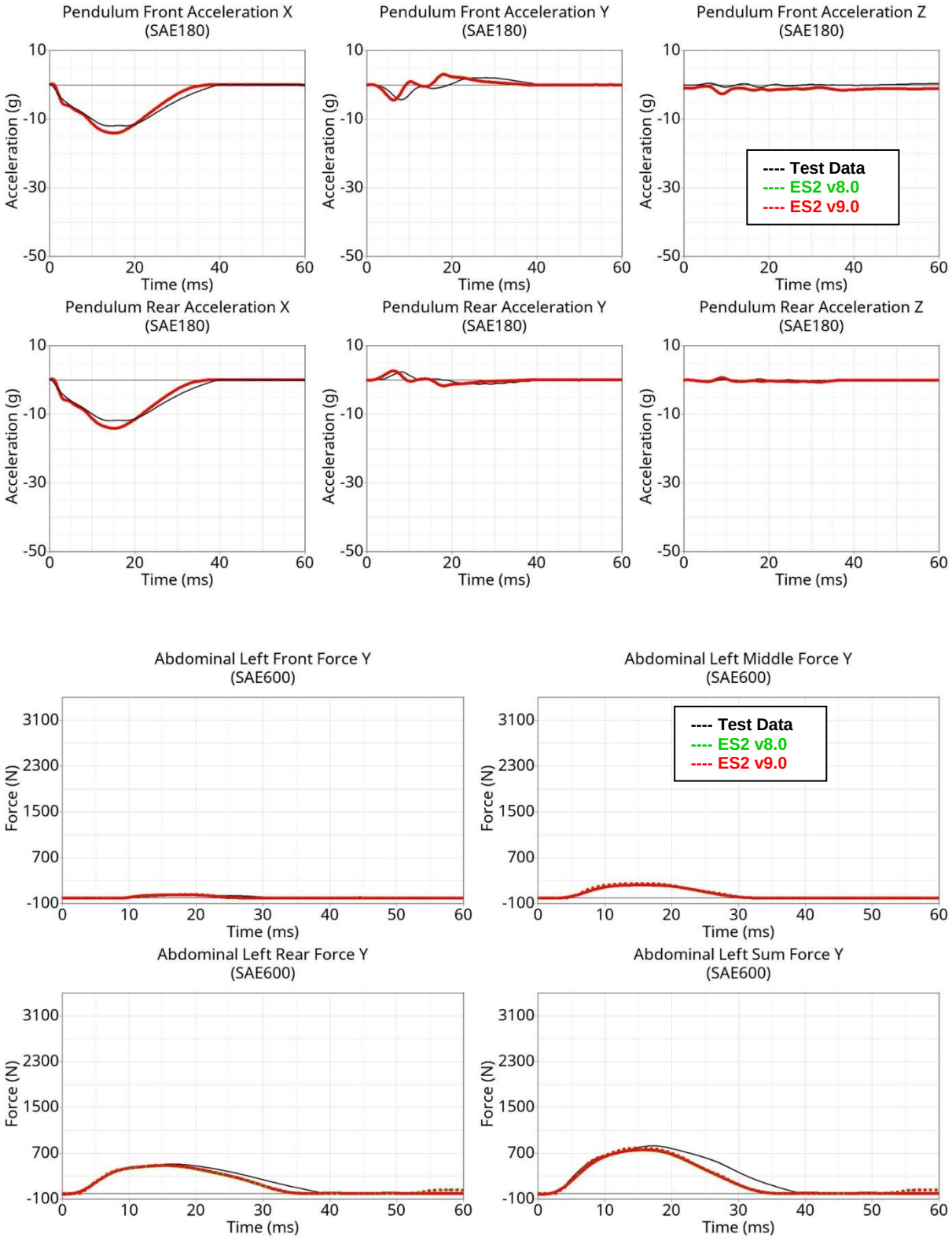
Results for 60° orientation, middle impact, medium velocity



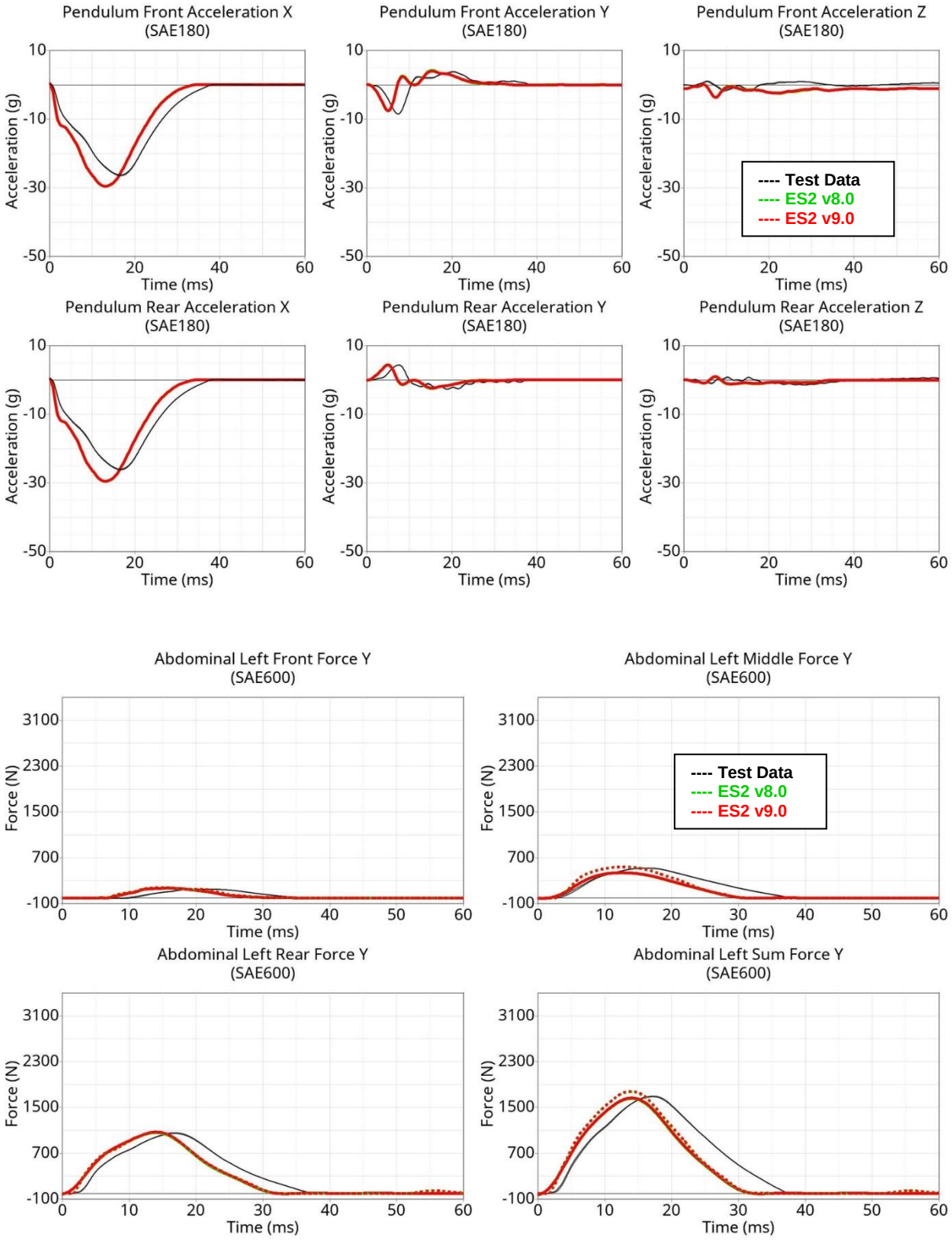
Results for 60° orientation, middle impact, high velocity



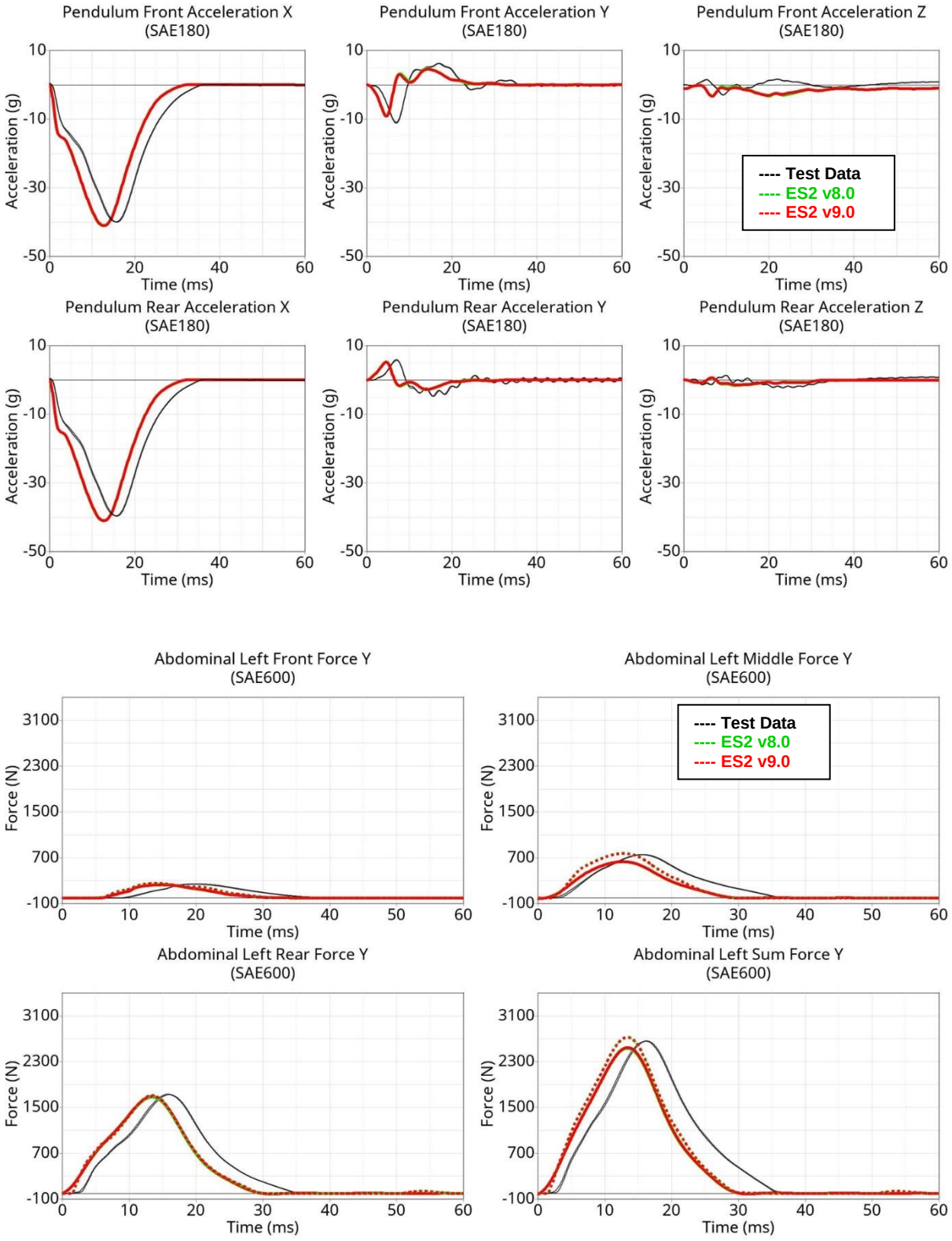
Results for 120° orientation, middle impact, low velocity



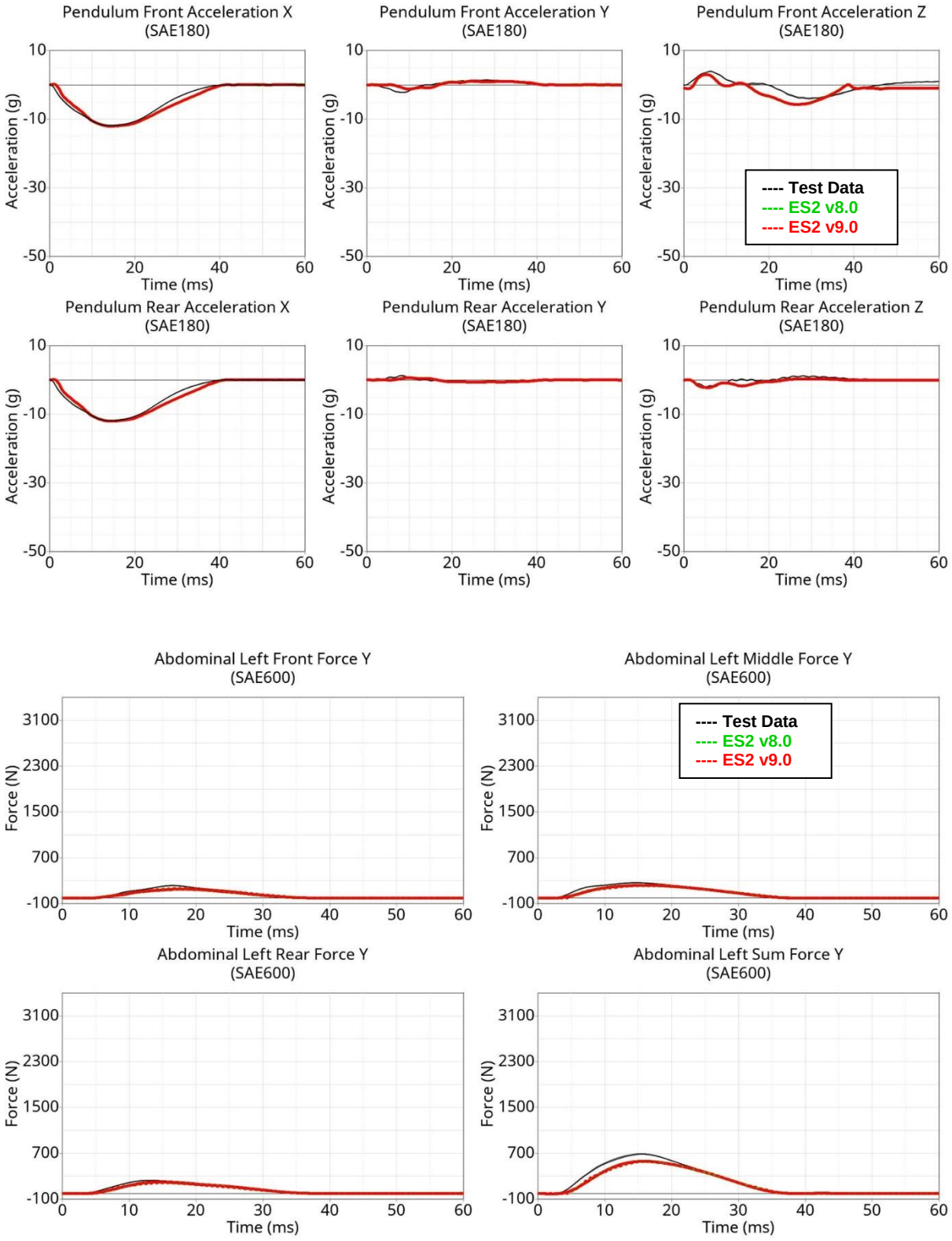
Results for 120° orientation, middle impact, medium velocity



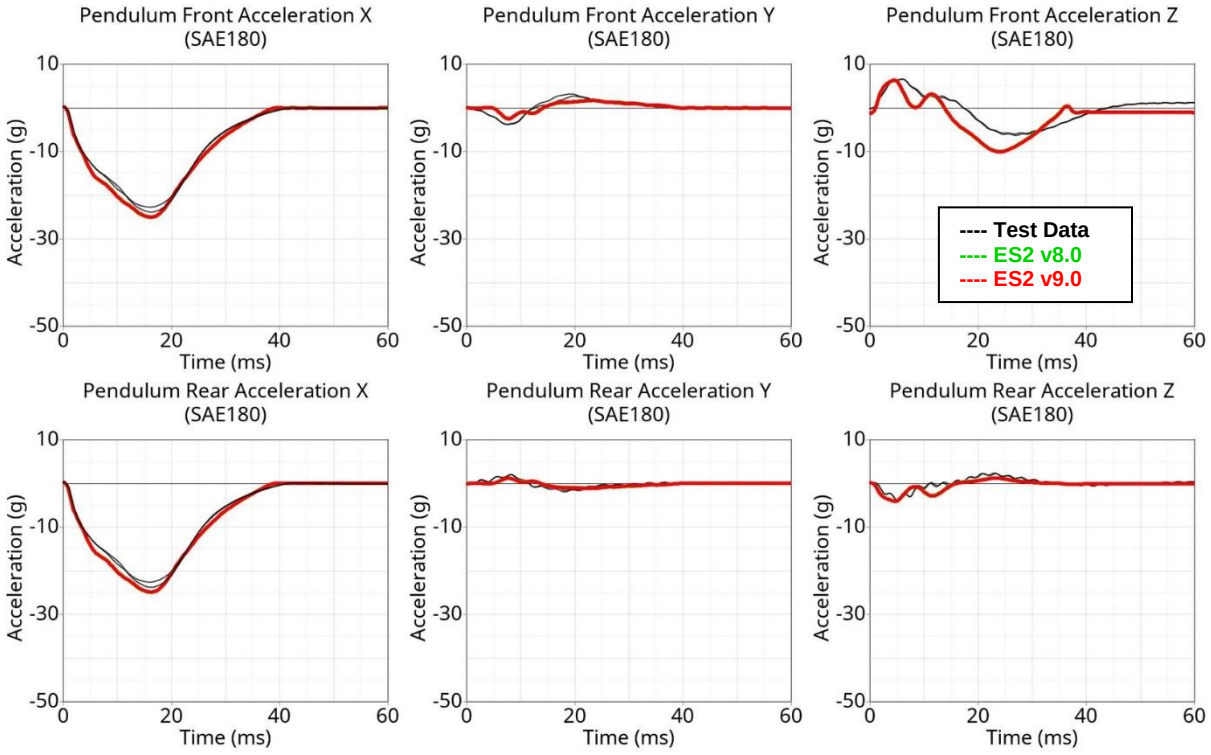
Results for 120° orientation, middle impact, high velocity

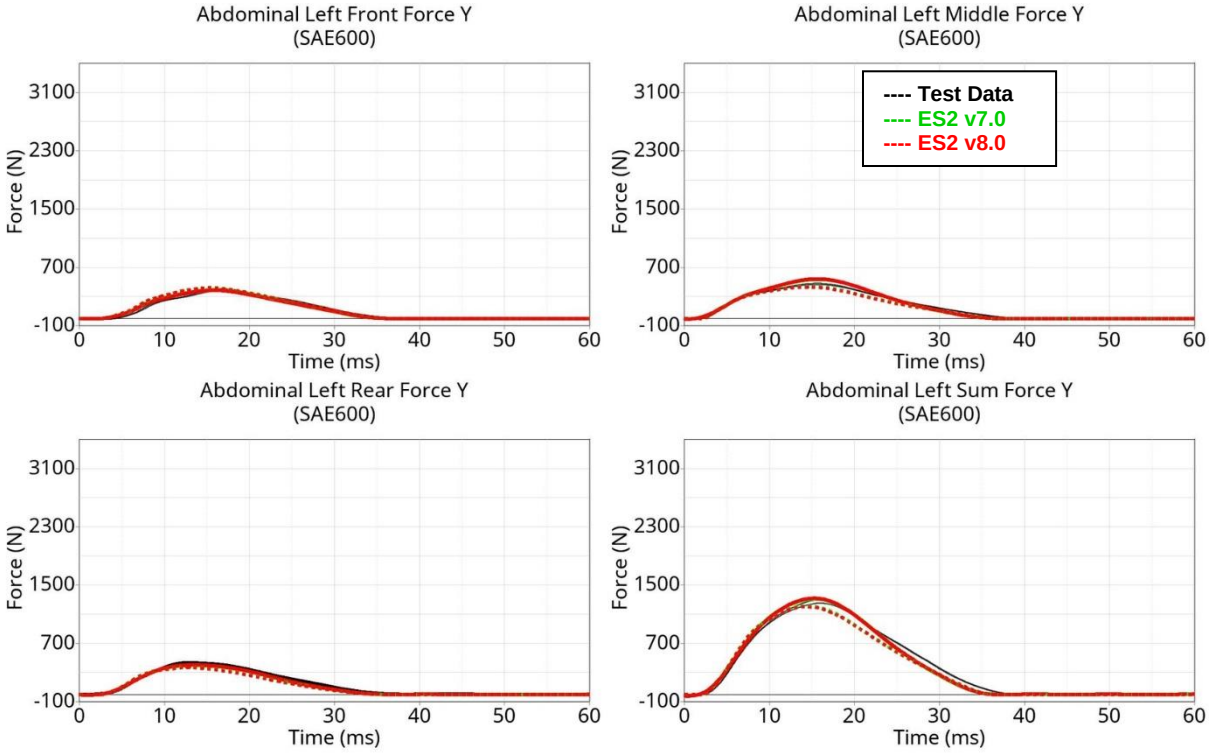


Results for 90° orientation, top impact, low velocity

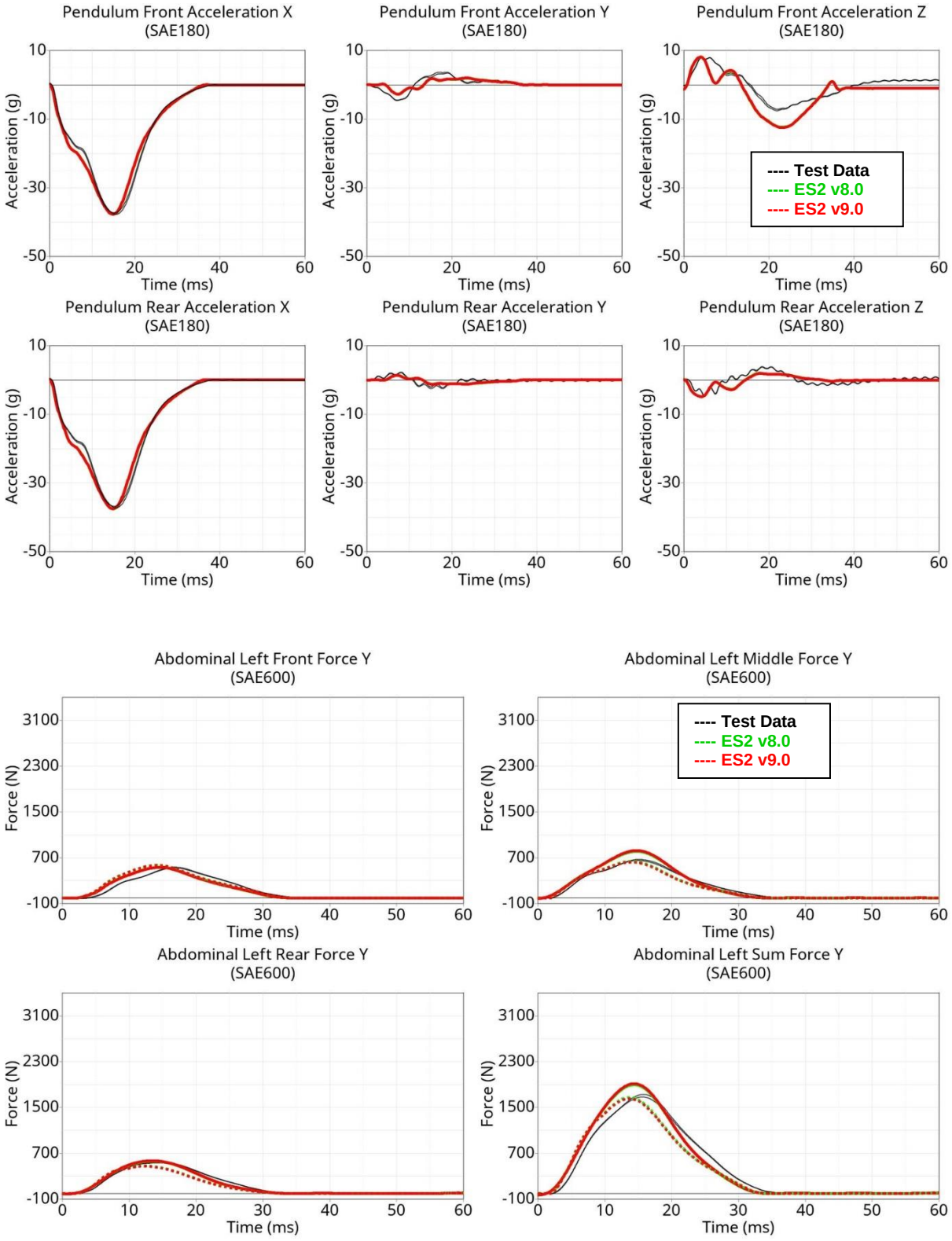


Results for 90° orientation, top impact, medium velocity

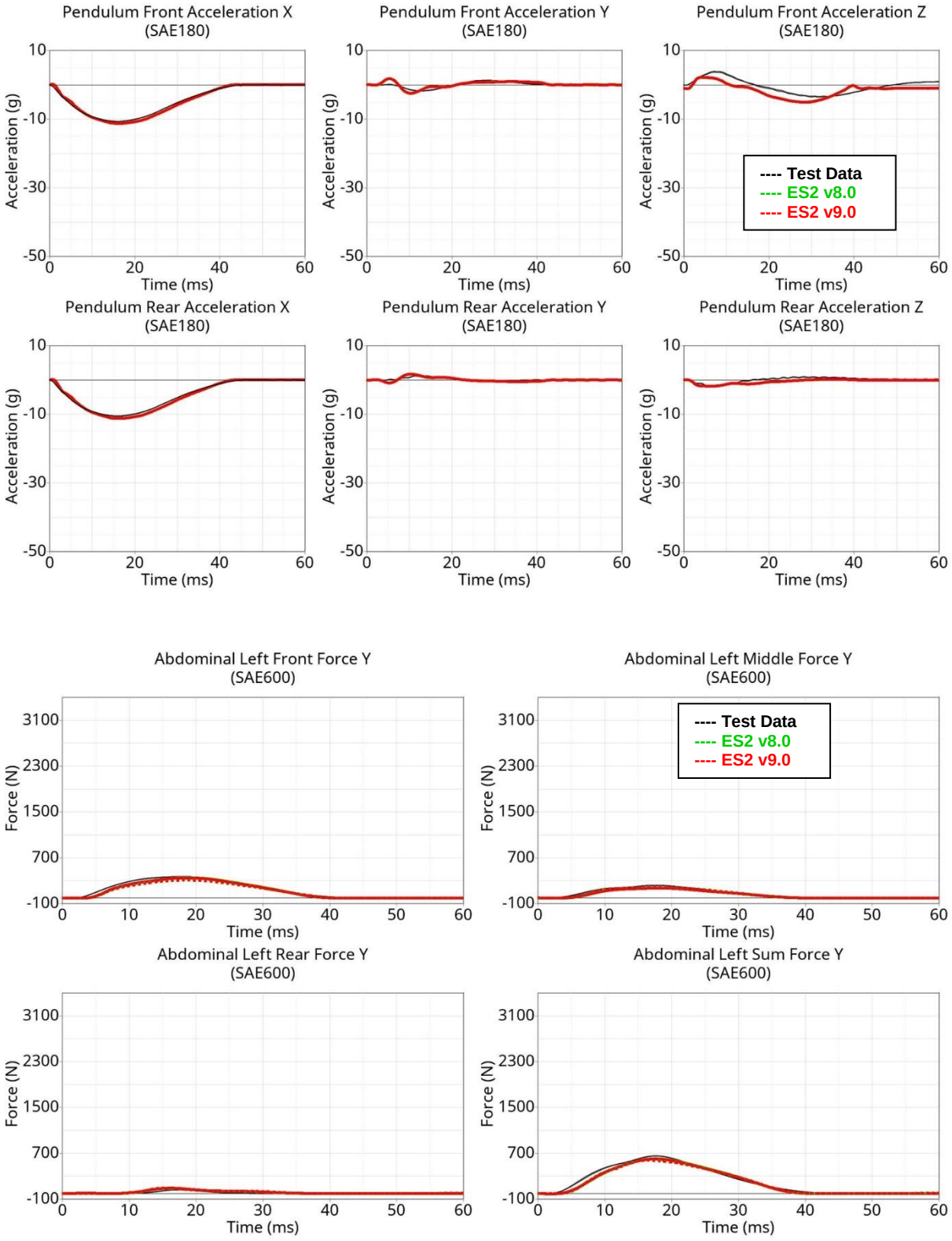




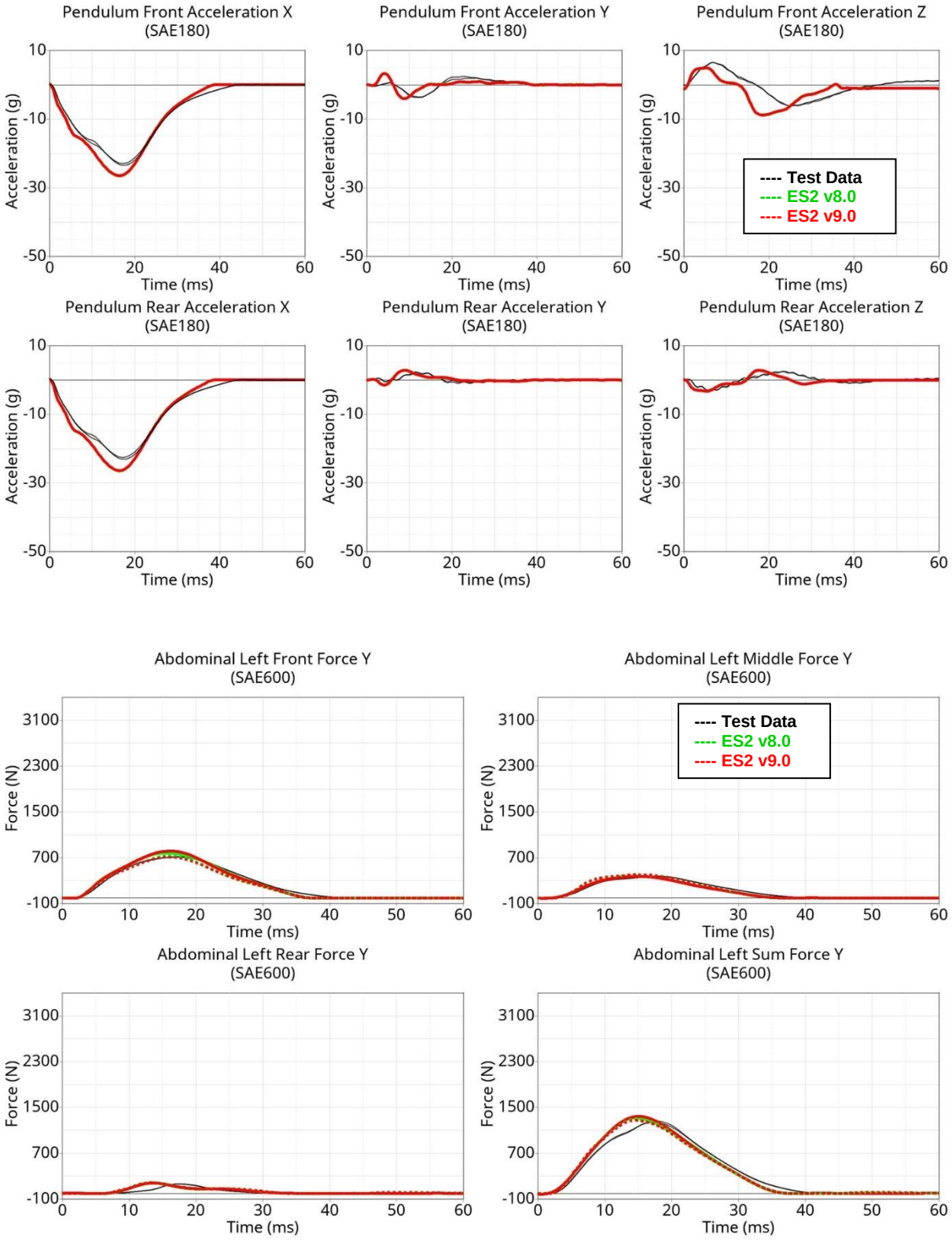
Results for 90° orientation, top impact, high velocity



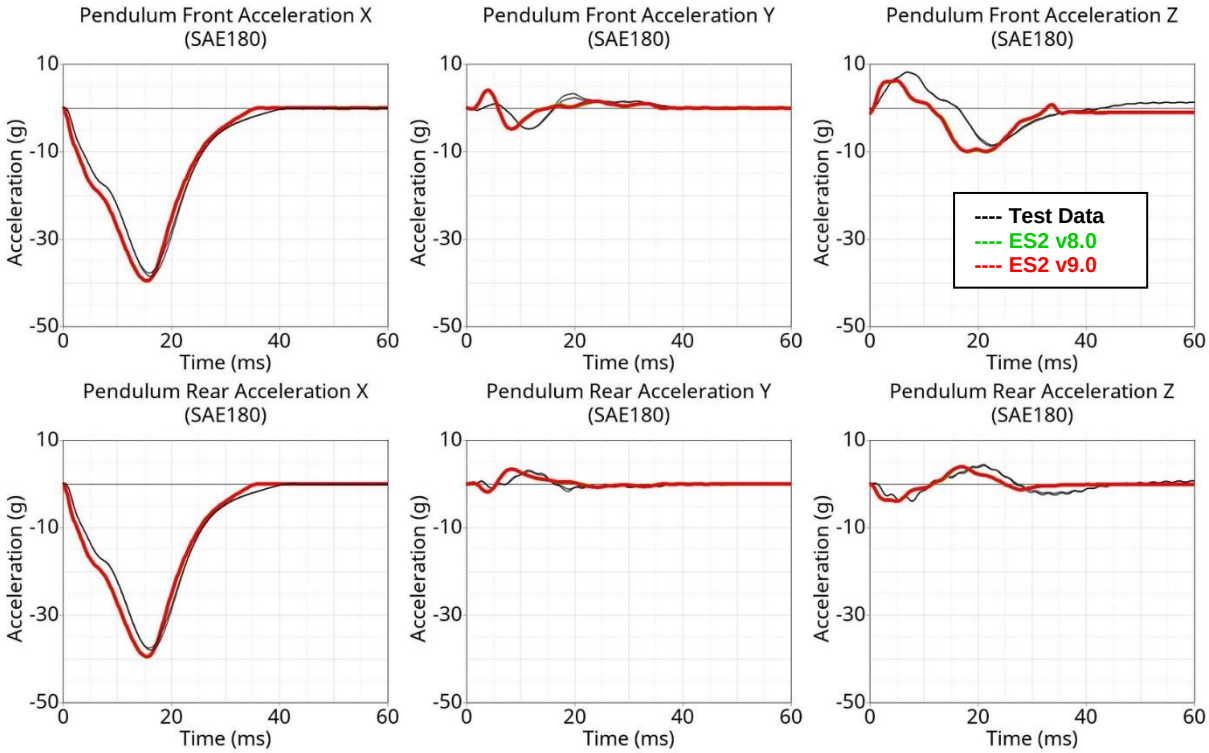
Results for 60° orientation, top impact, low velocity

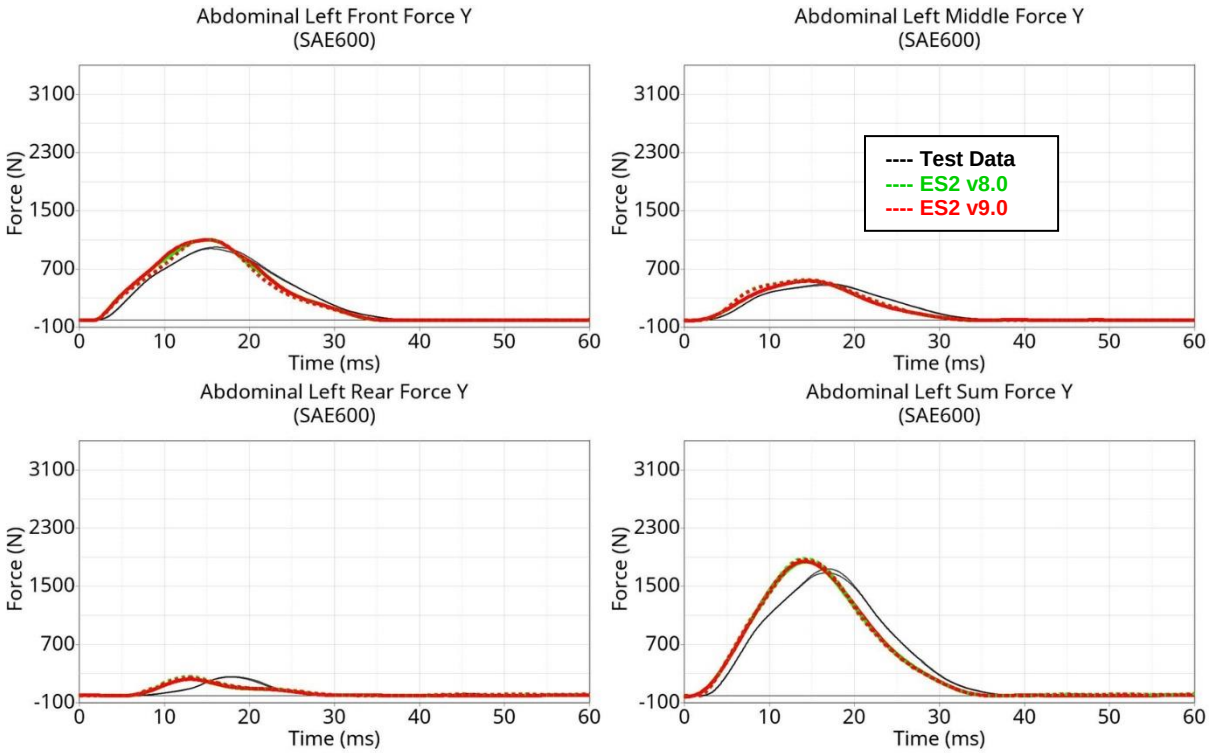


Results for 60° orientation, top impact, medium velocity

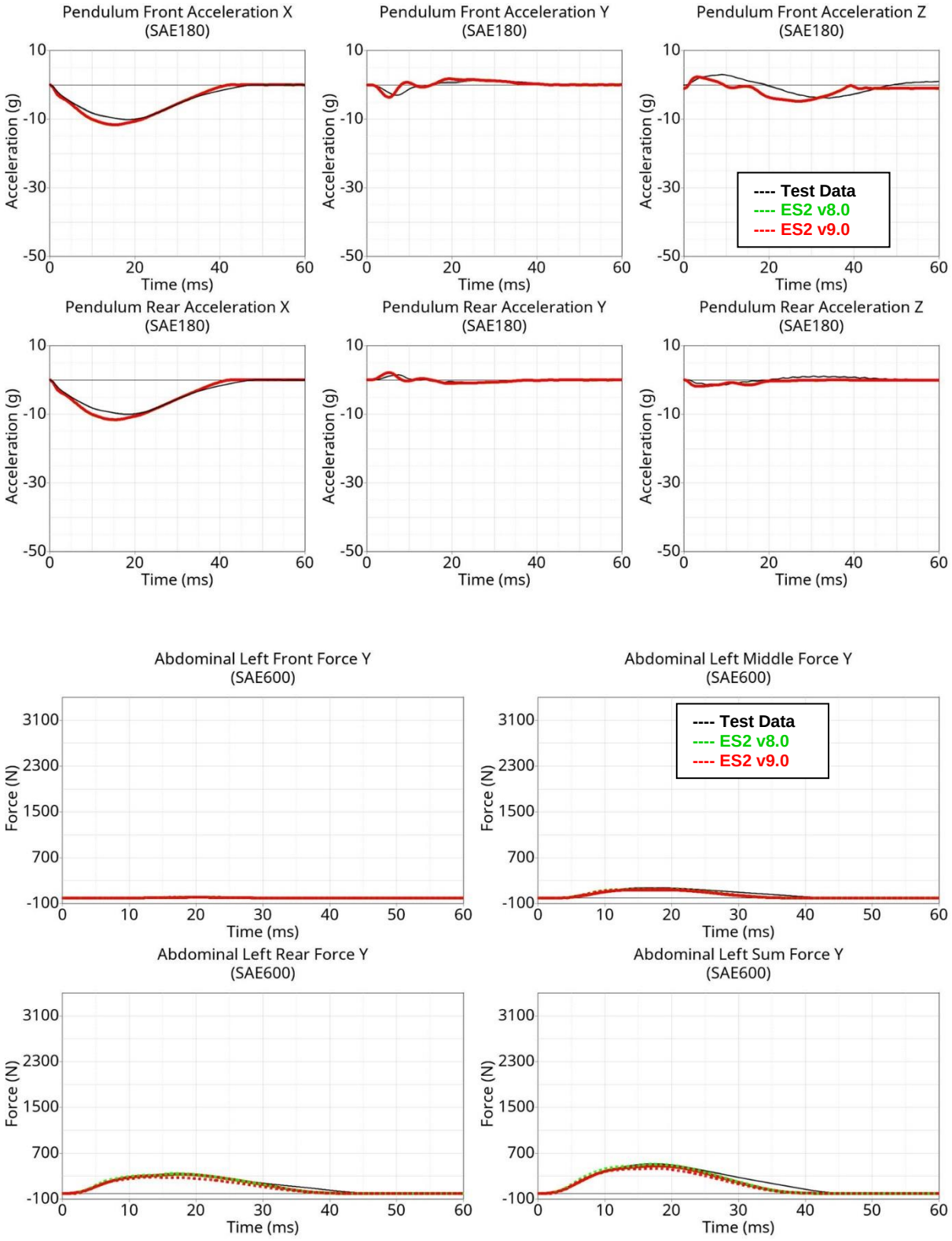


Results for 60° orientation, top impact, high velocity

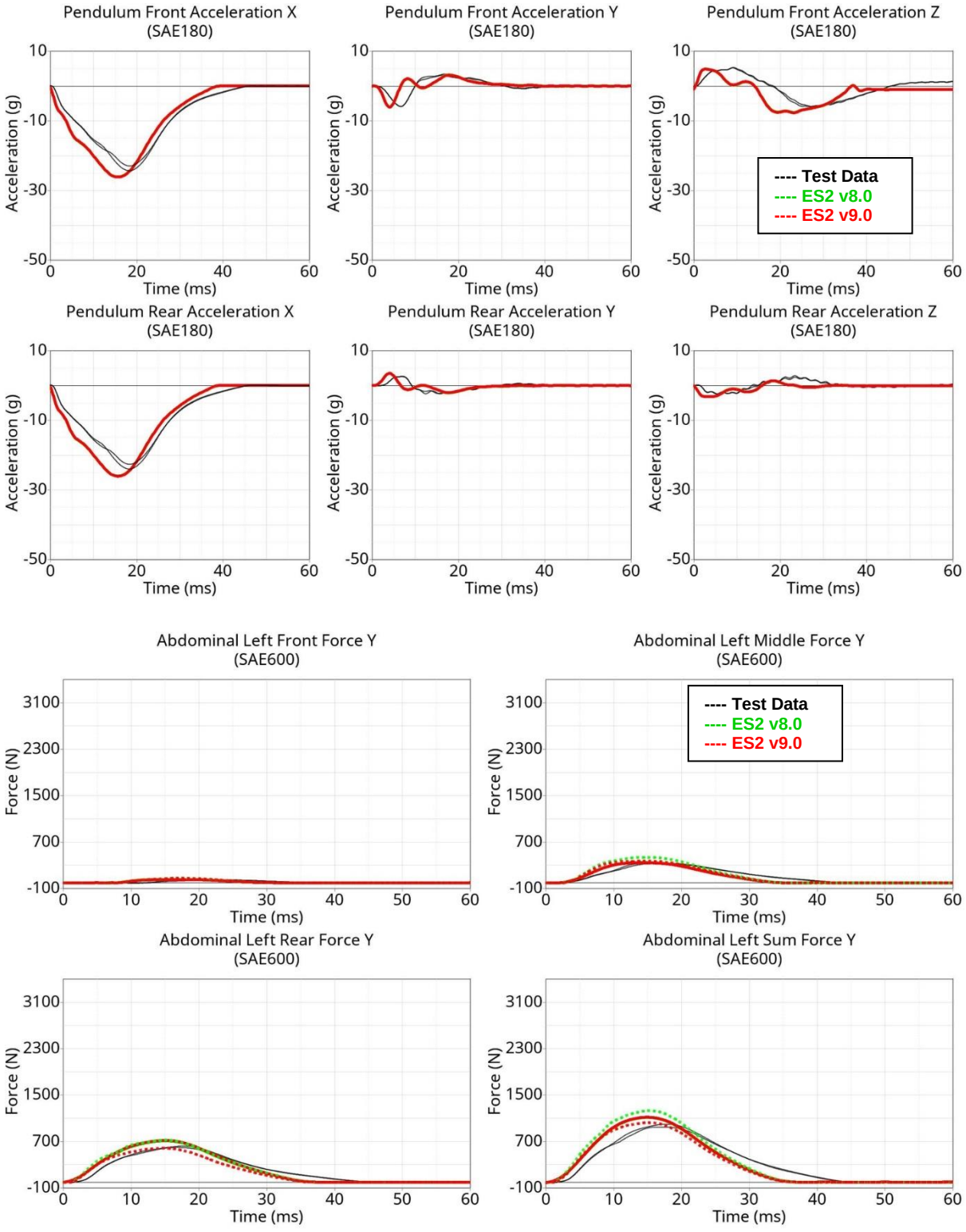




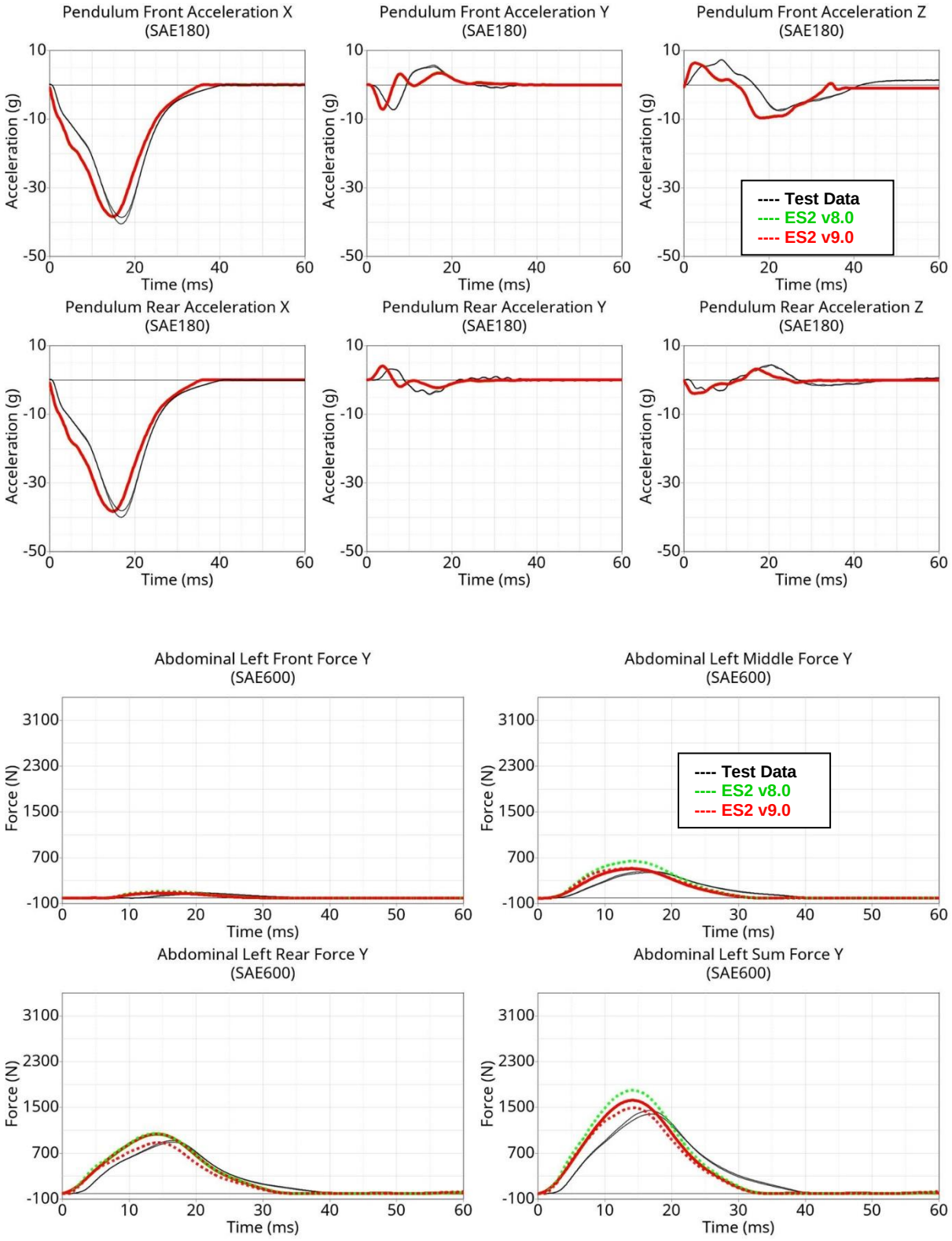
Results for 120° orientation, top impact, low velocity



Results for 120° orientation, top impact, medium velocity



Results for 120° orientation, top impact, high velocity



11.1.6 Lumbar spine test

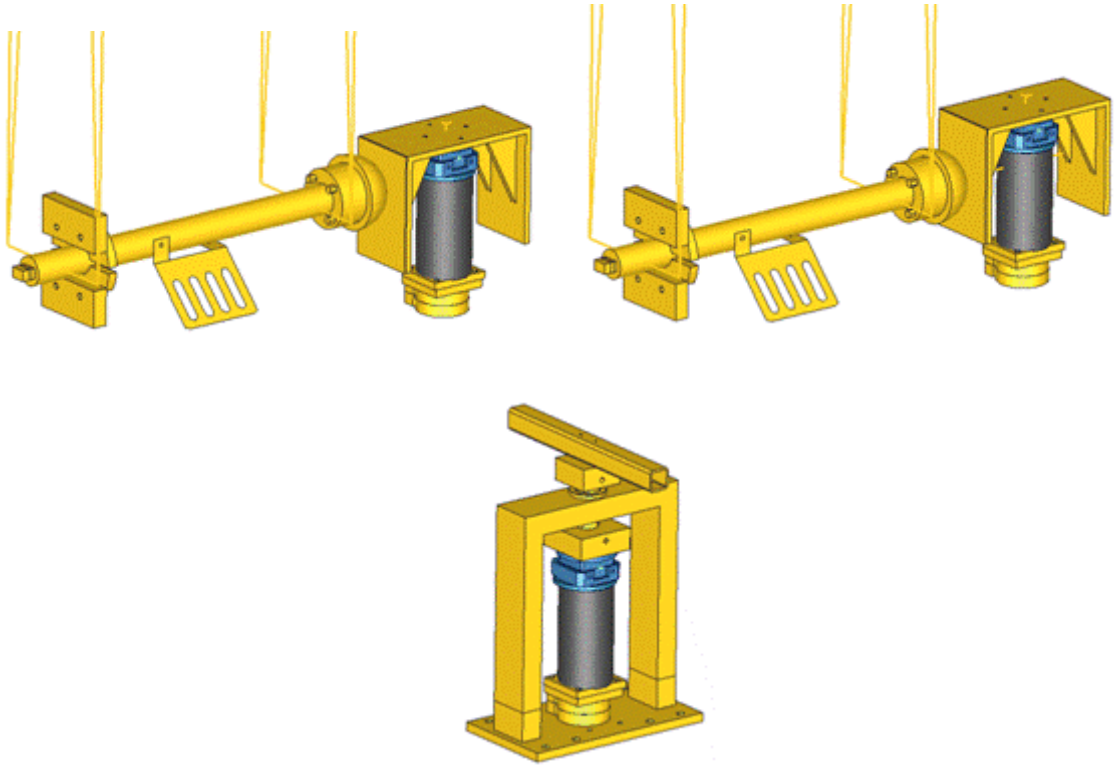
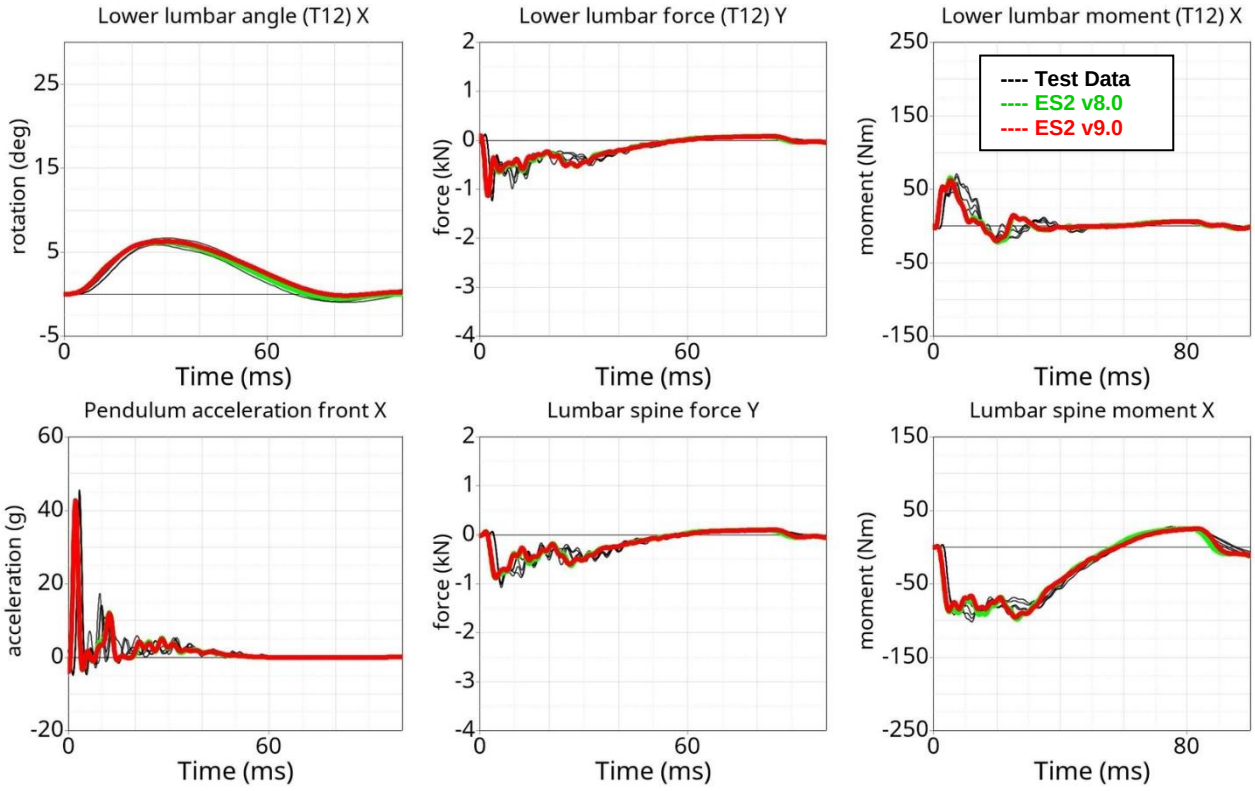


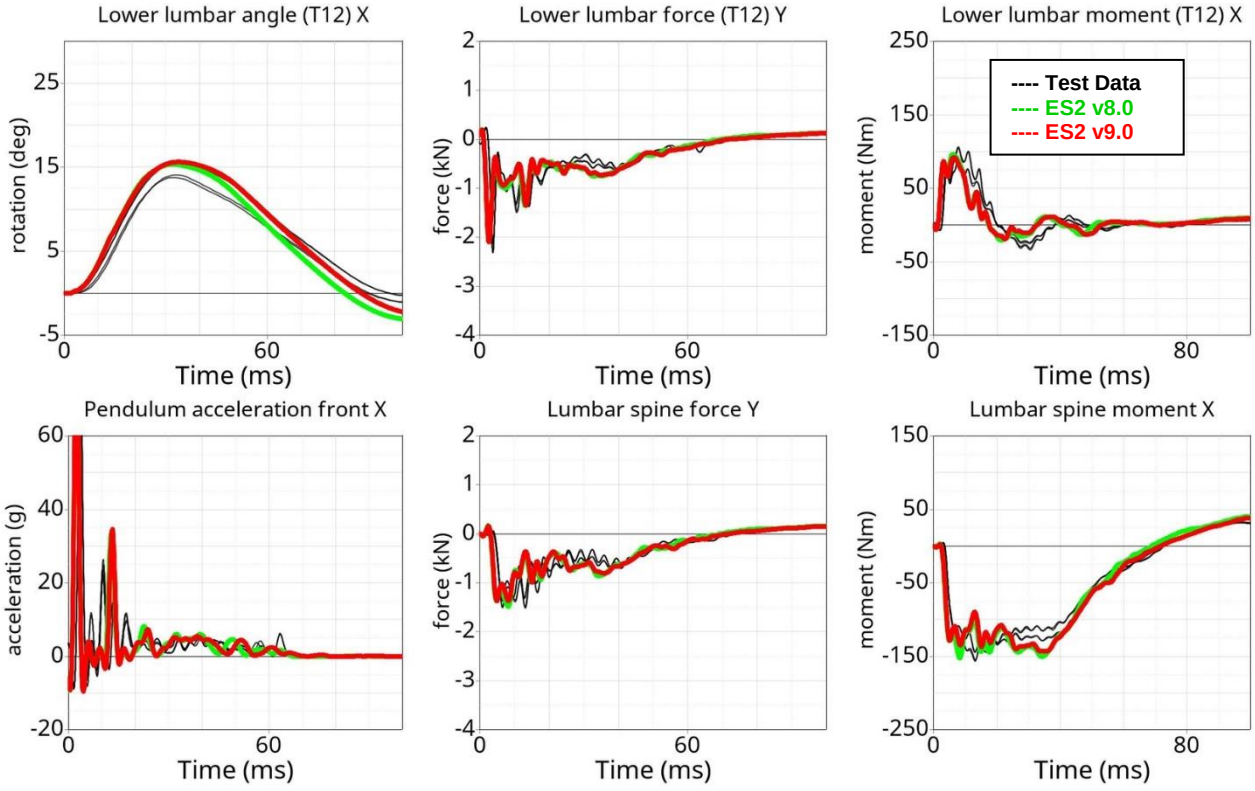
Figure 32: Setups for bending, shear and torsion tests on lumbar spine

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

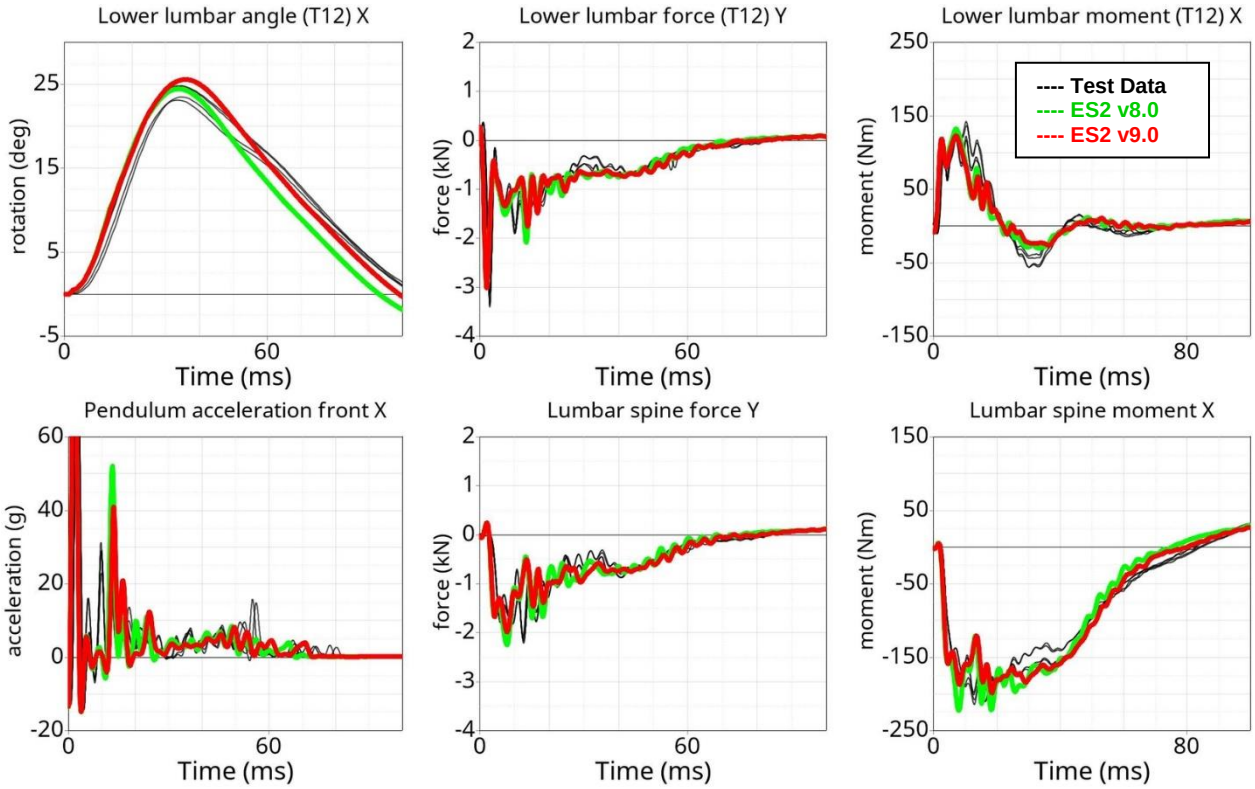
Results for bending low velocity



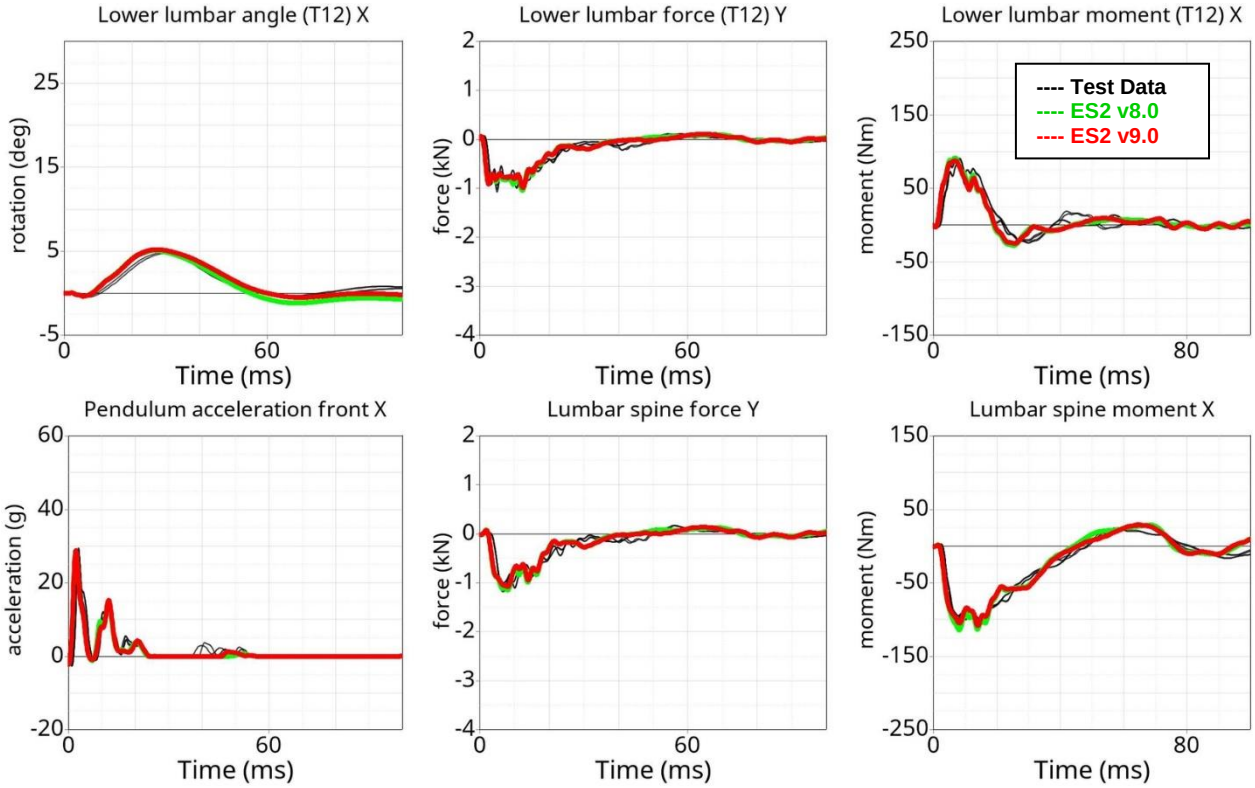
Results for bending medium velocity



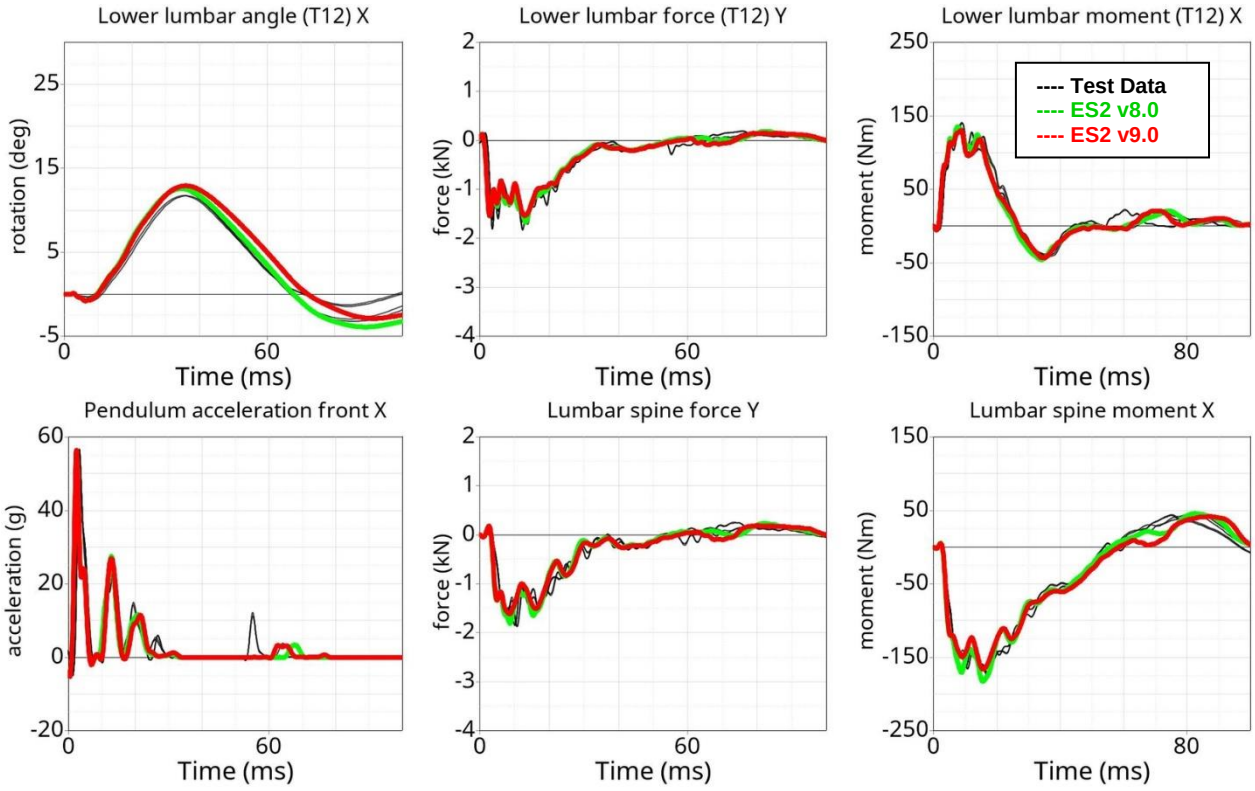
Results for bending high velocity



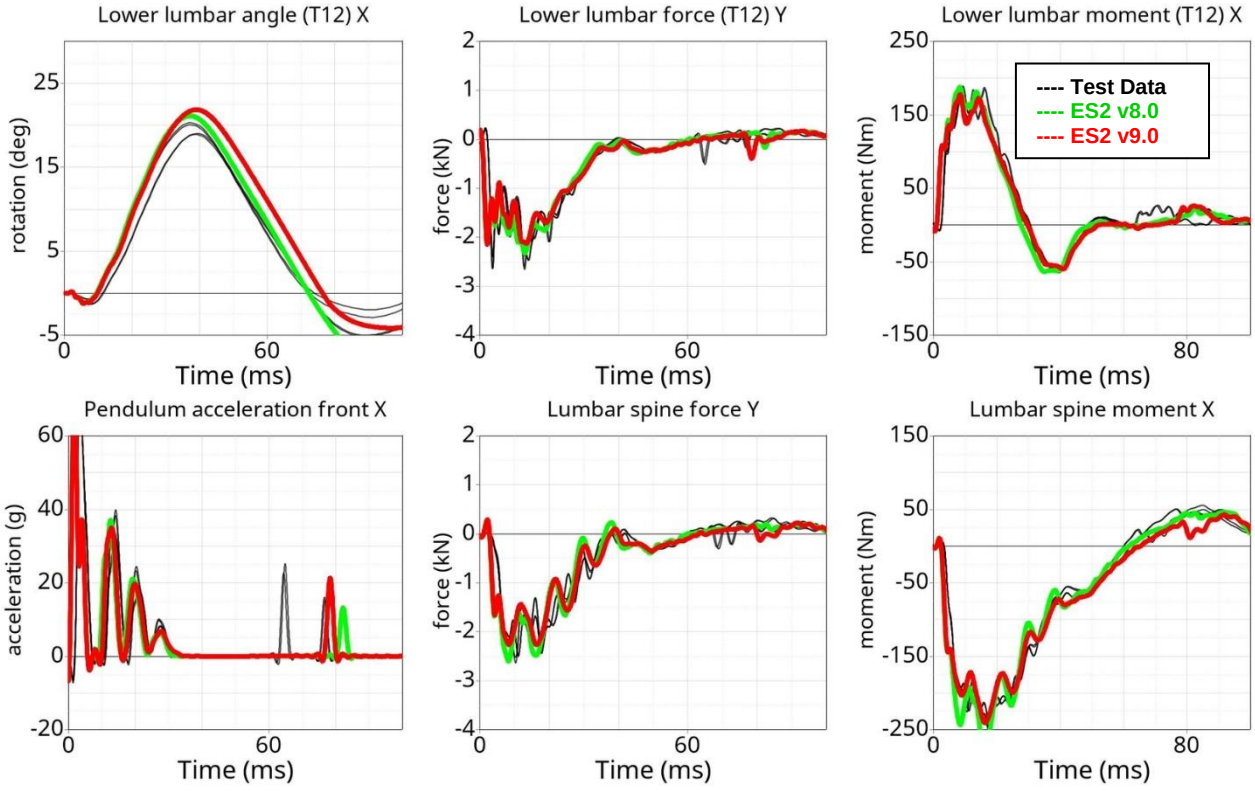
Results for shear low velocity



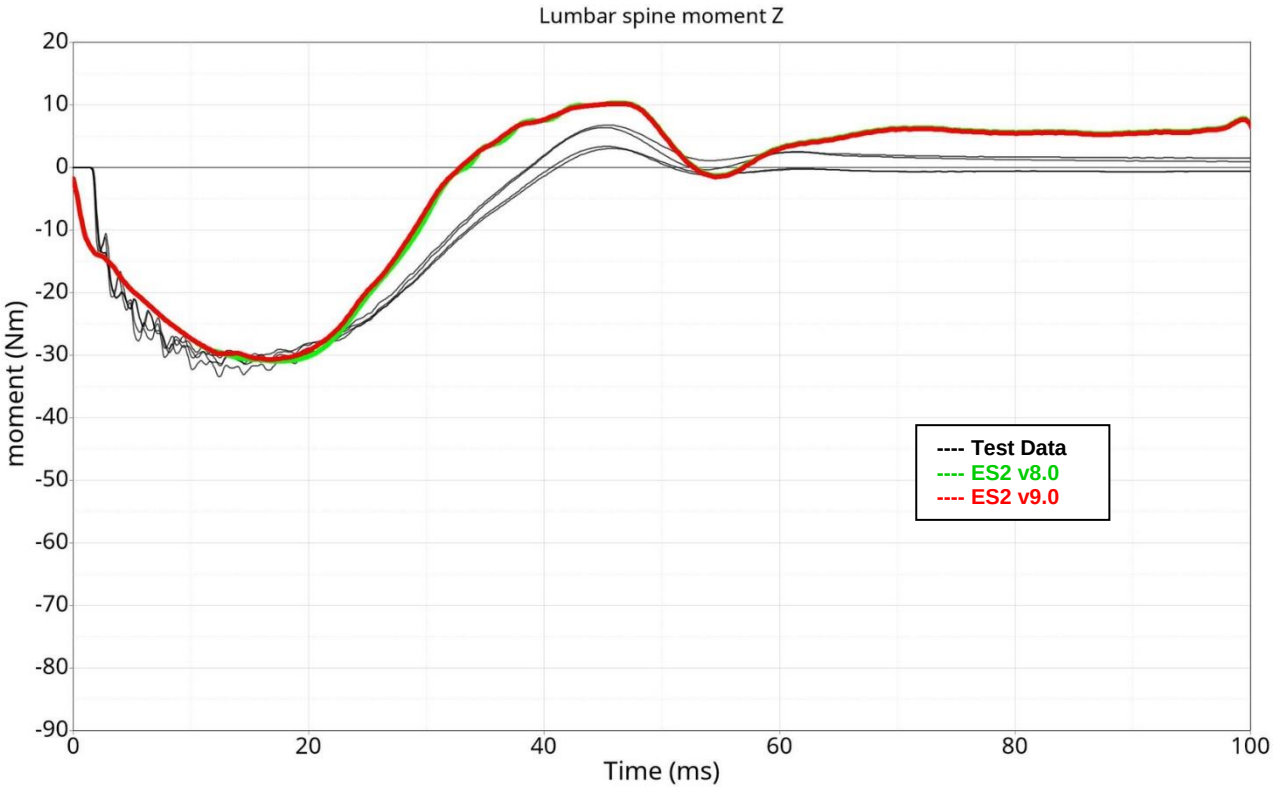
Results for shear medium velocity



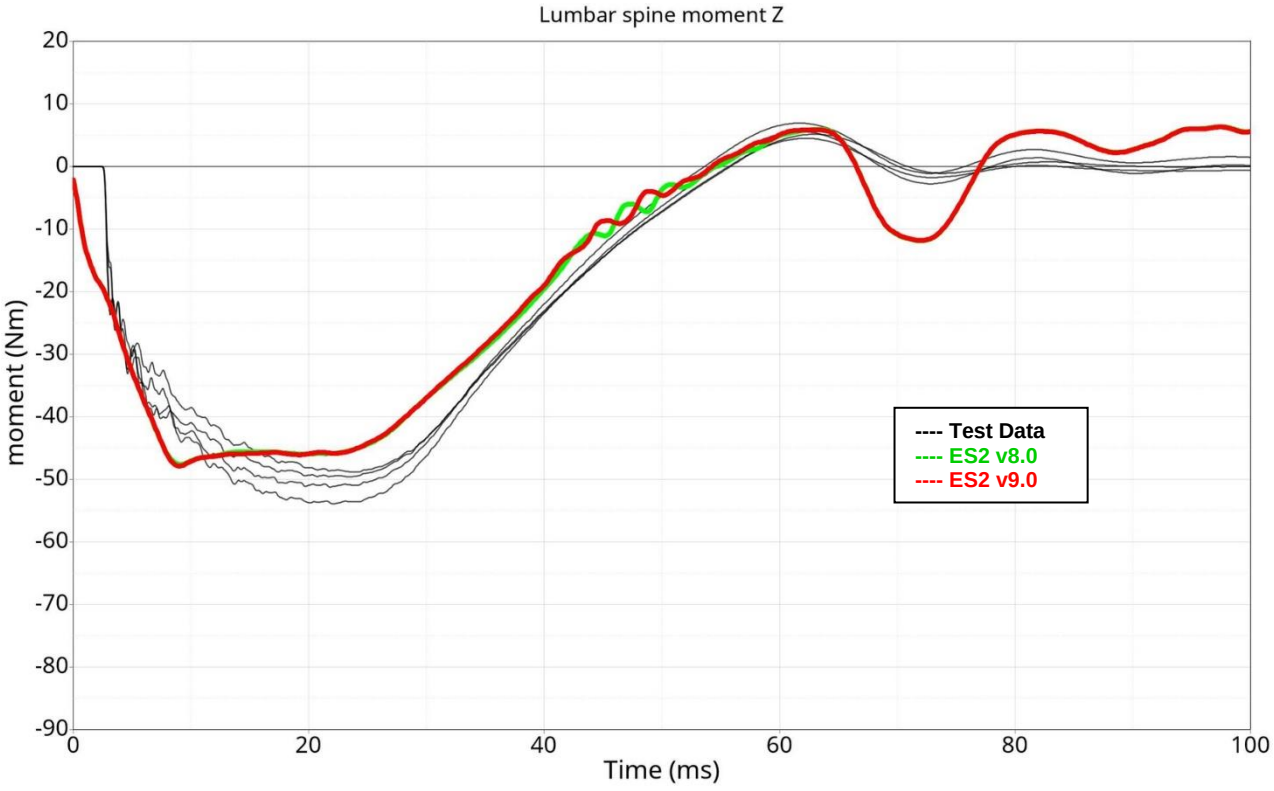
Results for shear high velocity



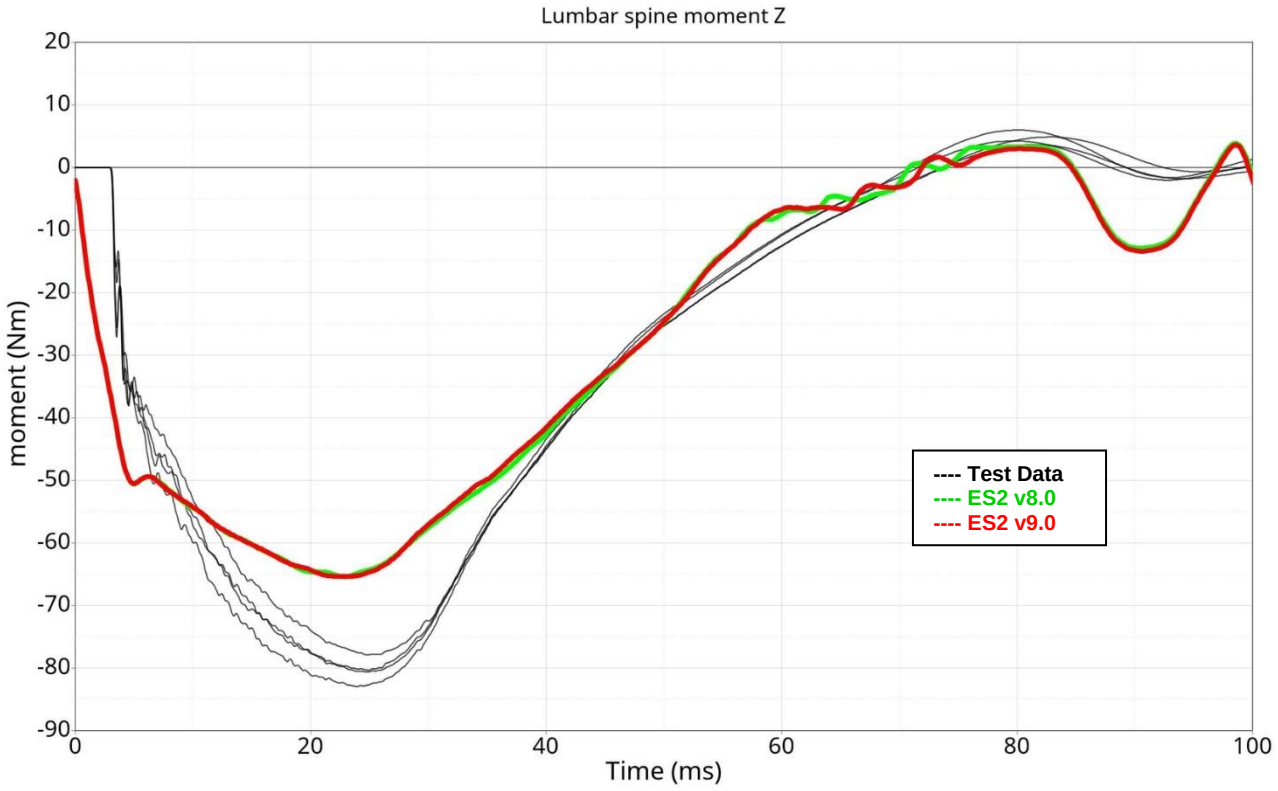
Results for torsion low velocity



Results for torsion medium velocity



Results for torsion high velocity



11.1.7 Iliac wing test

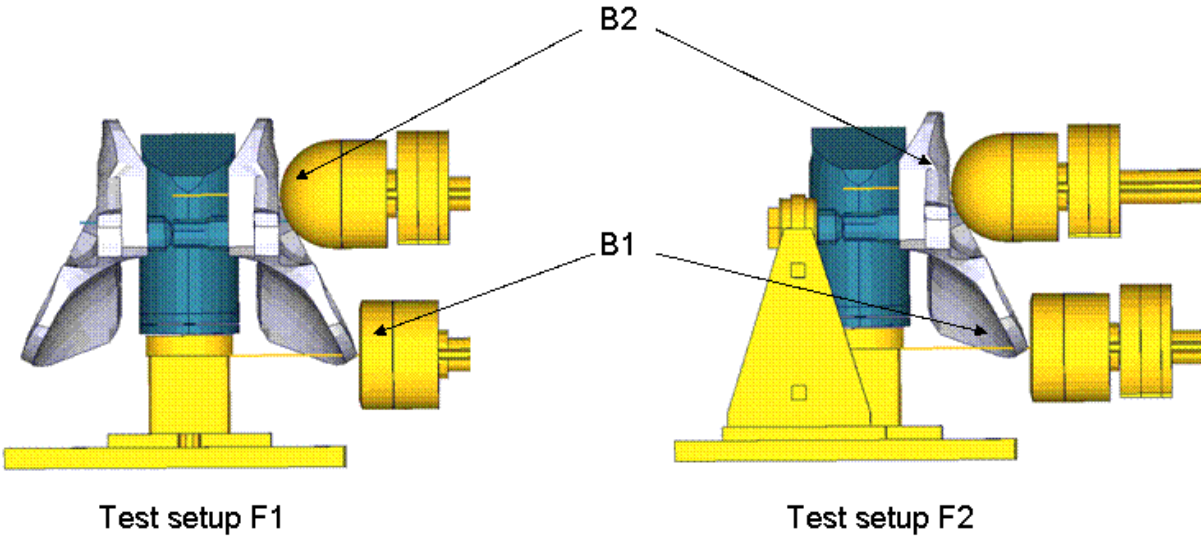
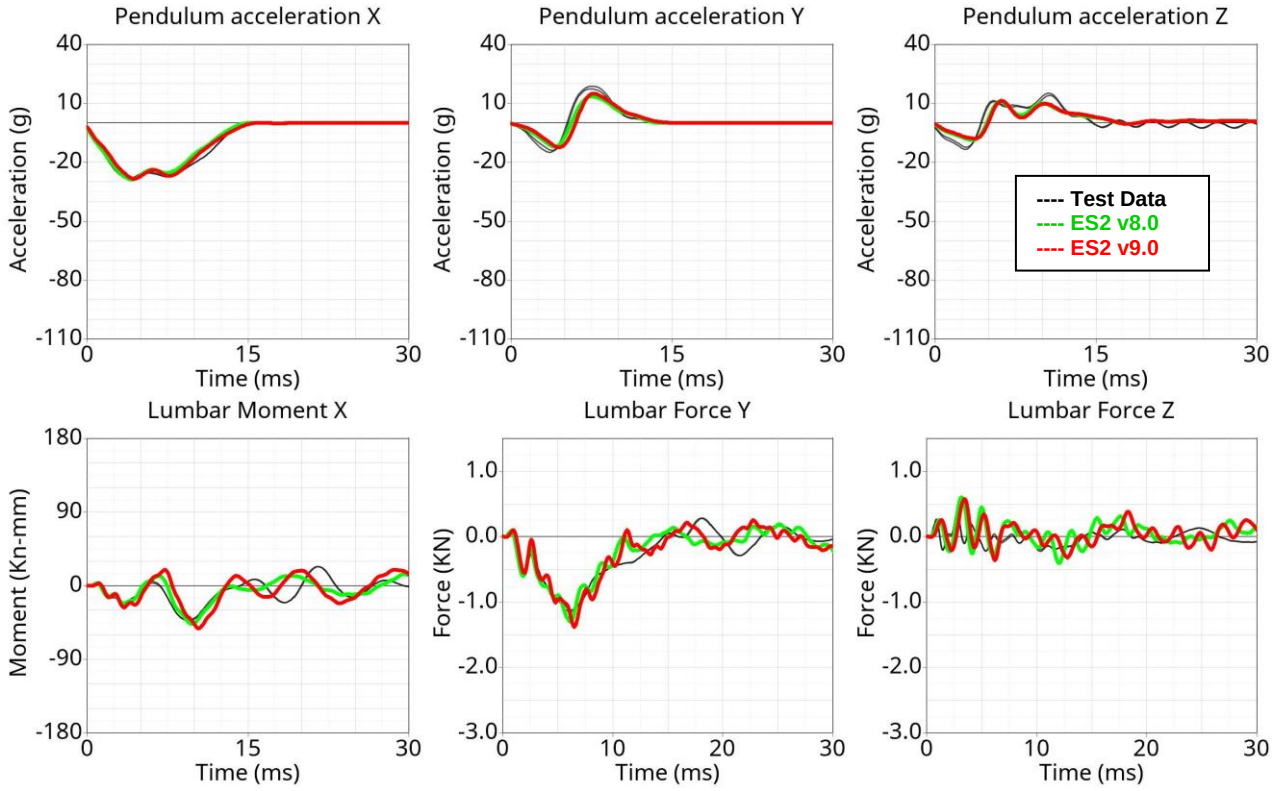
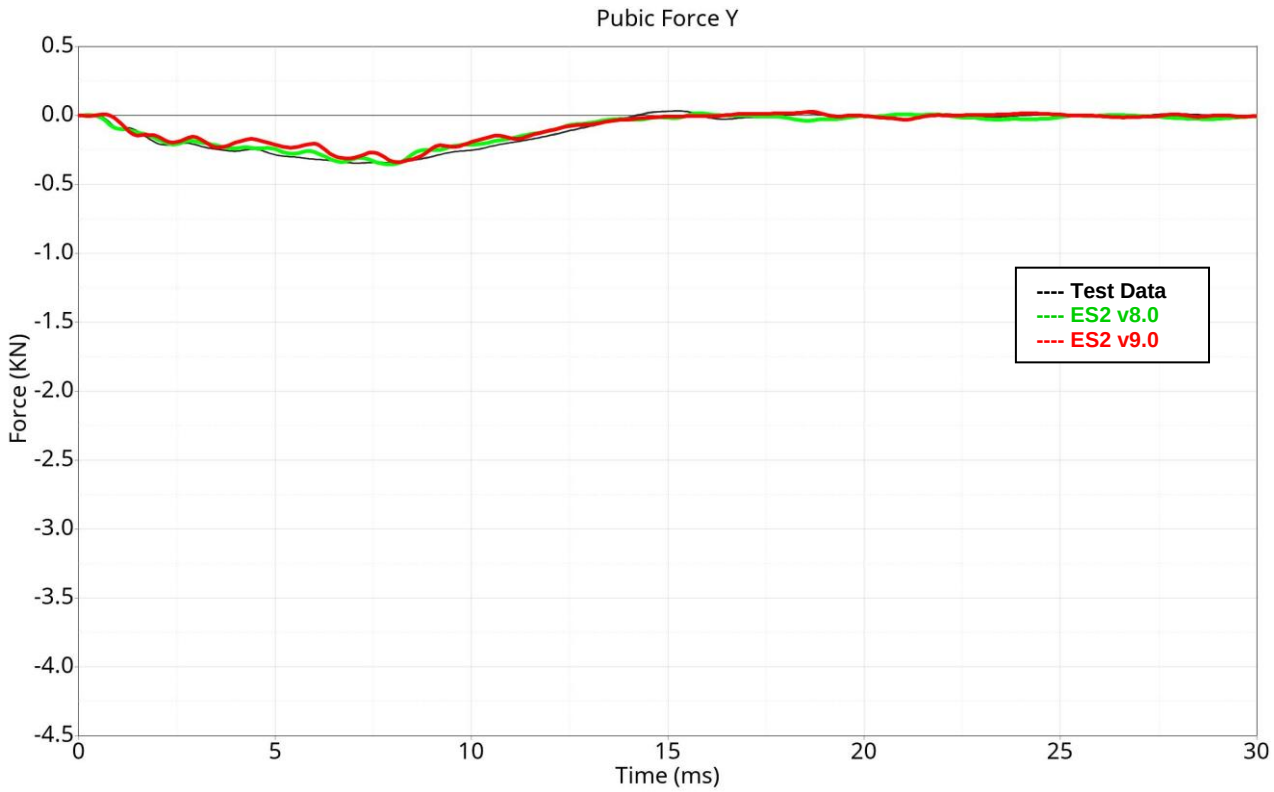


Figure 33: Test setup for iliac wing test

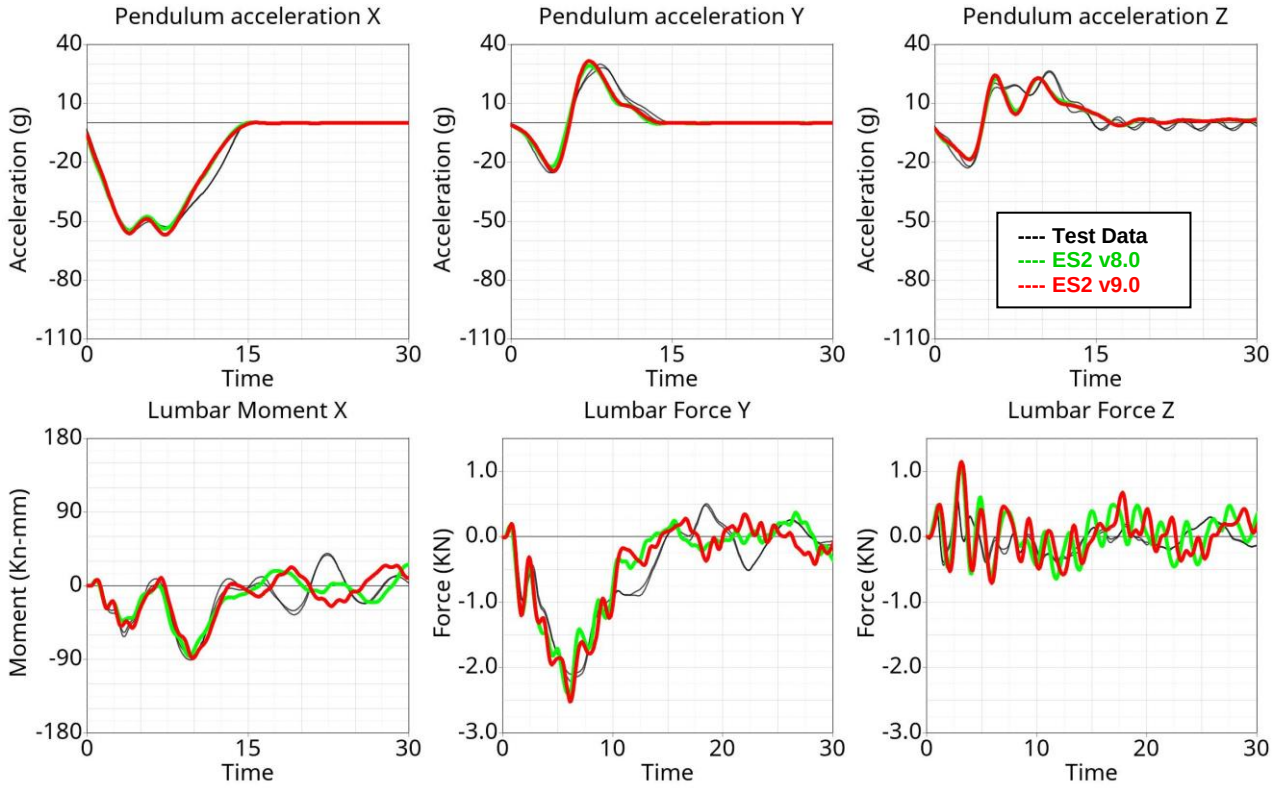
The Iliac wing assembly is mounted on a test block as shown in the figure above. The Iliac wings are impacted by a hemispherical-headed pendulum and a cylindrical-headed pendulum at two different points as indicated in the figure. The pendulum masses are varied for different configurations and the test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

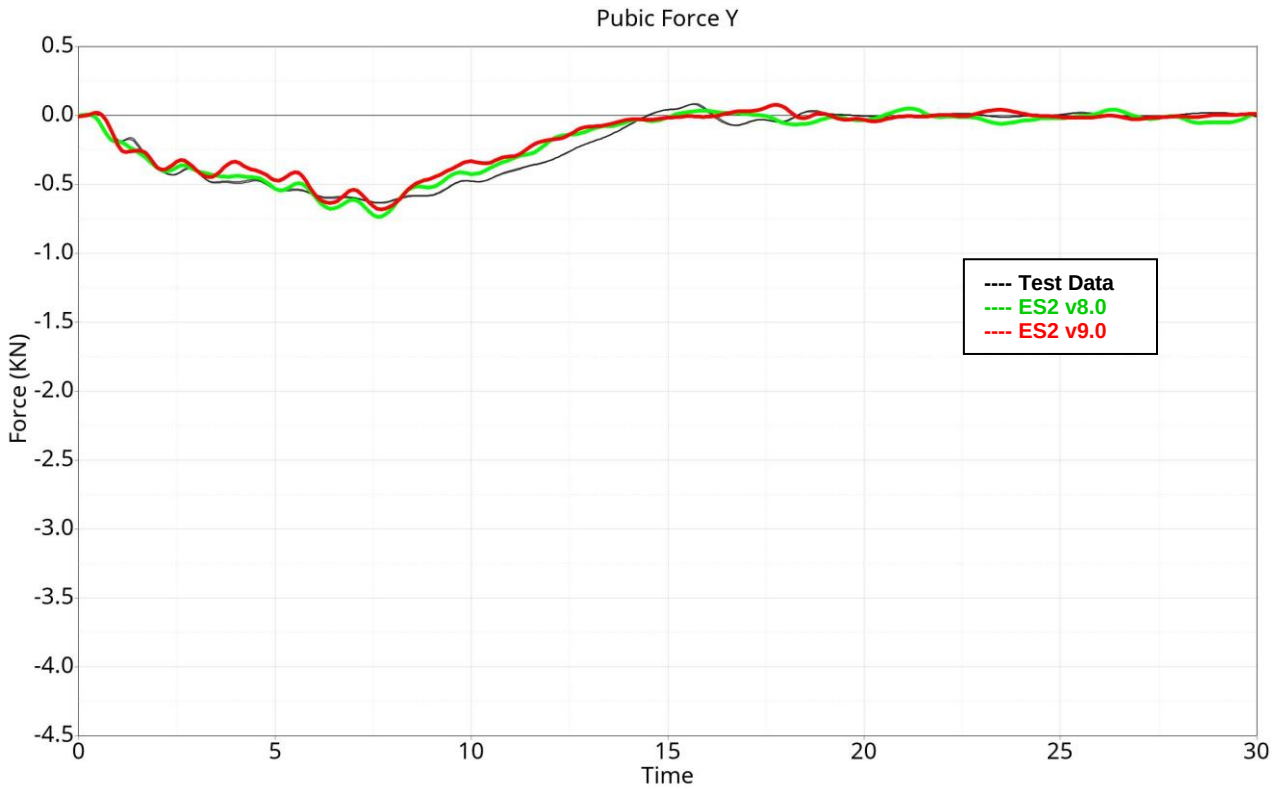
Results for configuration F1B1M1, low velocity



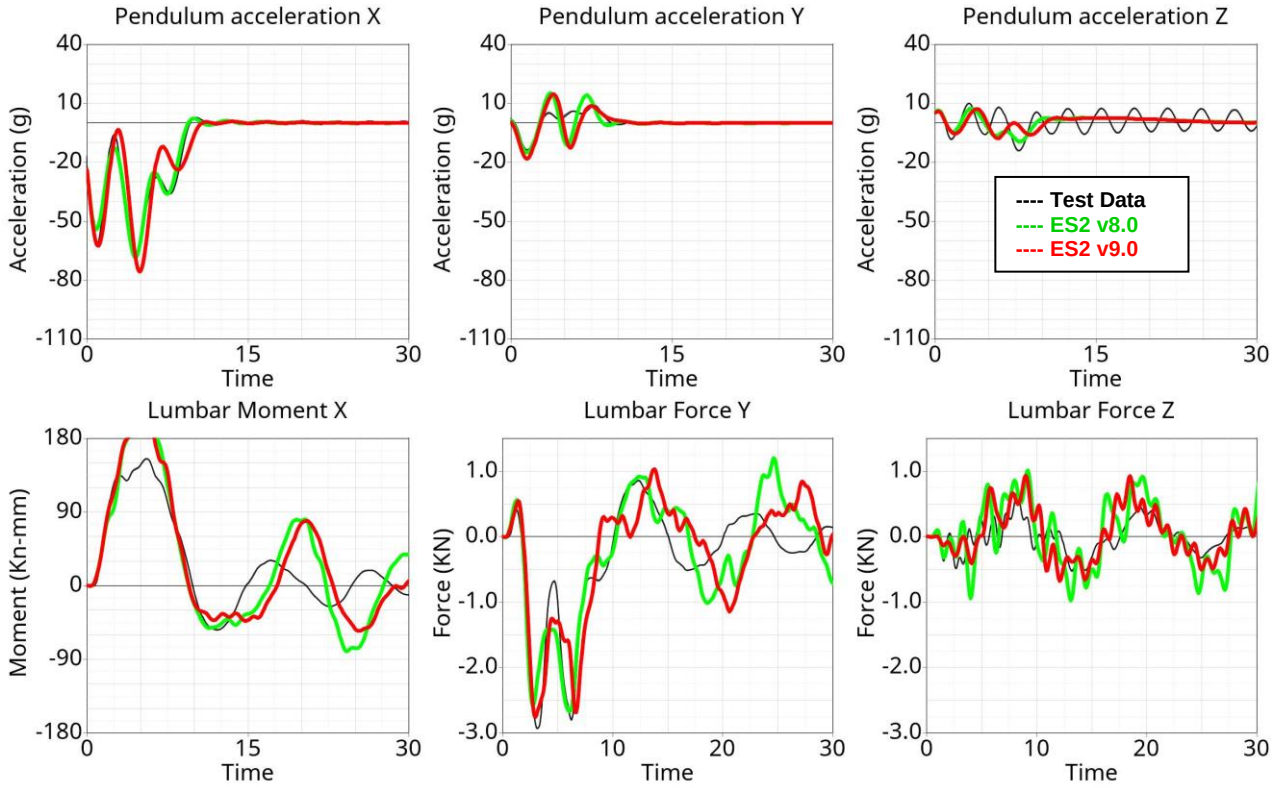


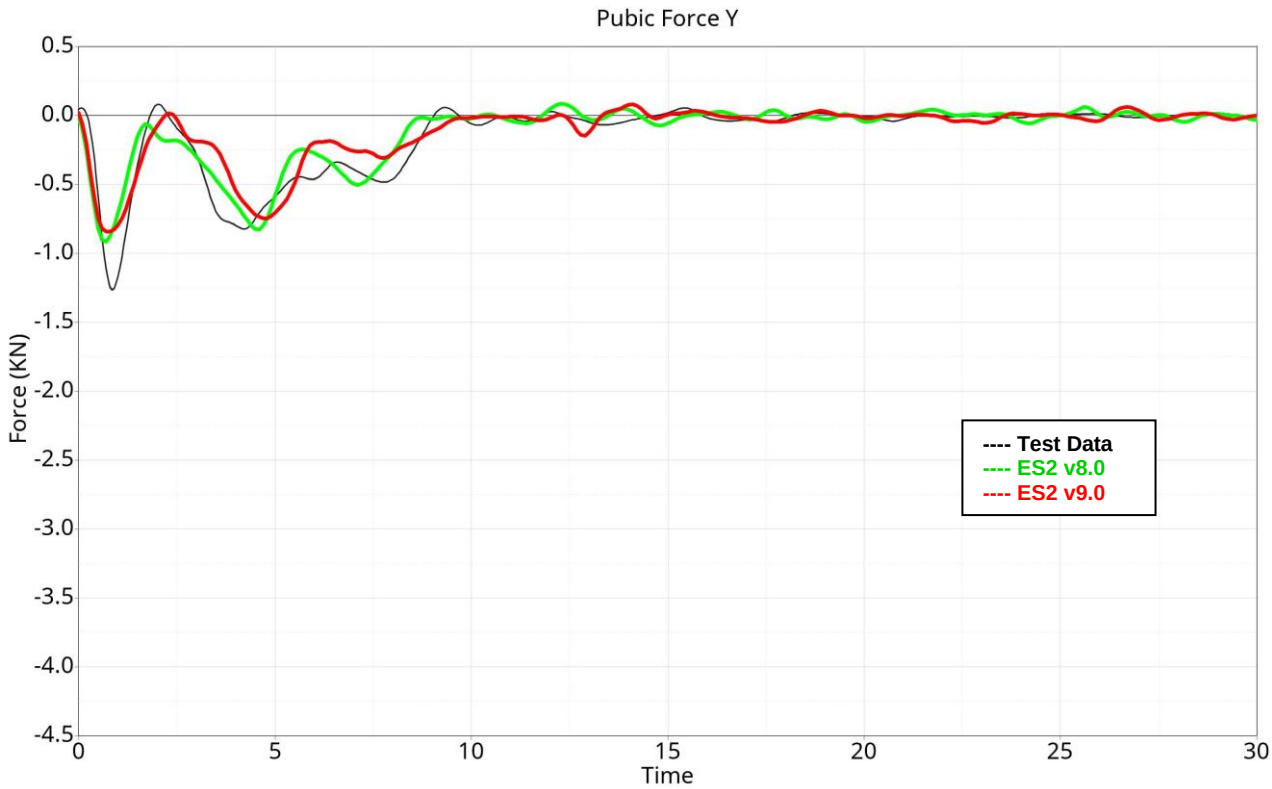
Results for configuration F1B1M1, high velocity



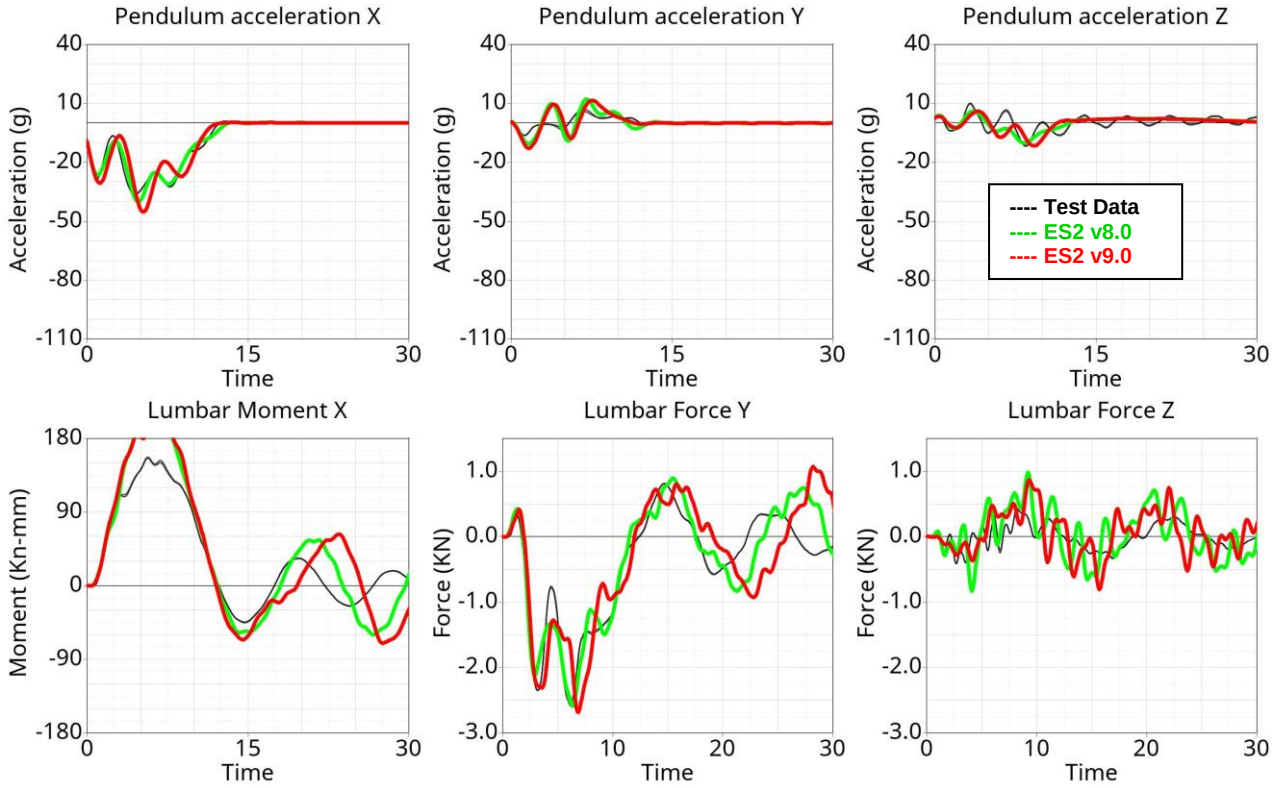


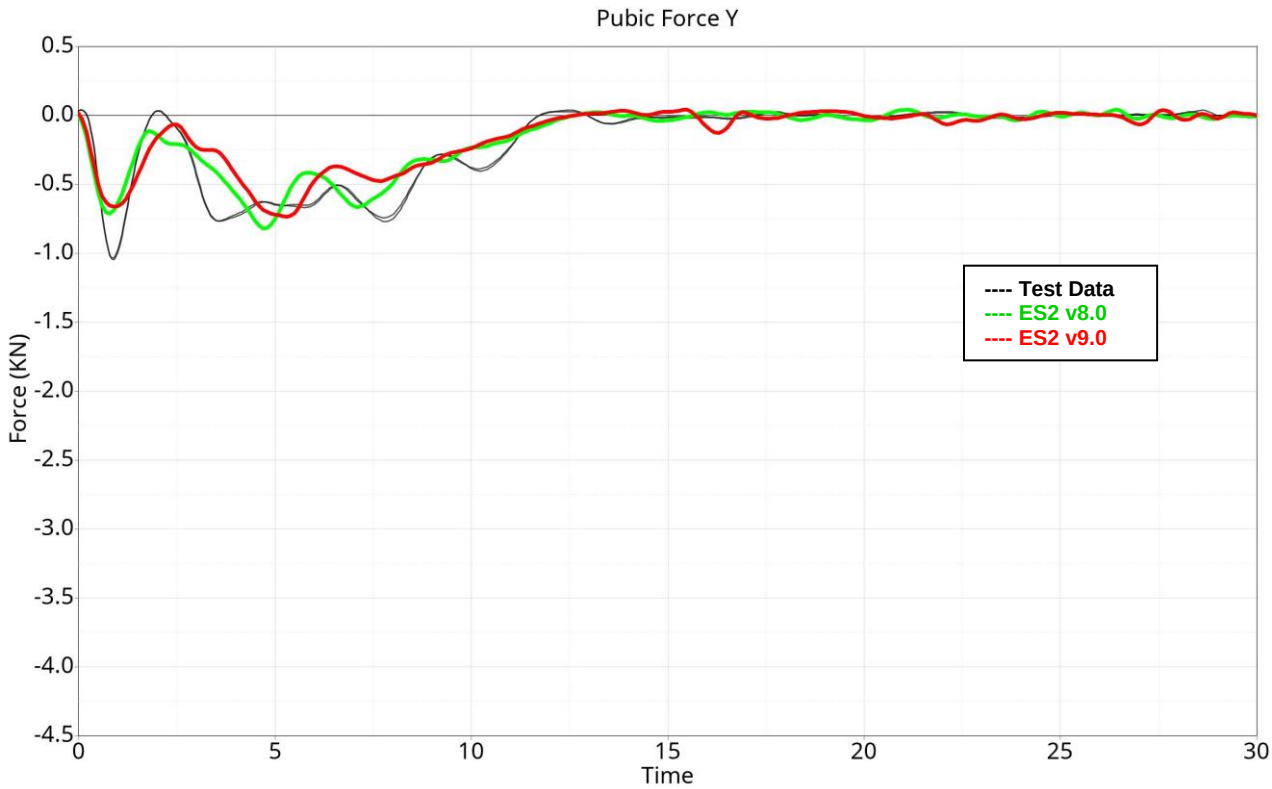
Results for configuration F1B2M1, high velocity



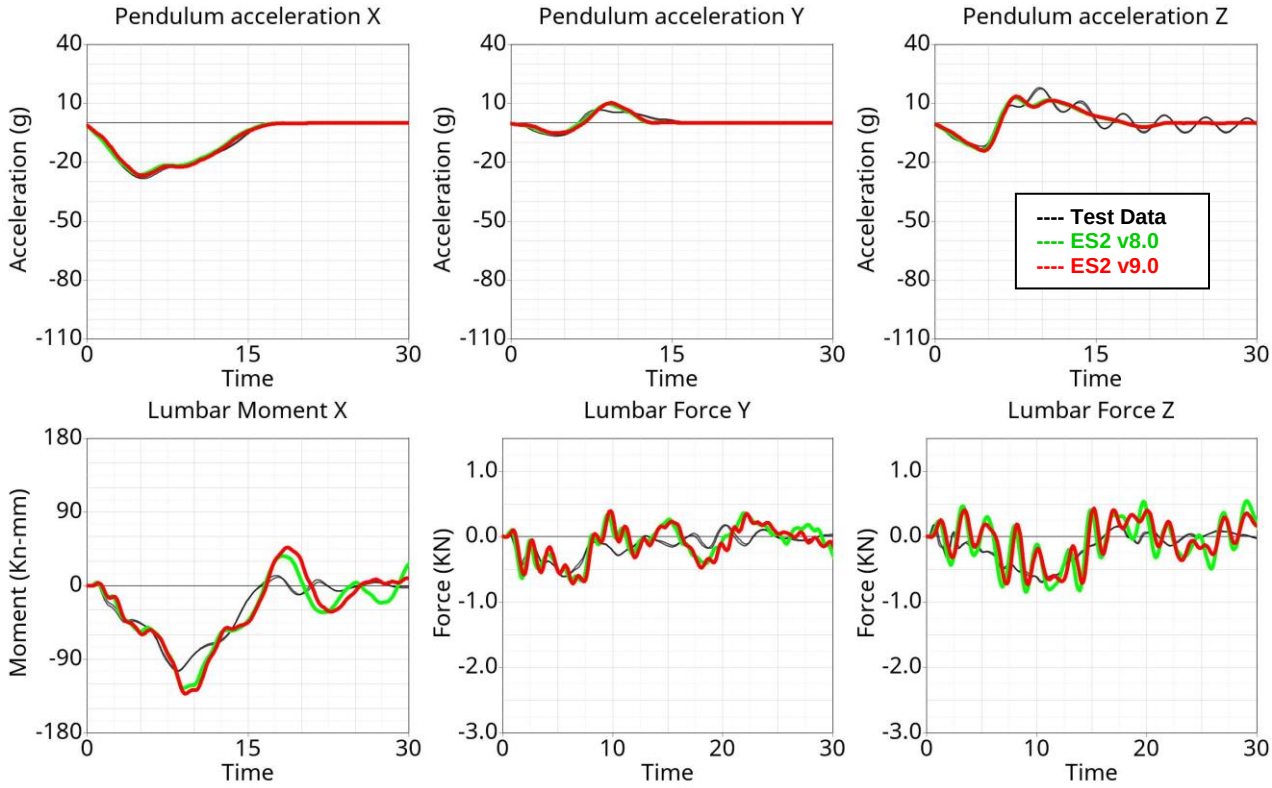


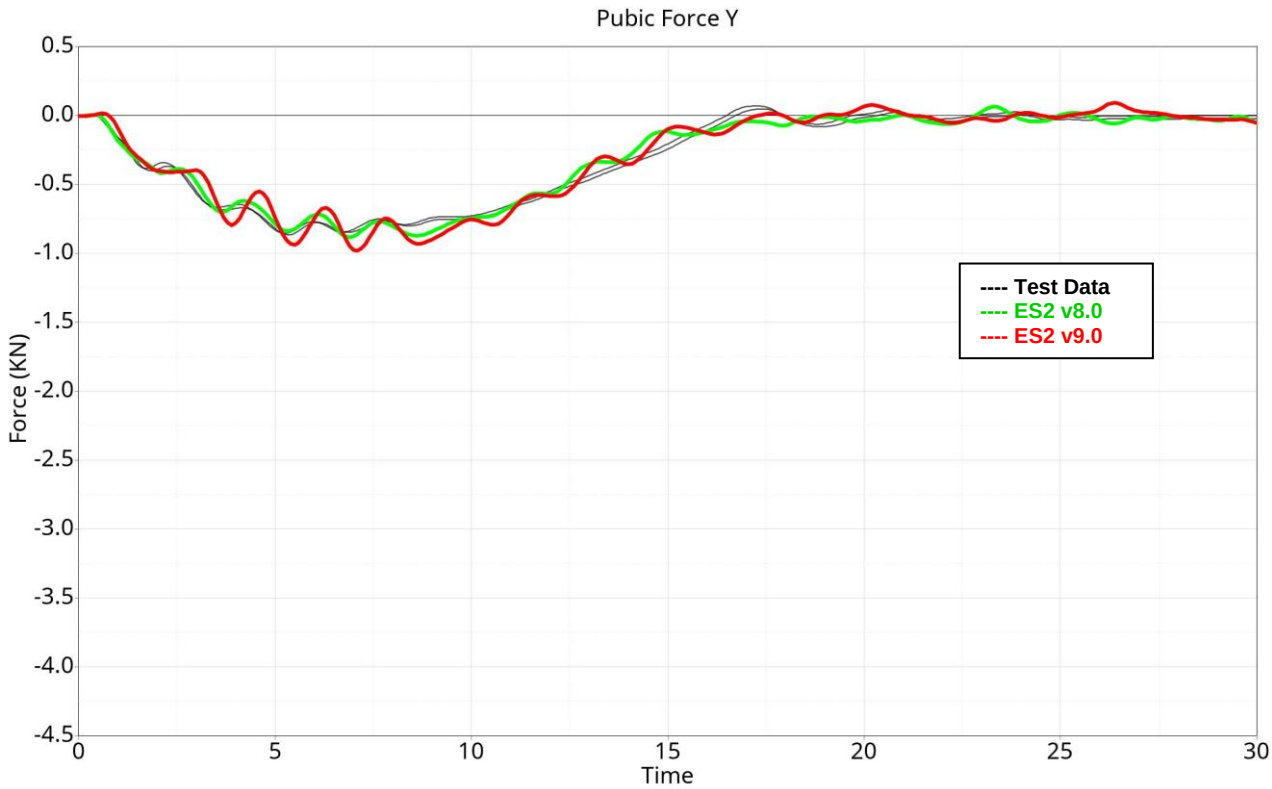
Results for configuration F1B2M2, low velocity



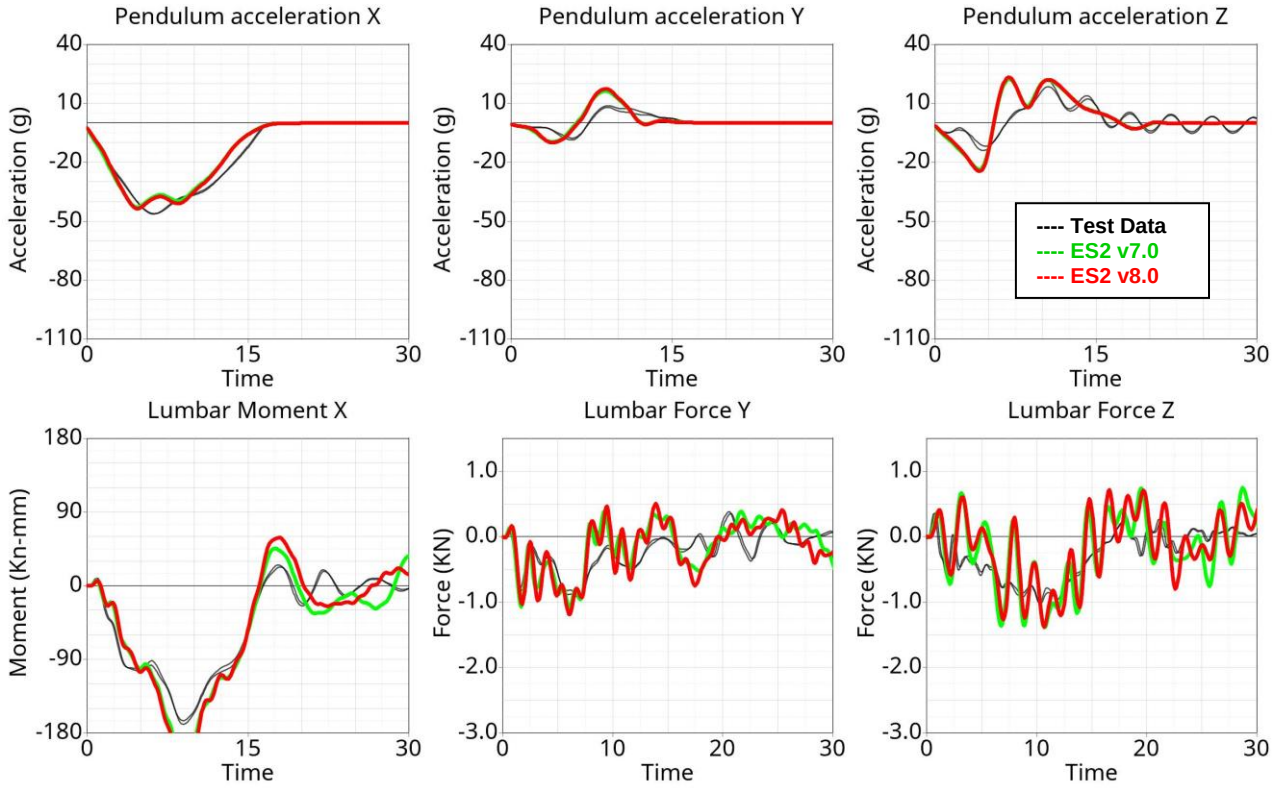


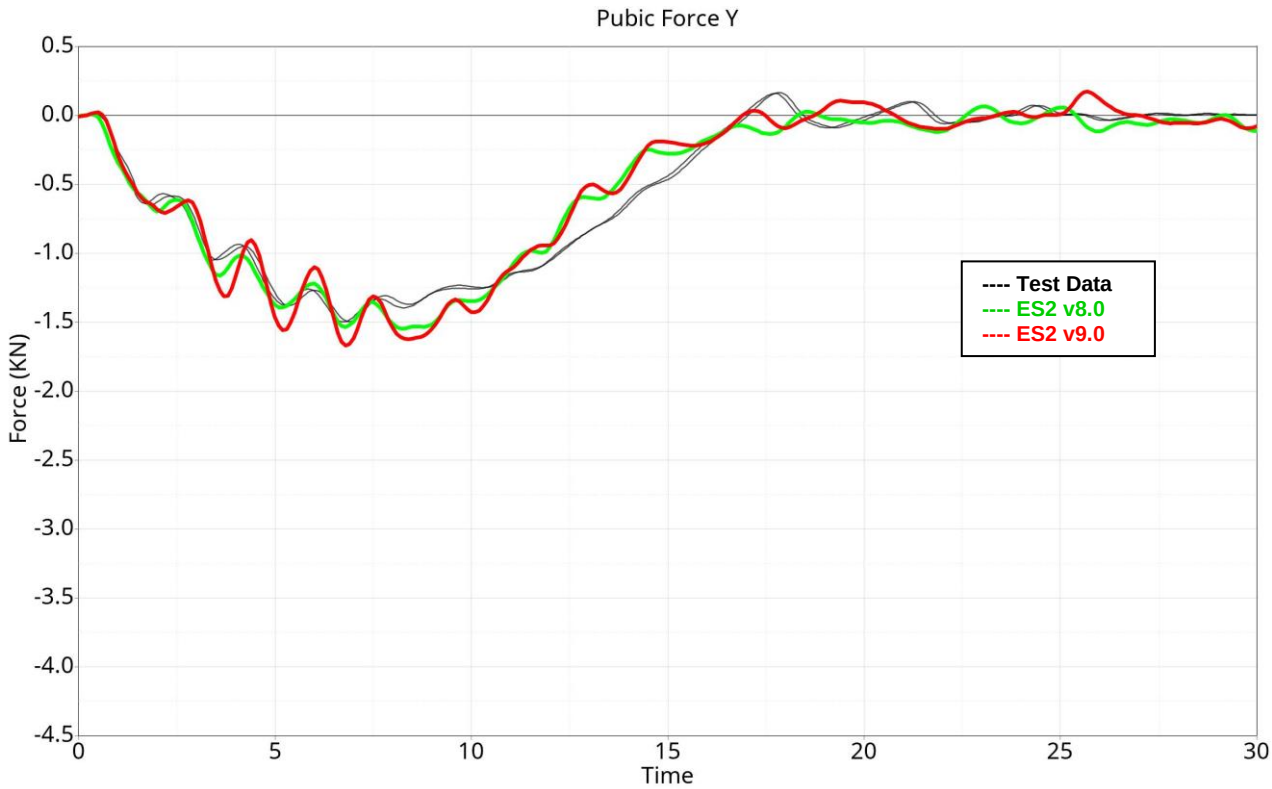
Results for configuration F2B1M2, low velocity



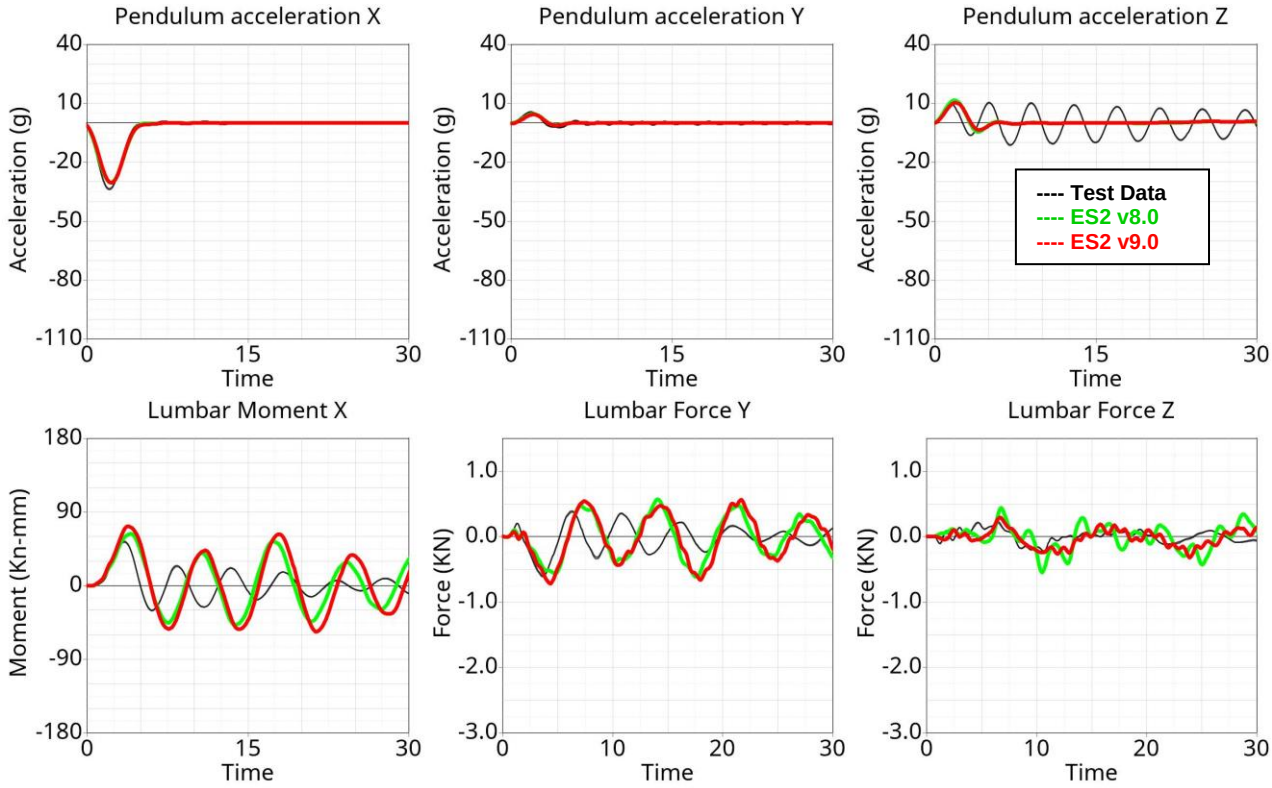


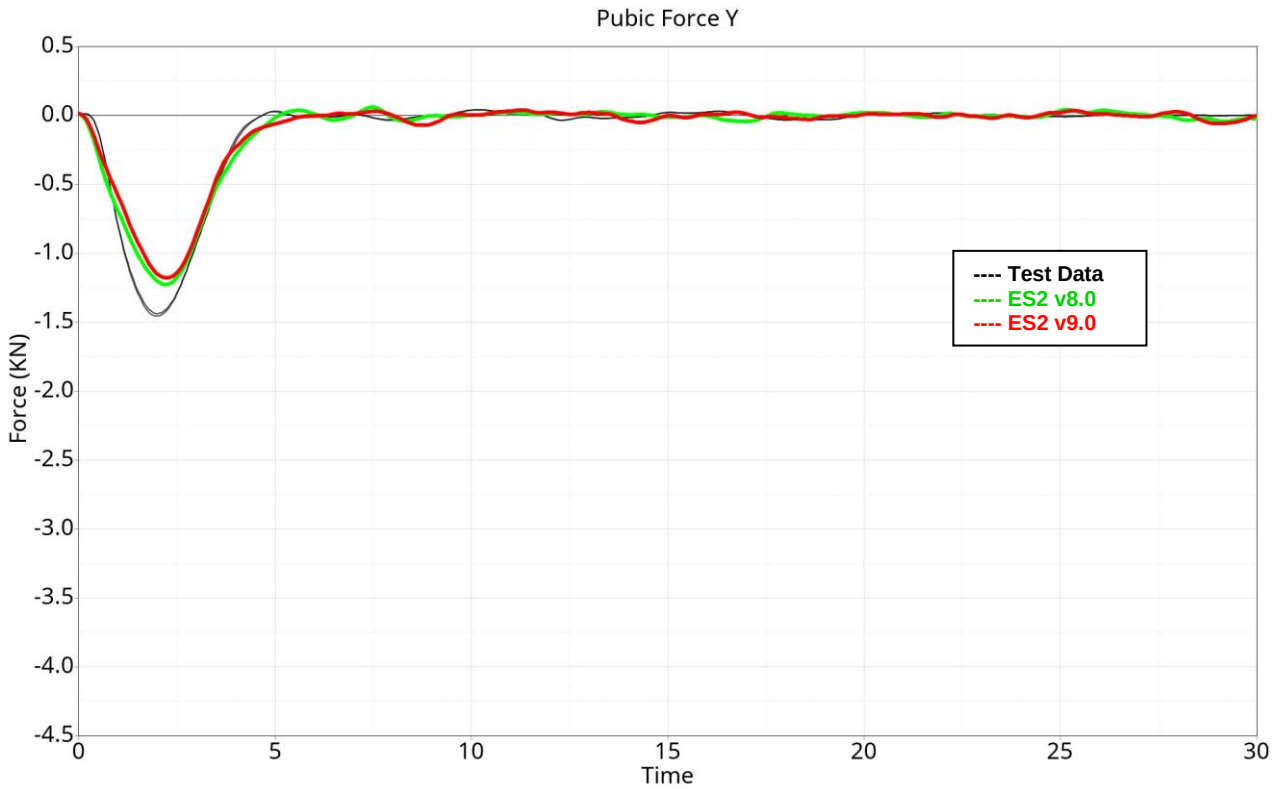
Results for configuration F2B1M2, high velocity



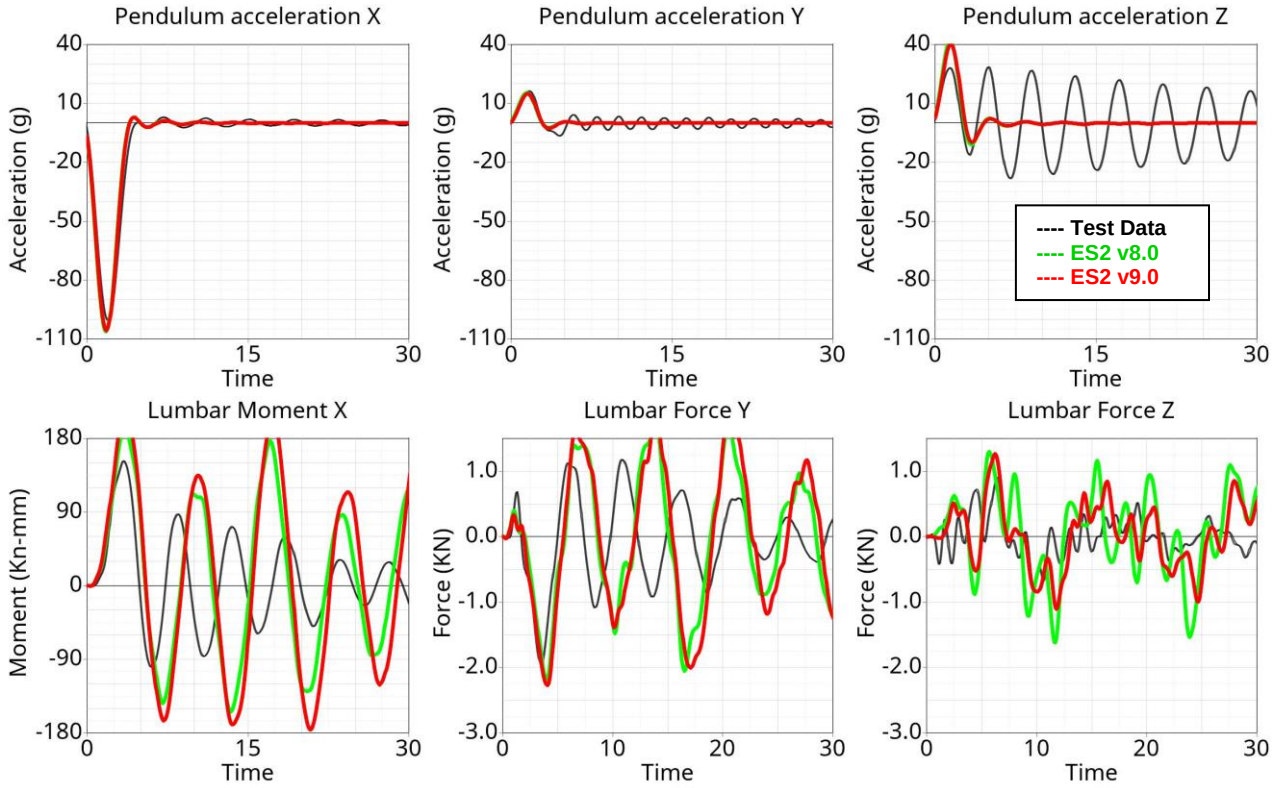


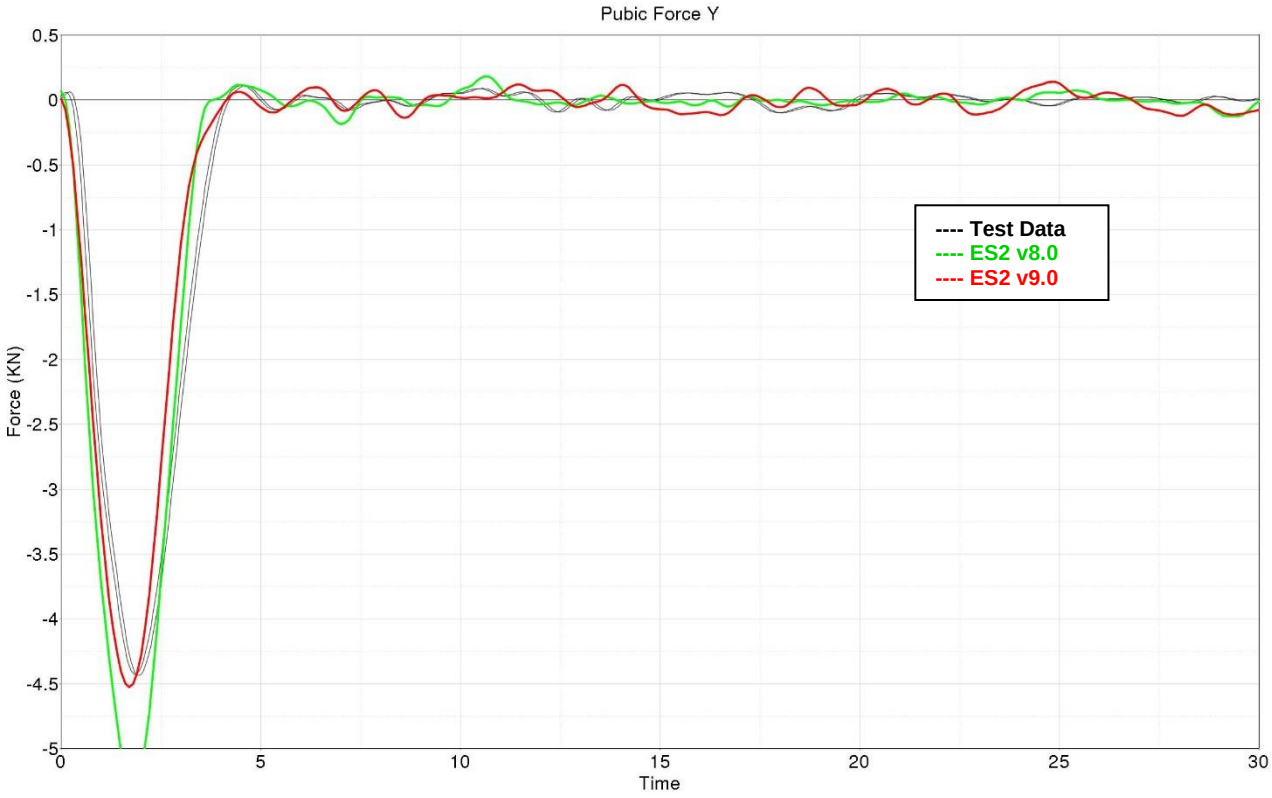
Results for configuration F2B2M2, low velocity





Results for configuration F2B2M2, high velocity





11.1.8 Femur stopper test

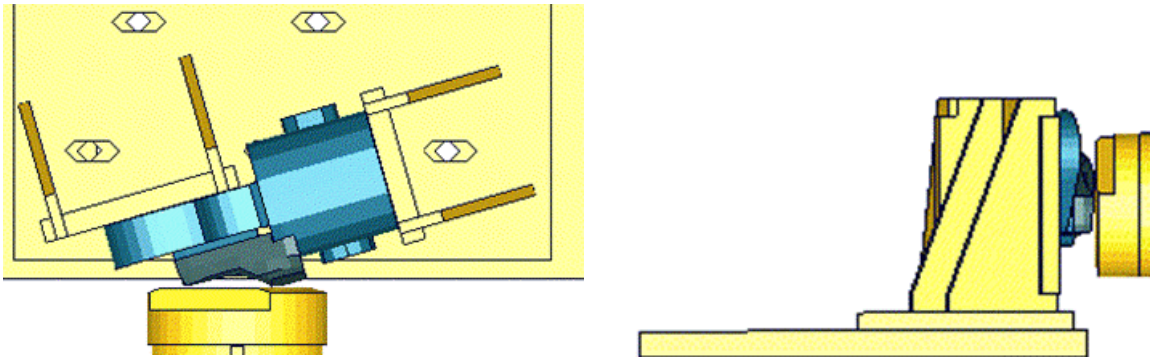
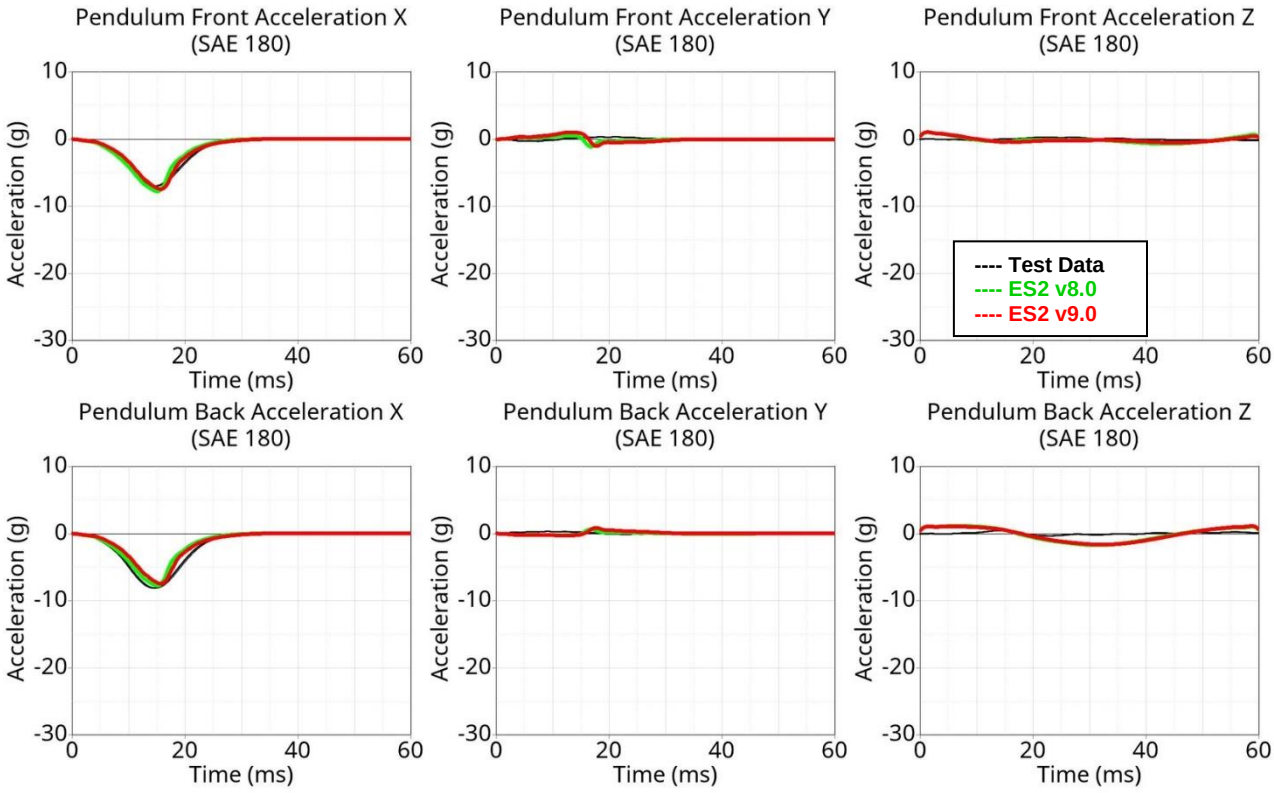


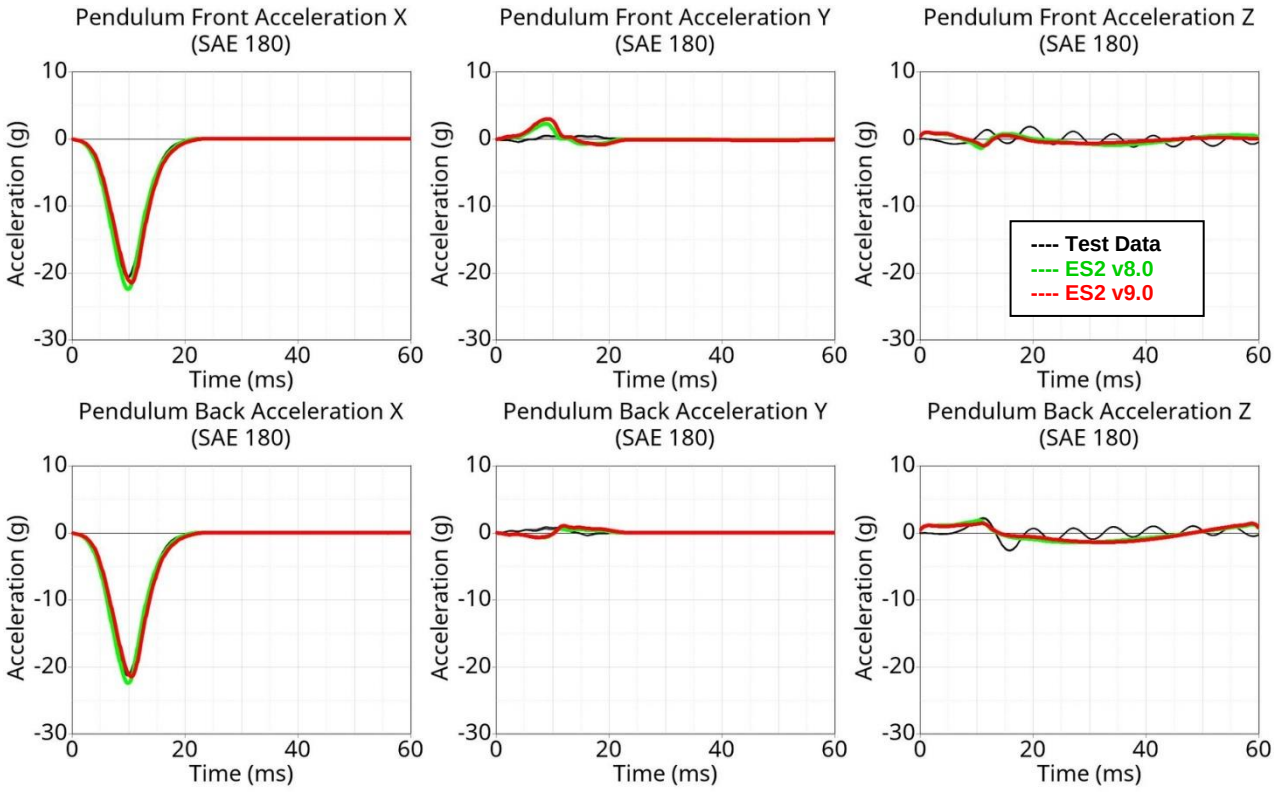
Figure 34: Femur stopper test

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

Results low velocity



Results high velocity



11.2 Rib module tests

11.2.1 Test setup 1

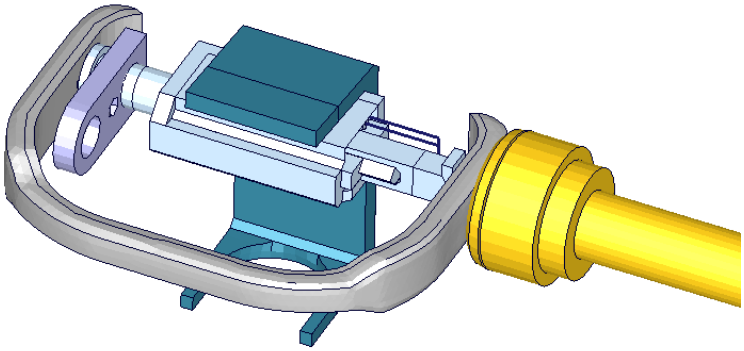
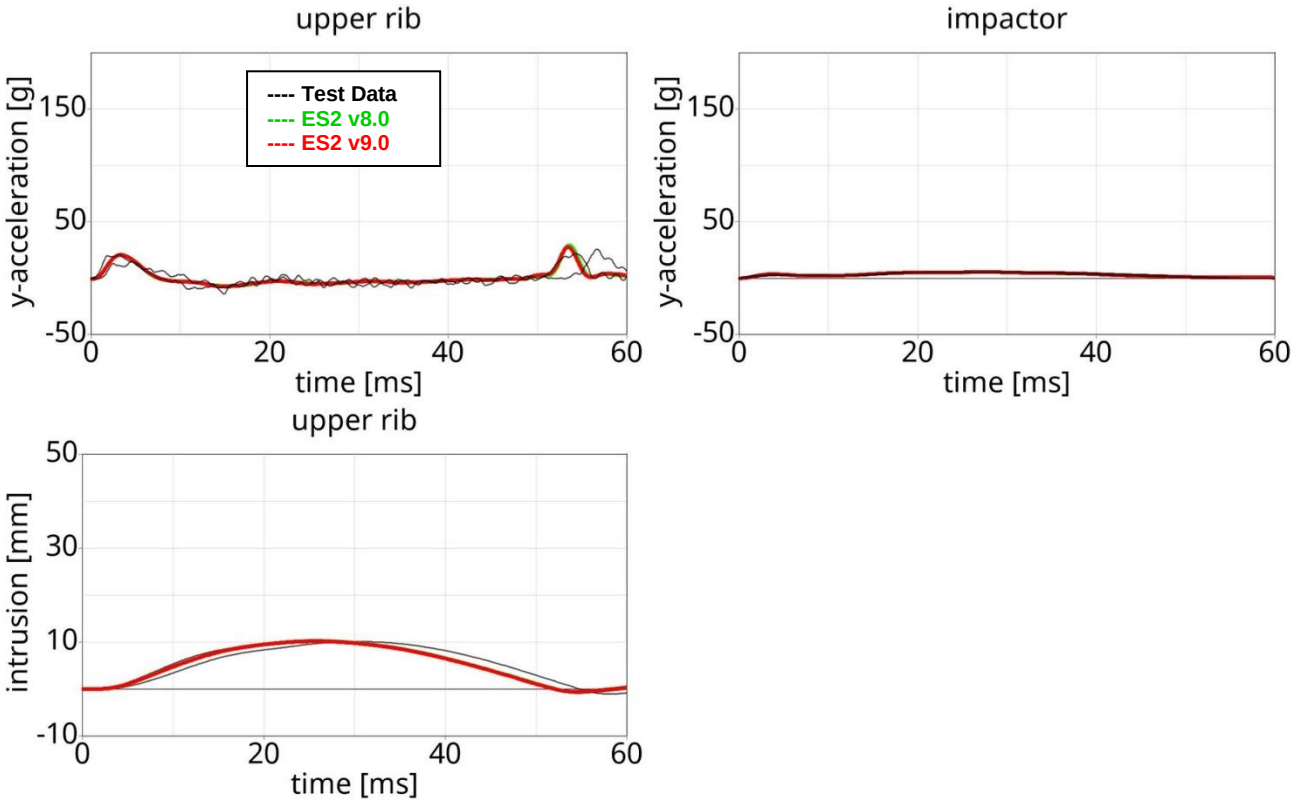


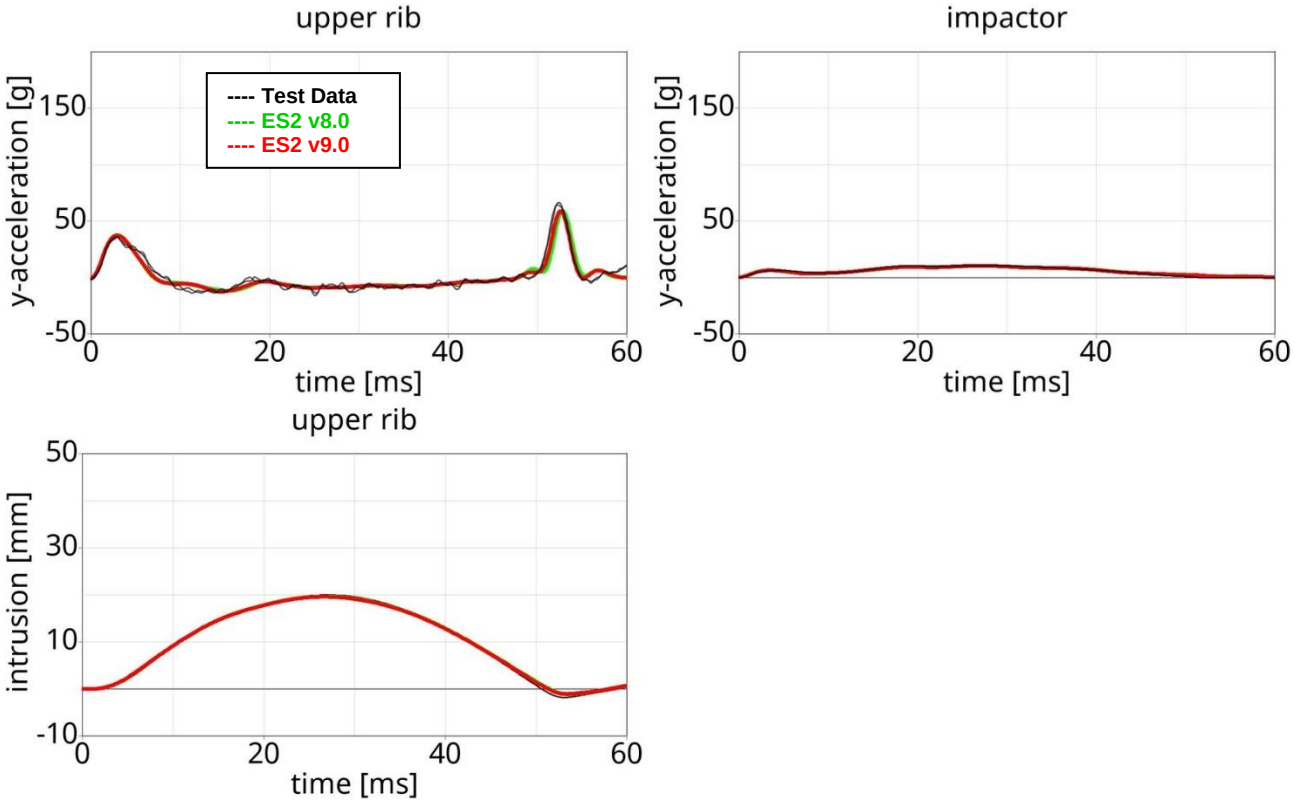
Figure 35: ES-2 rib module test setup 1

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

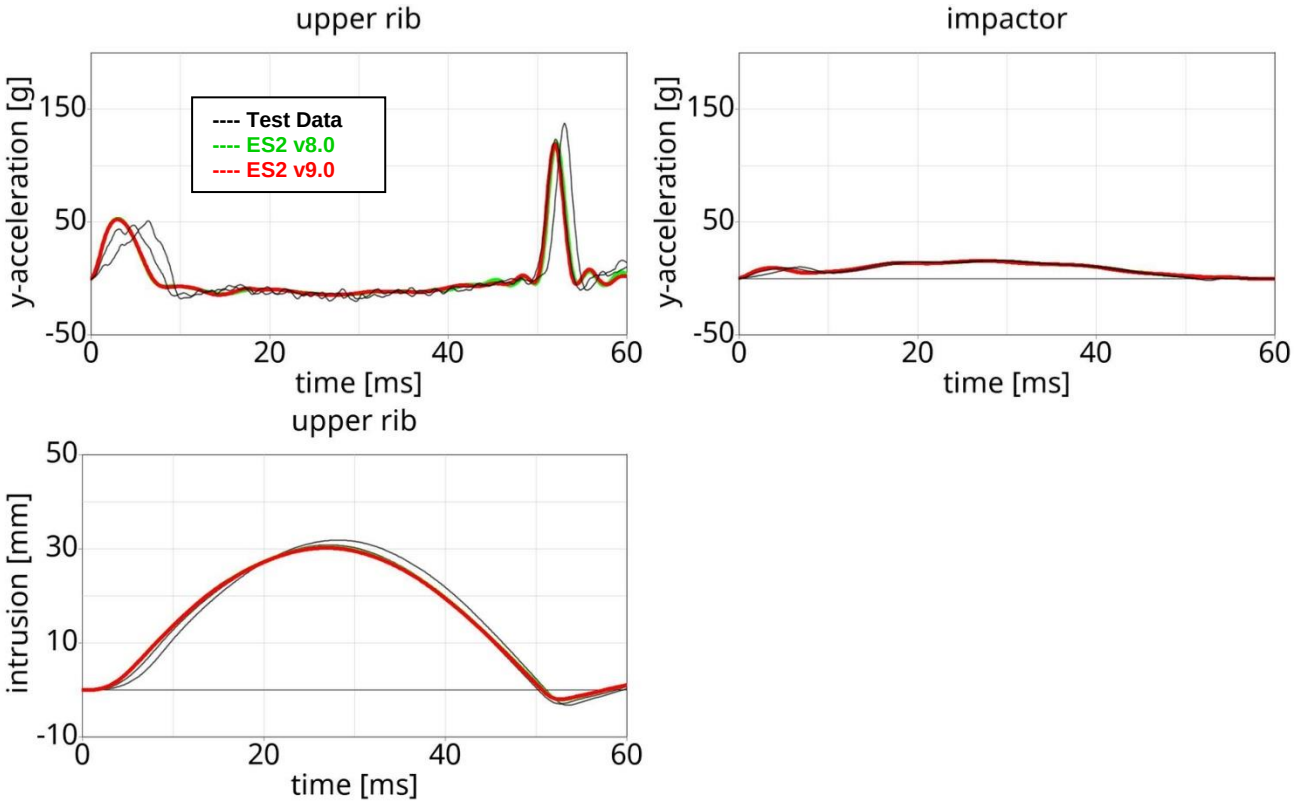
11.2.2 Test setup 1: velocity 1



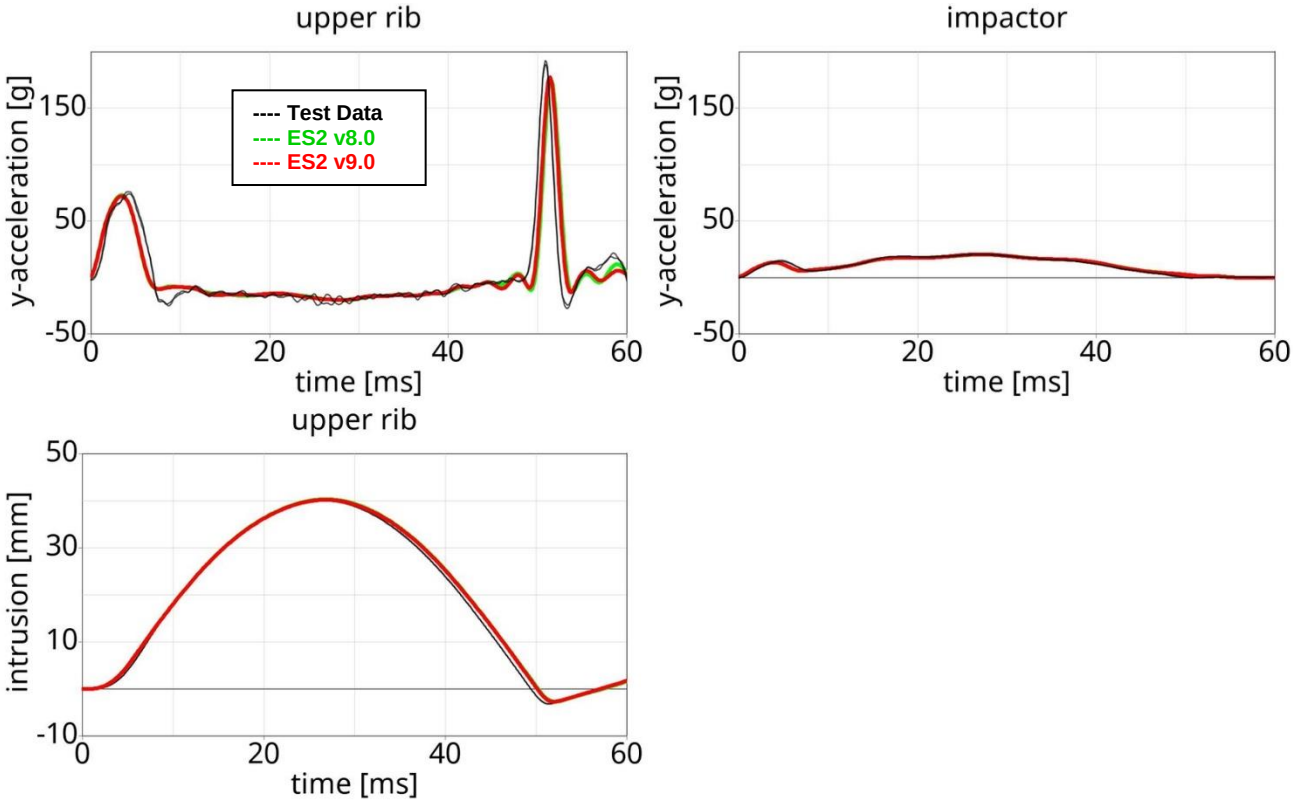
11.2.3 Test setup 1: velocity 2



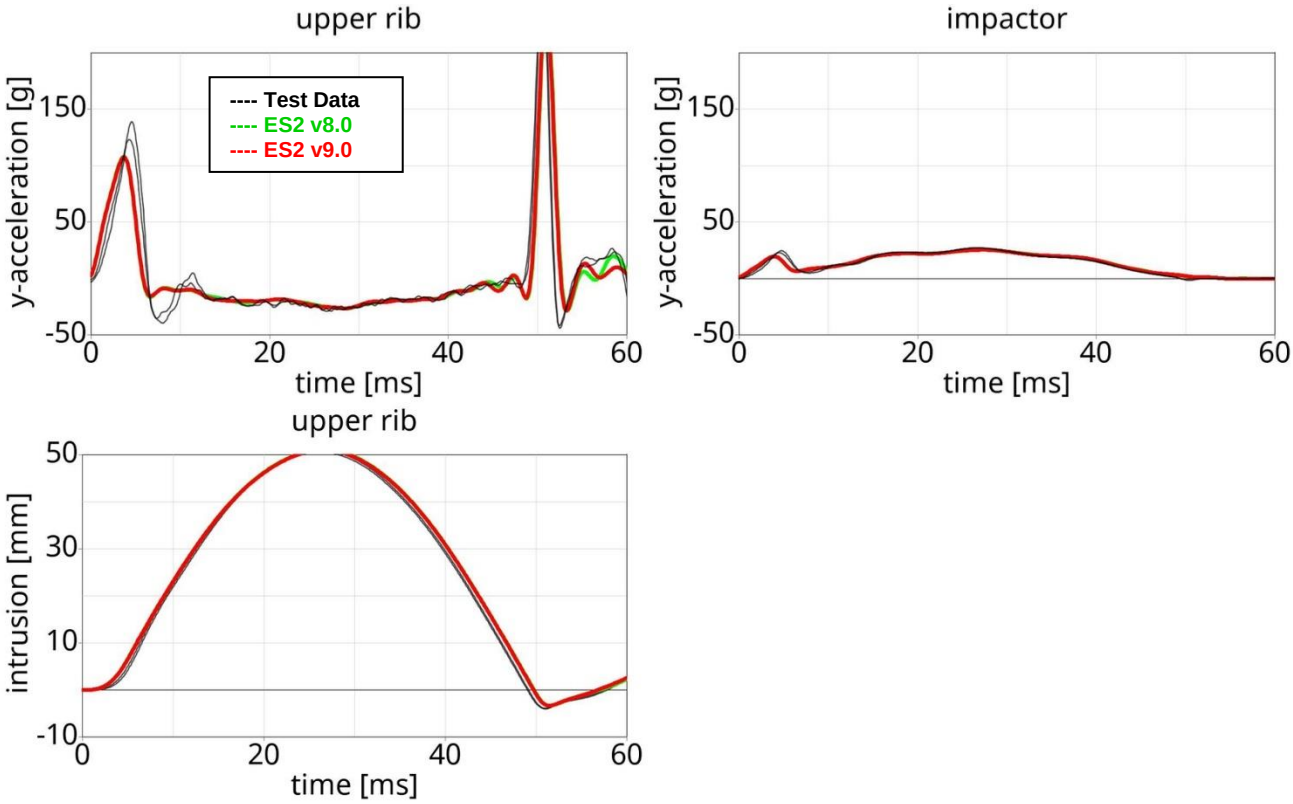
11.2.4 Test setup 1: velocity 3



11.2.5 Test setup 1: velocity 4



11.2.6 Test setup 1: velocity 5



11.2.7 Test setup 2

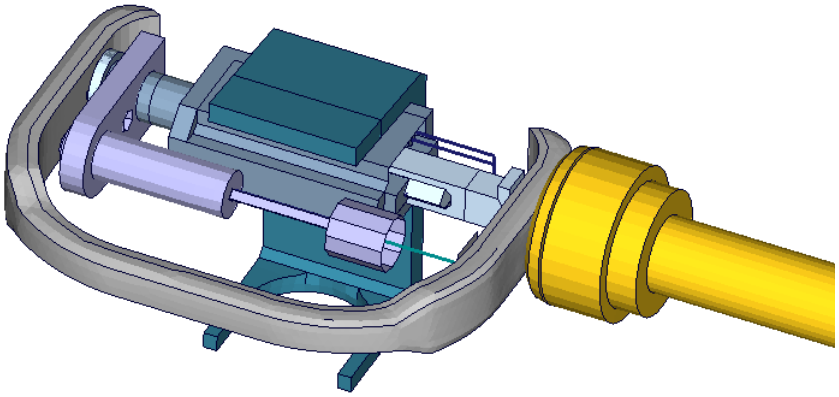
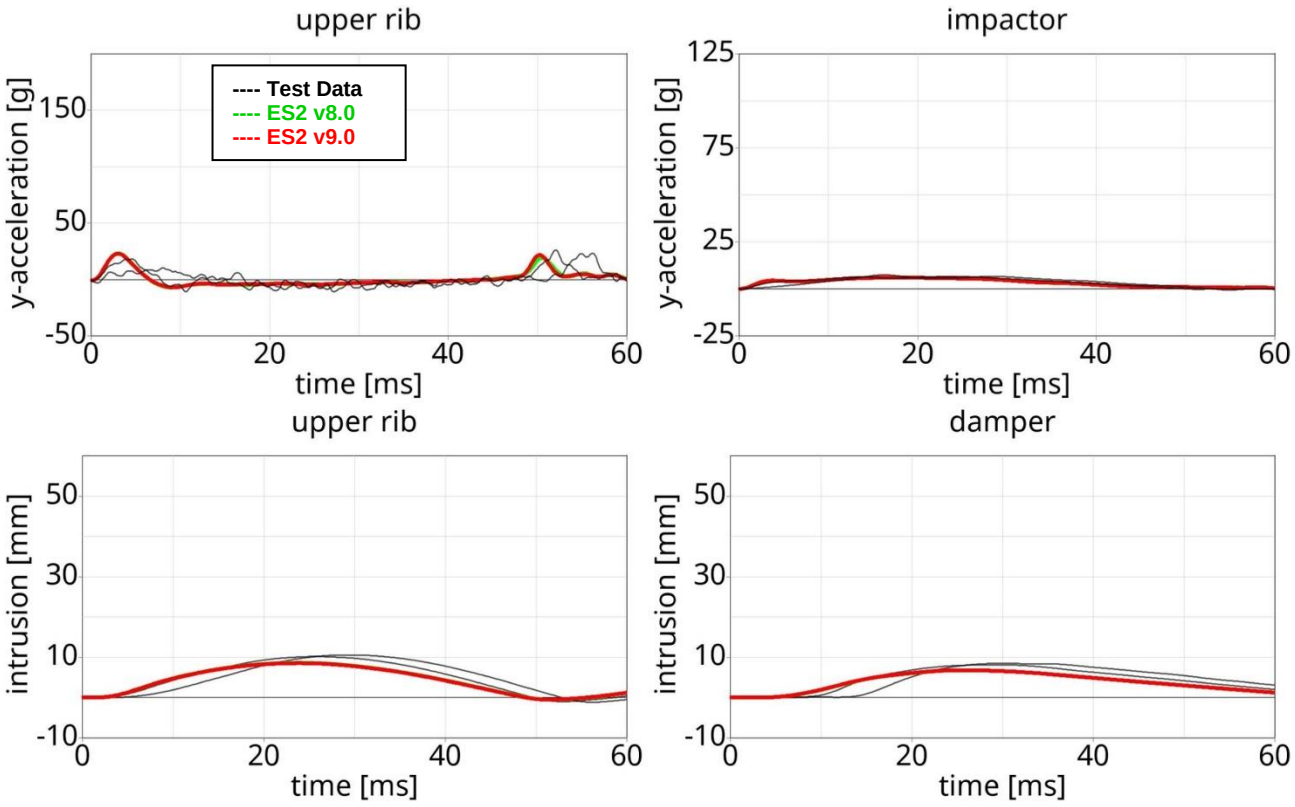


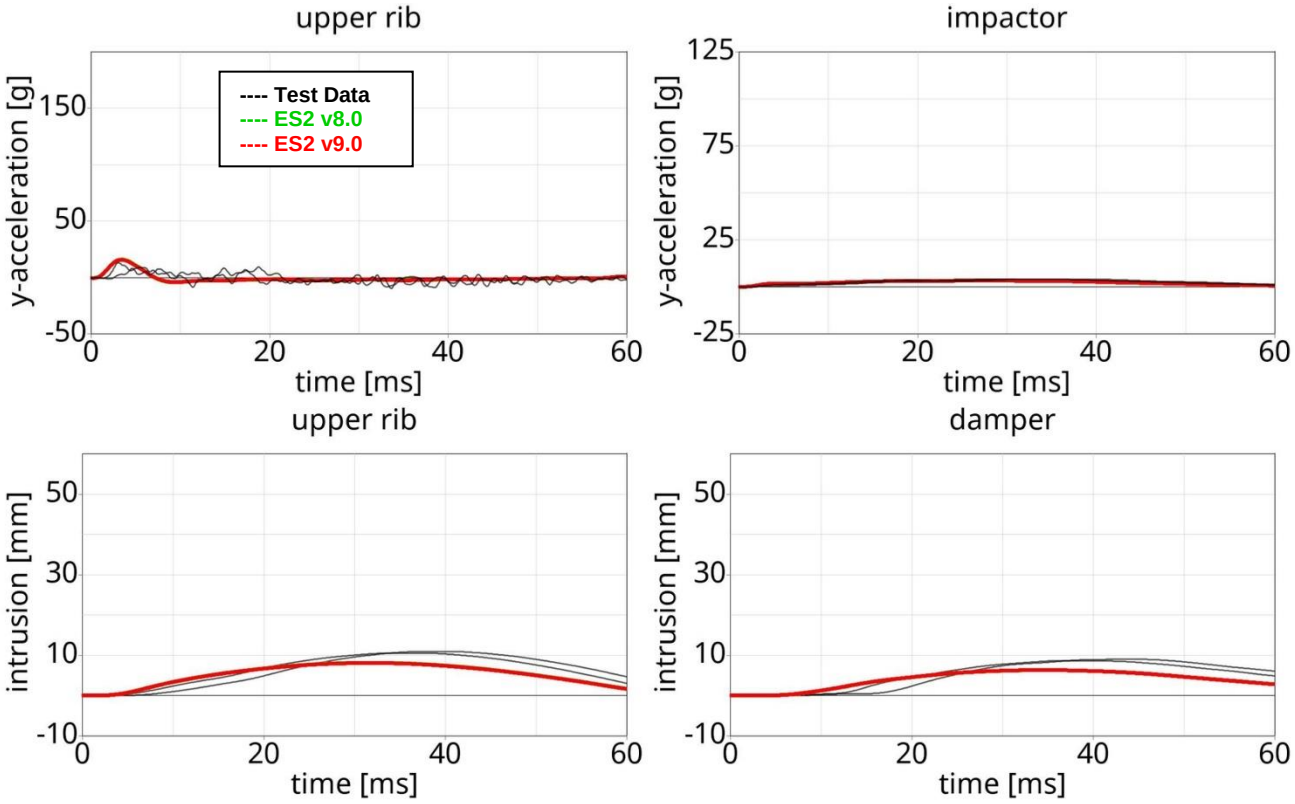
Figure 36: ES-2 rib module test setup 2

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

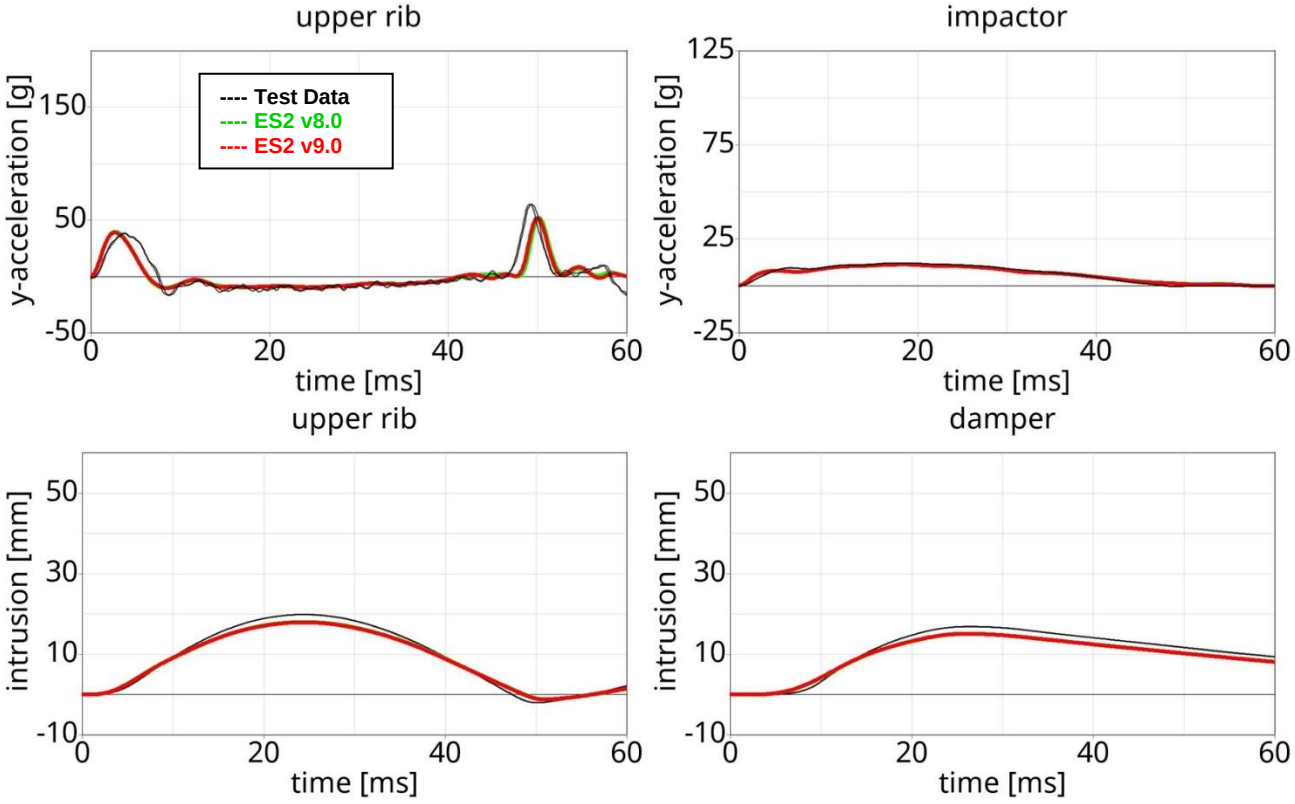
11.2.8 Test setup 2: velocity 1 low mass



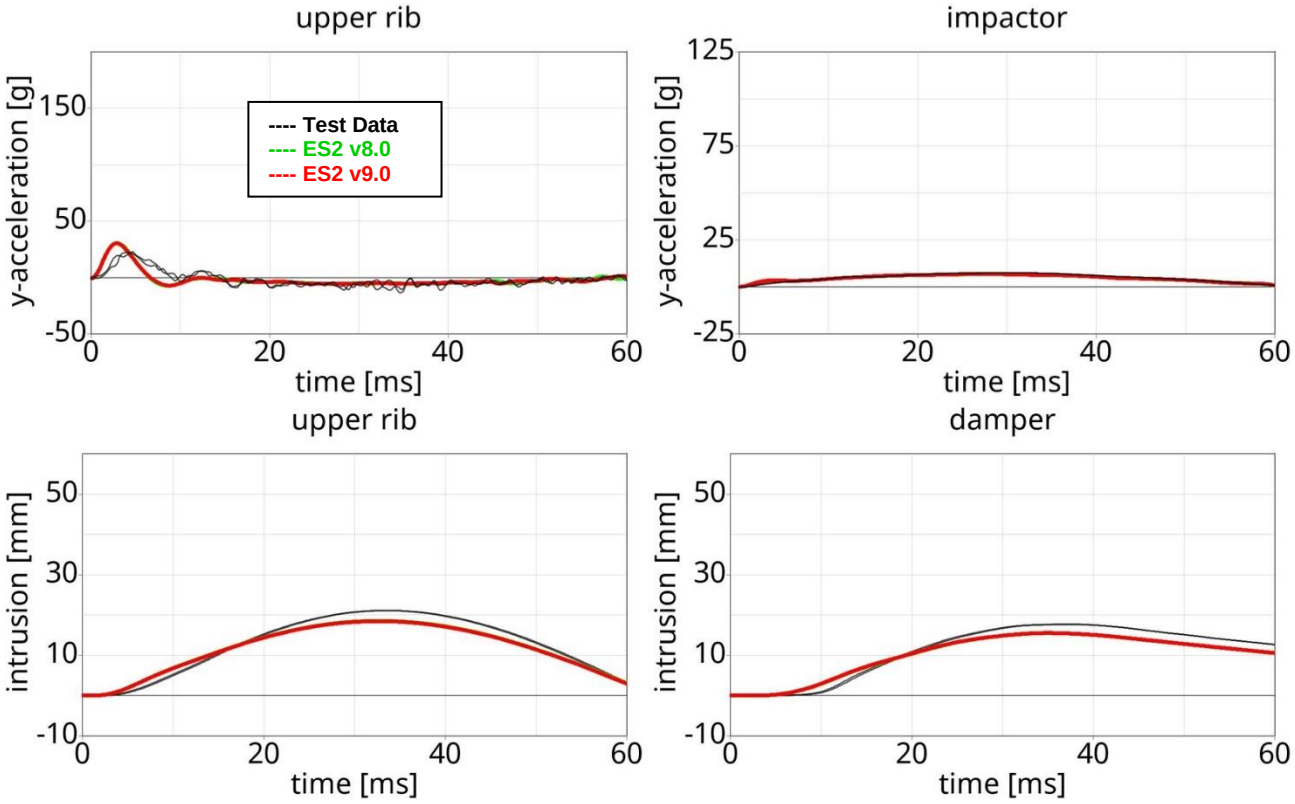
11.2.9 Test setup 2: velocity 1 high mass



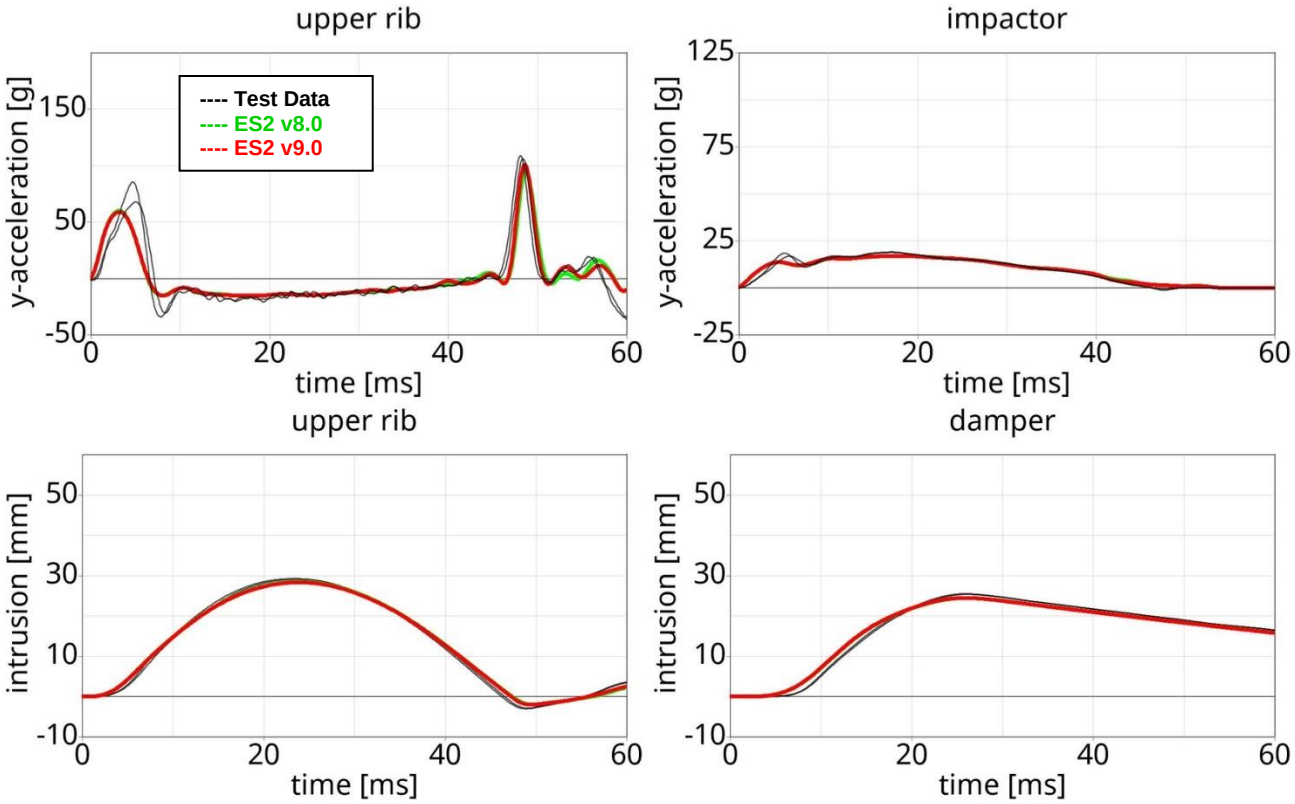
11.2.10 Test setup 2: velocity 2 low mass



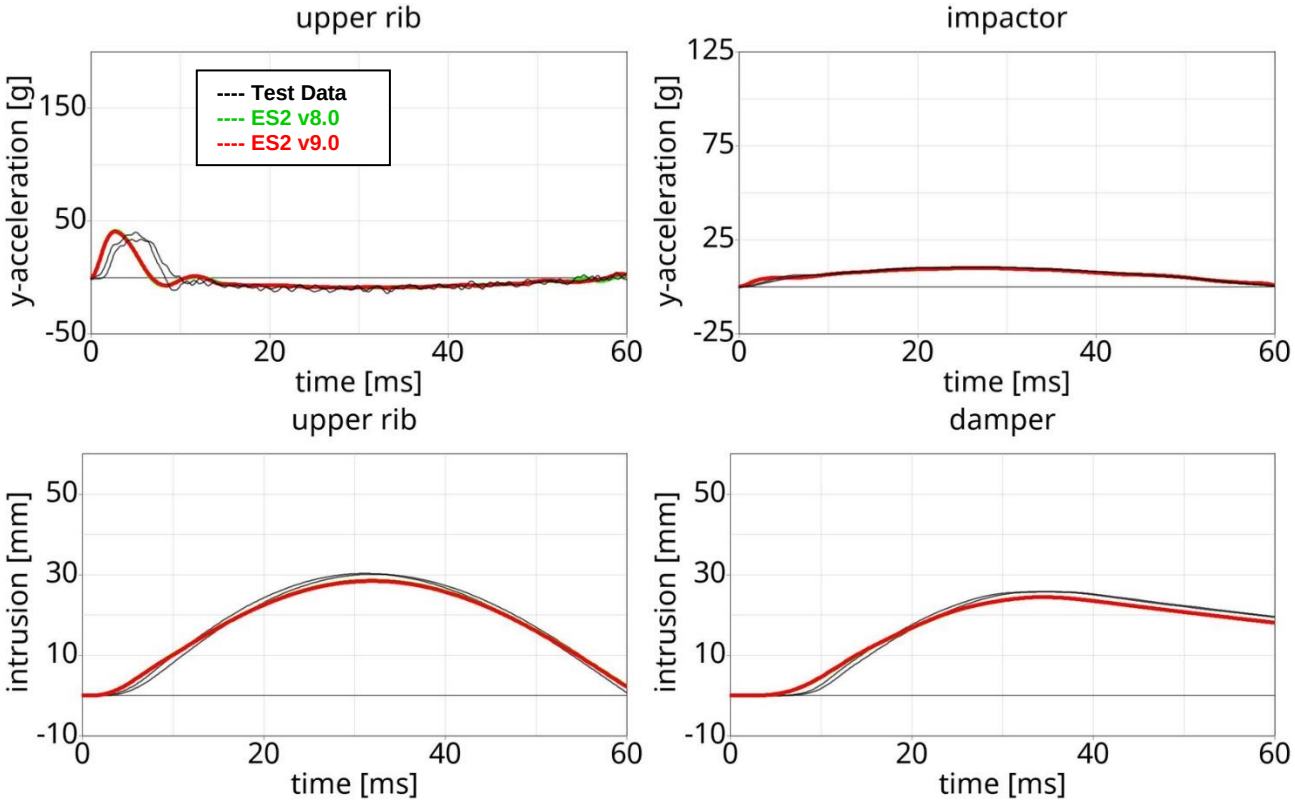
11.2.11 Test setup 2: velocity 2 high mass



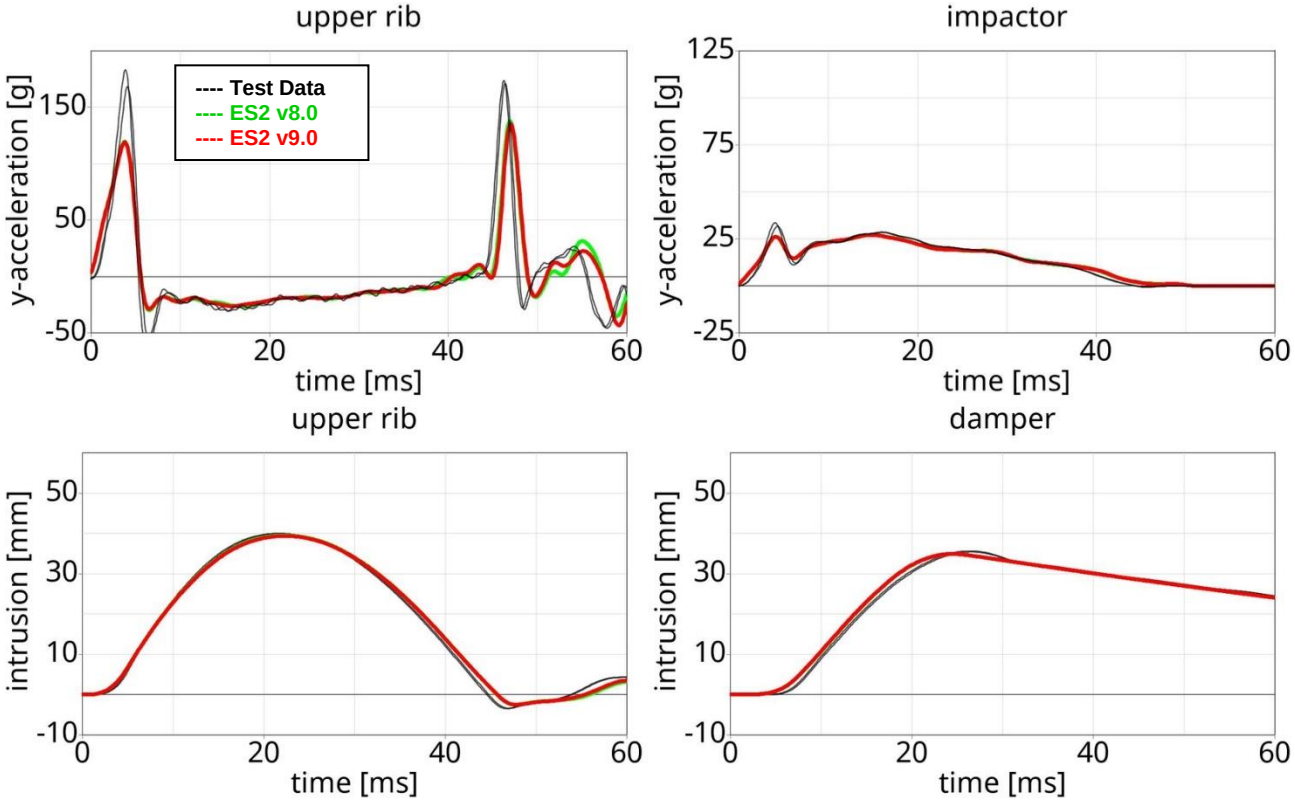
11.2.12 Test setup 2: velocity 3 low mass



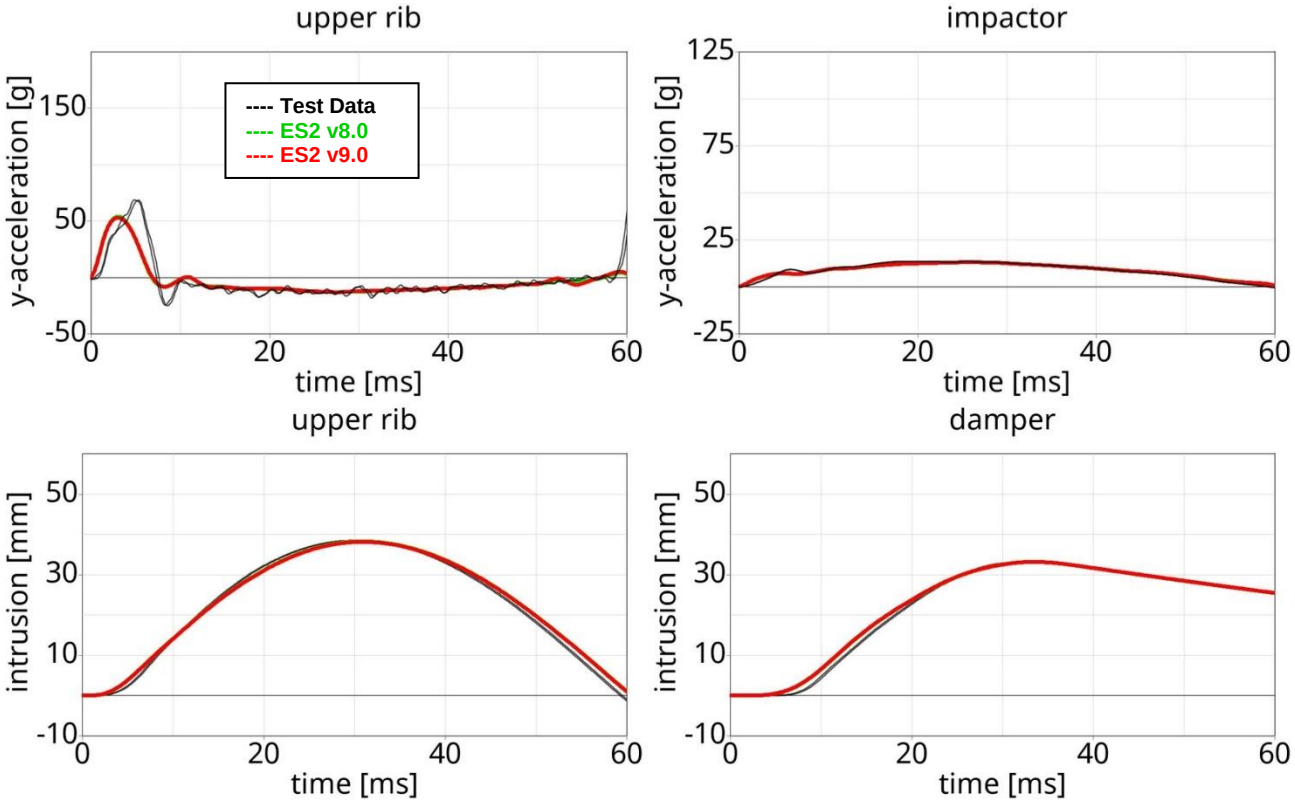
11.2.13 Test setup 2: velocity 3 high mass



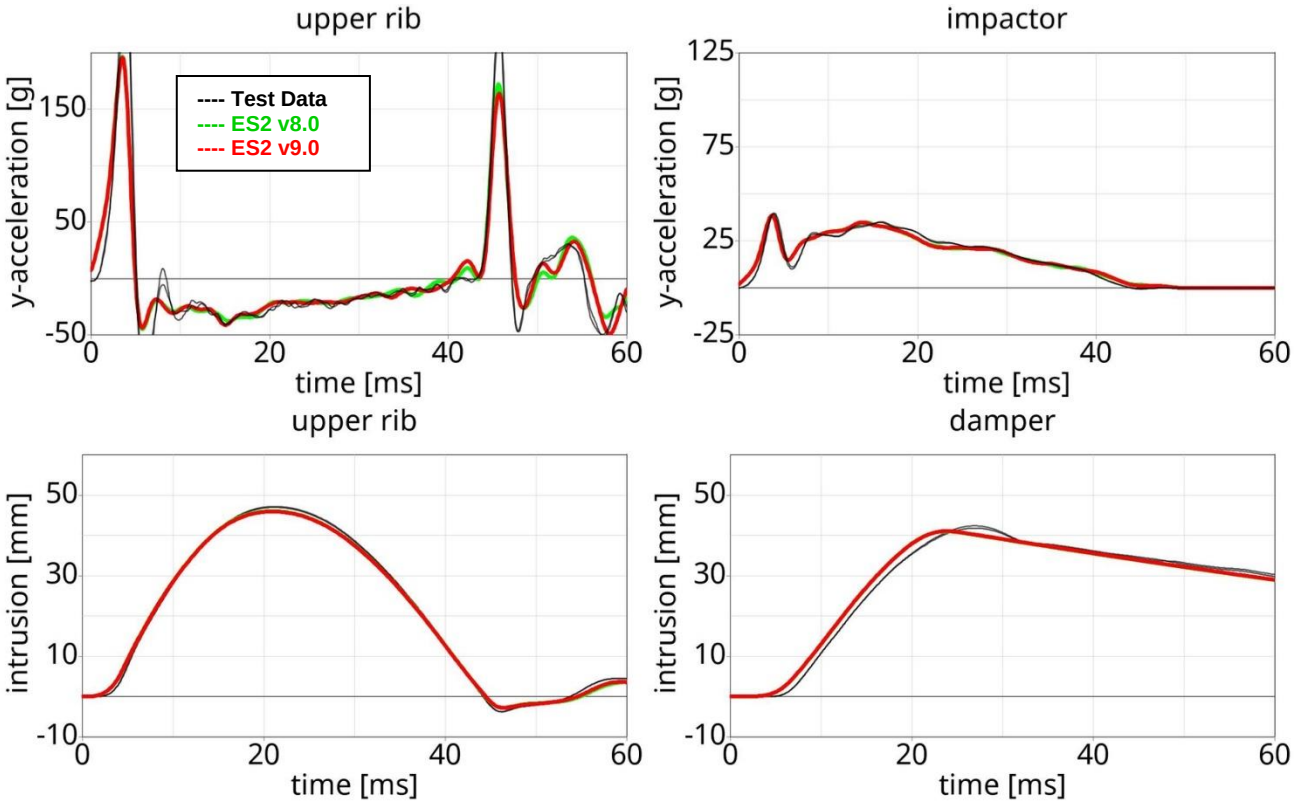
11.2.14 Test setup 2: velocity 4 low mass



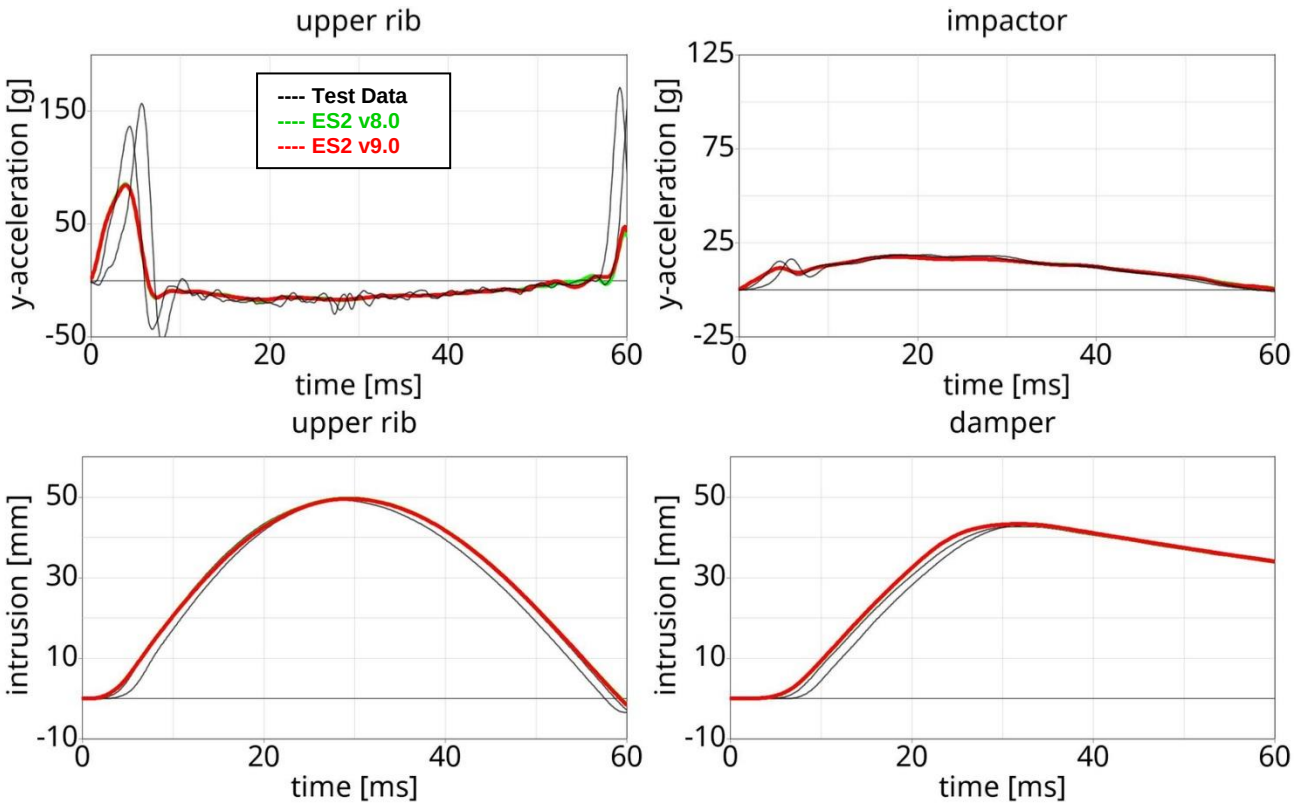
11.2.15 Test setup 2: velocity 4 high mass



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

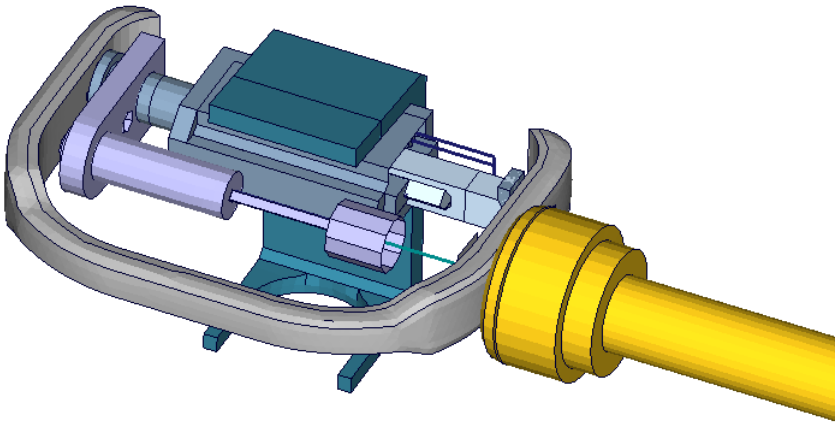
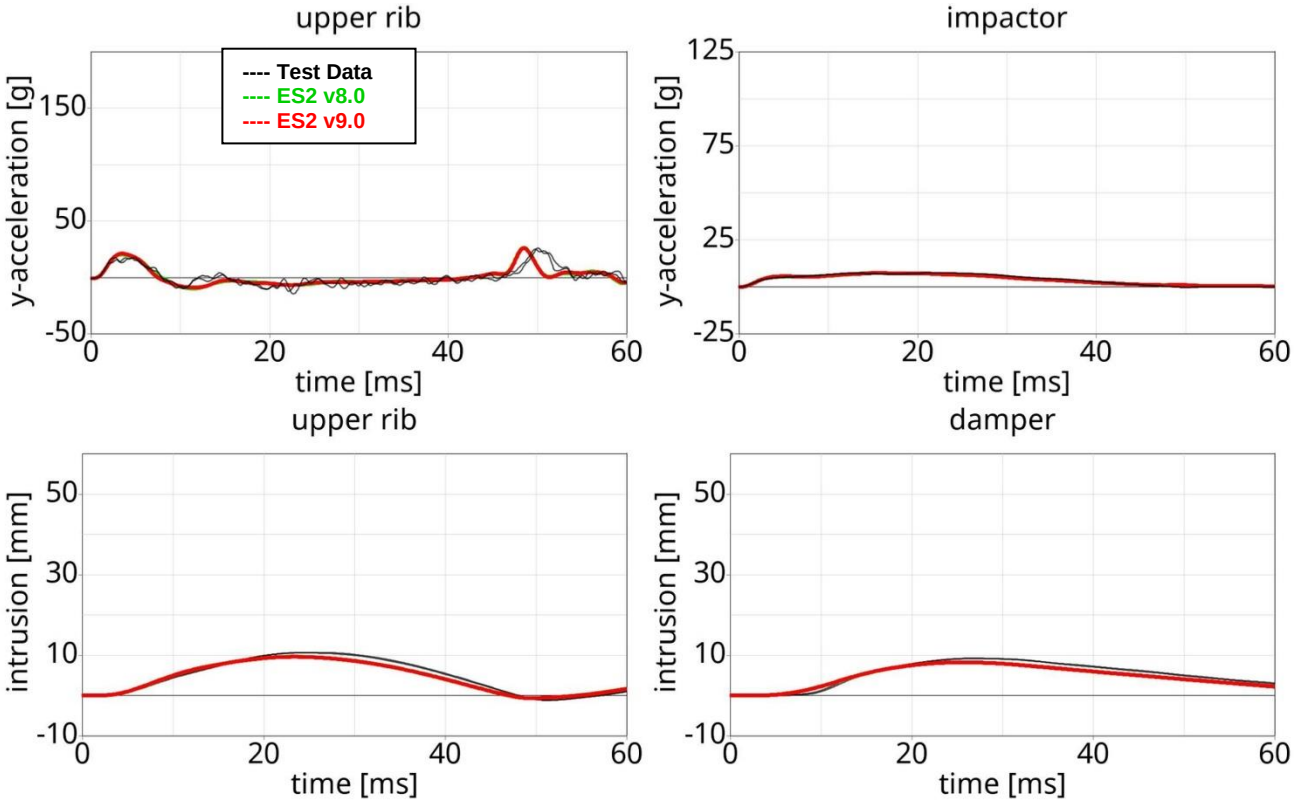


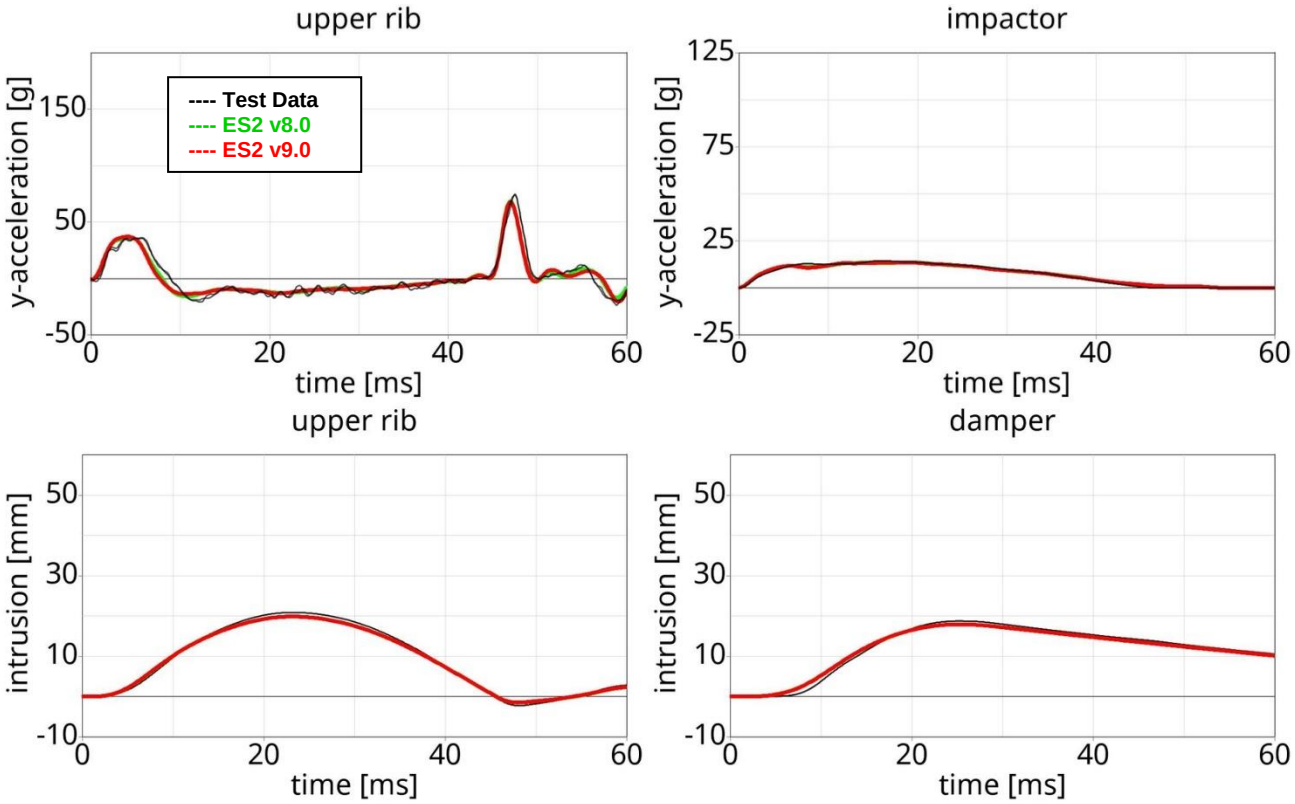
Figure 37: ES-2 rib module test setup 3

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

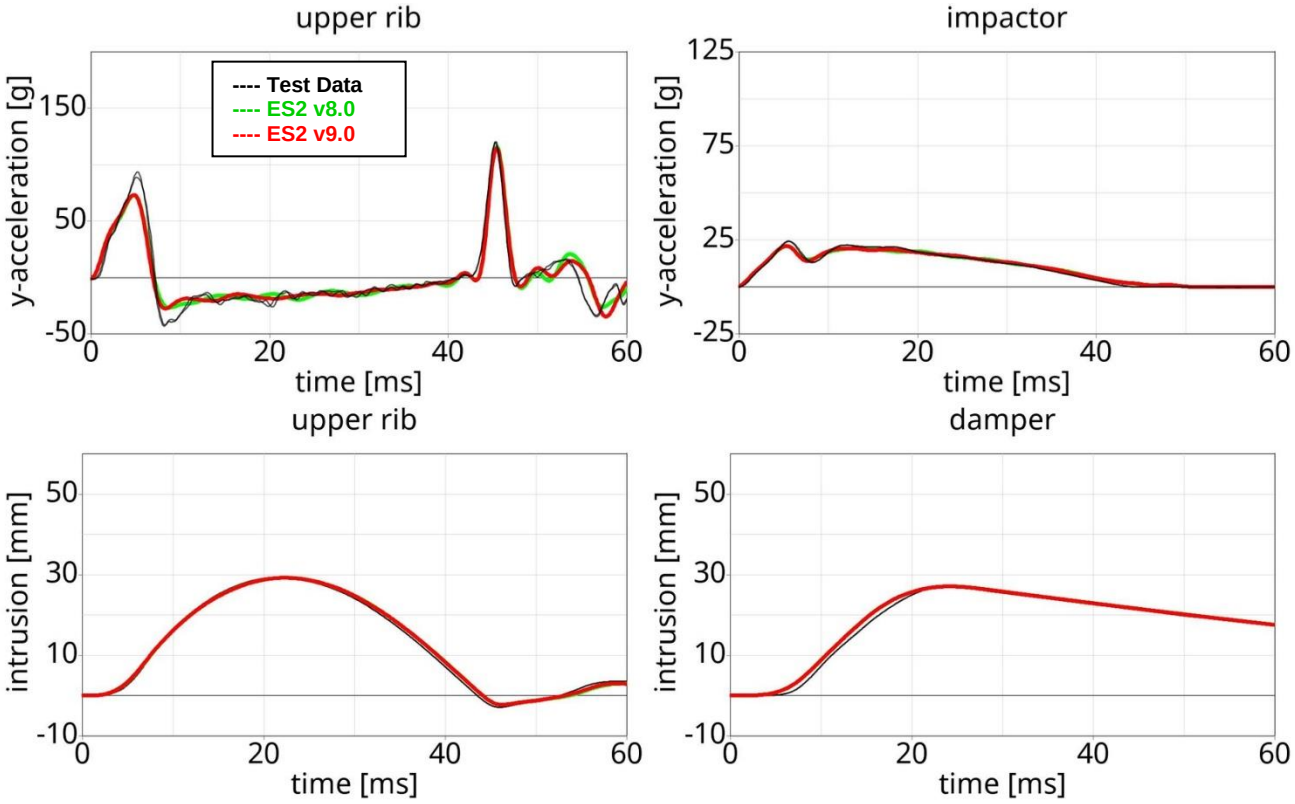
11.2.19 Test setup 3: velocity 1



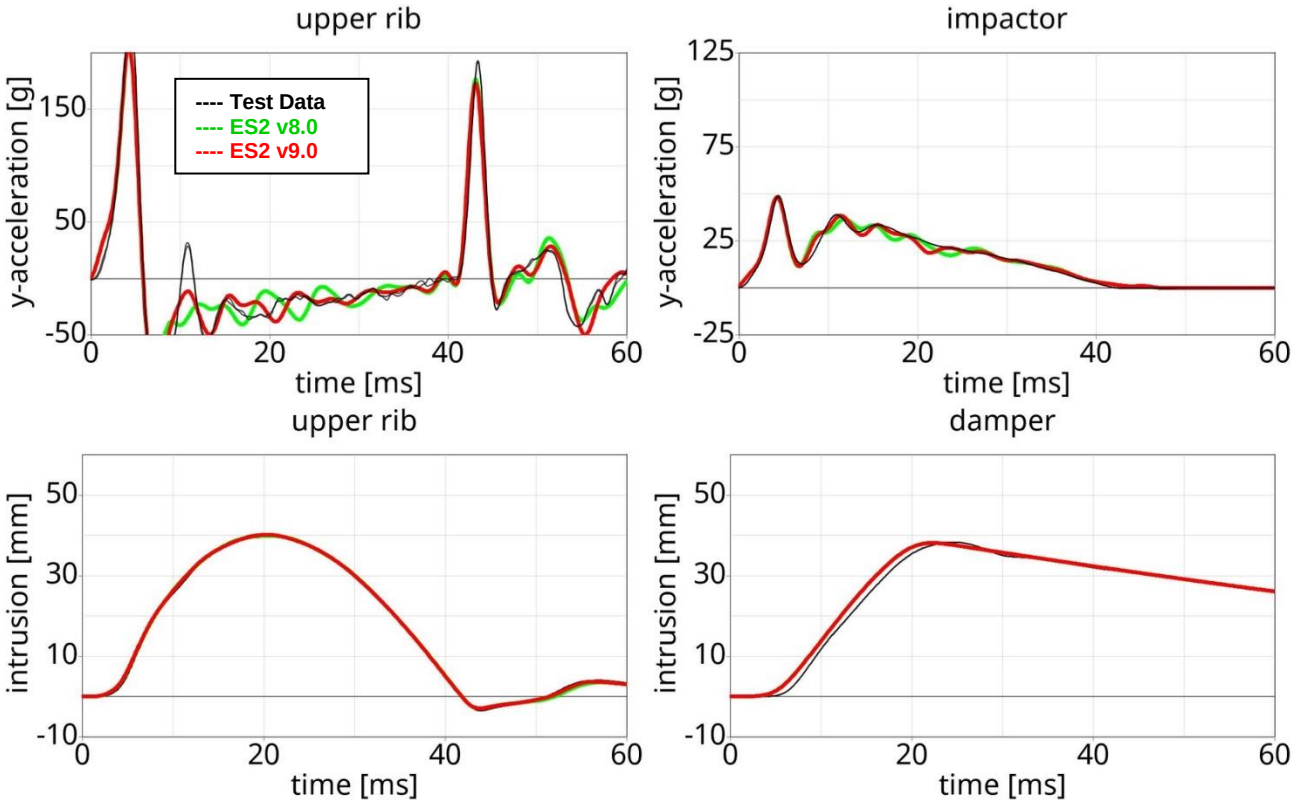
11.2.20 Test setup 3: velocity 2



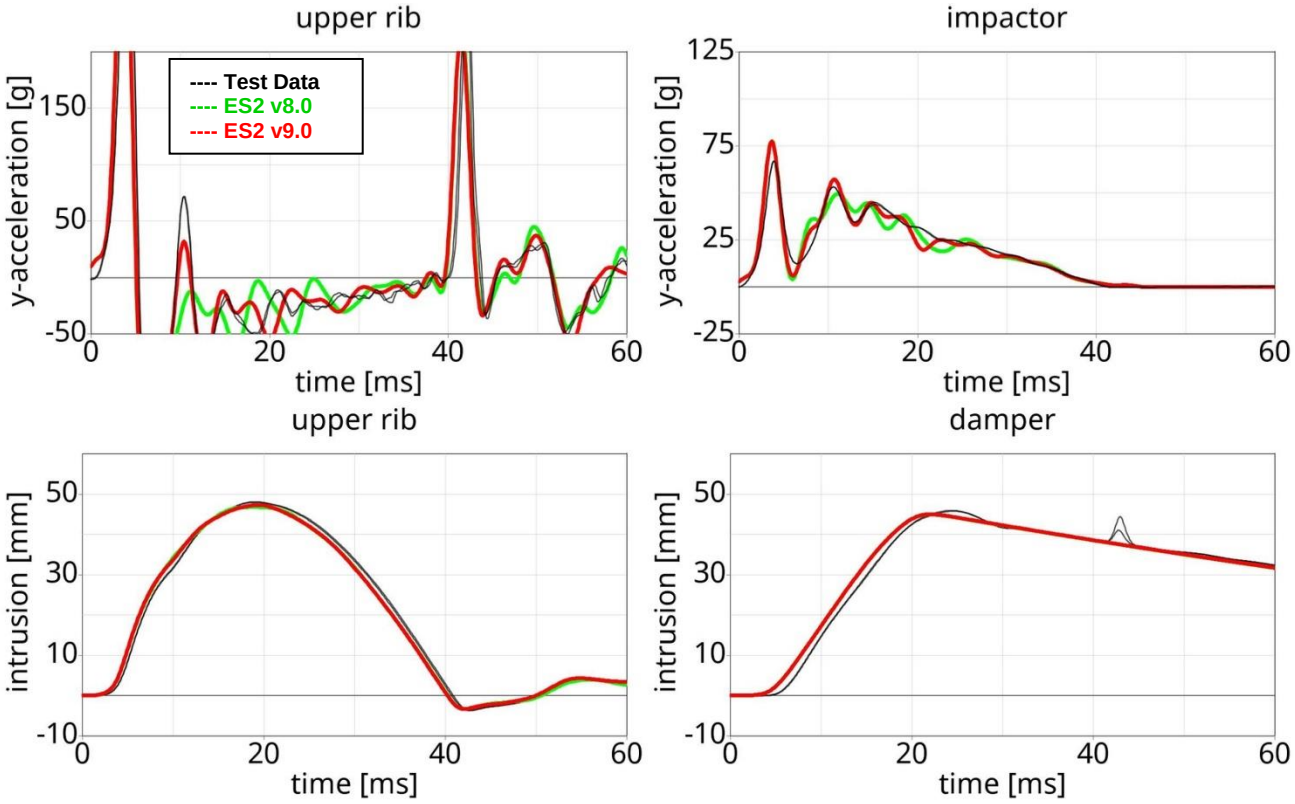
11.2.21 Test setup 3: velocity 3



11.2.22 Test setup 3: velocity 4



11.2.23 Test setup 3: velocity 5



11.2.24 Test setup 4

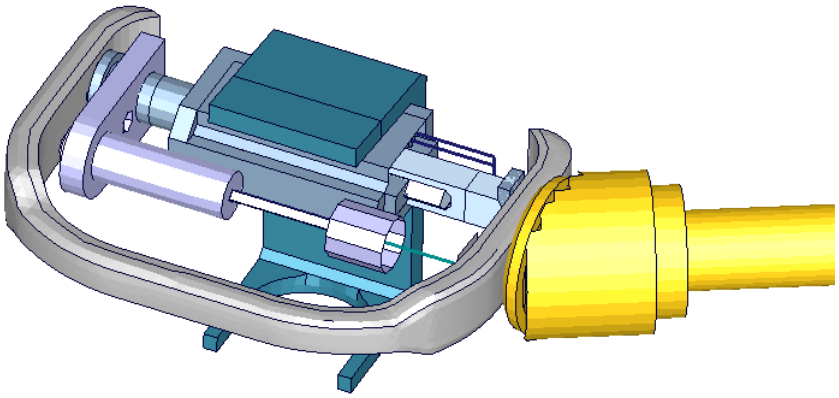
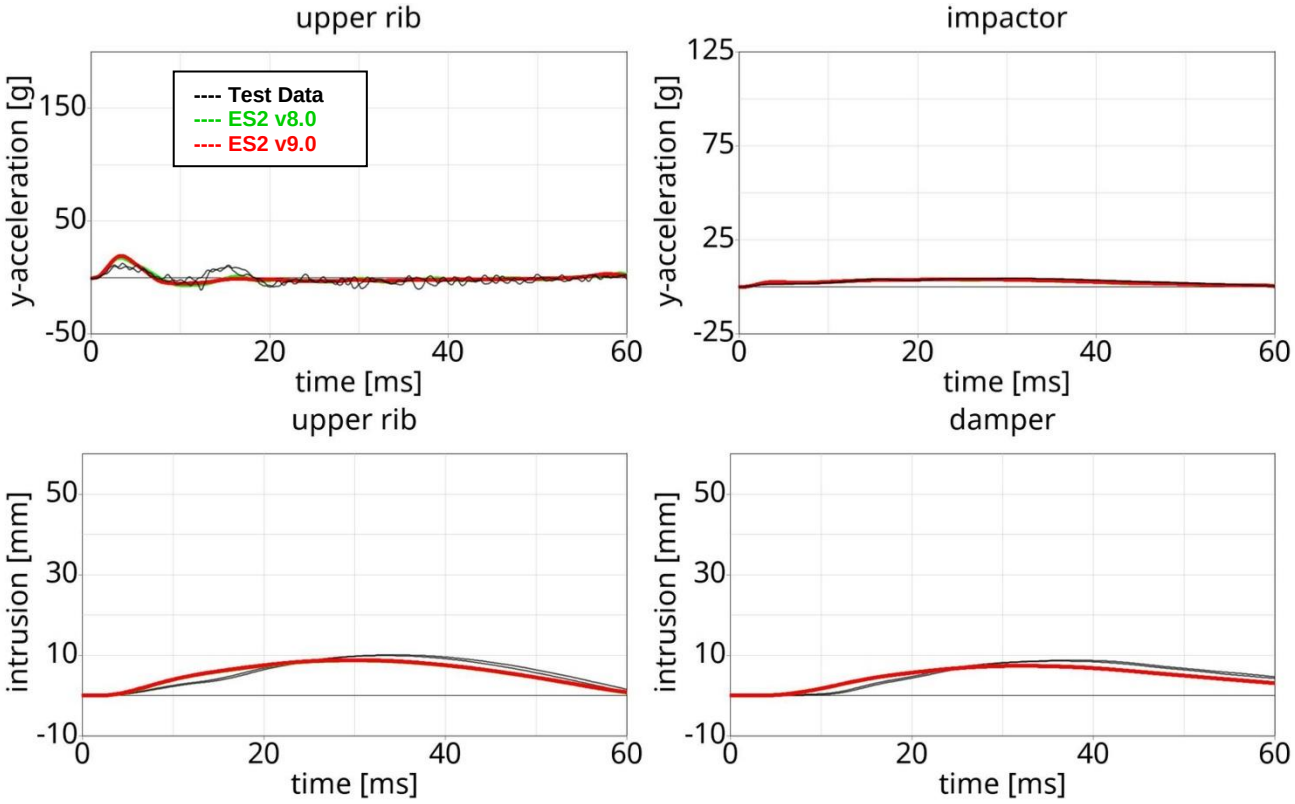


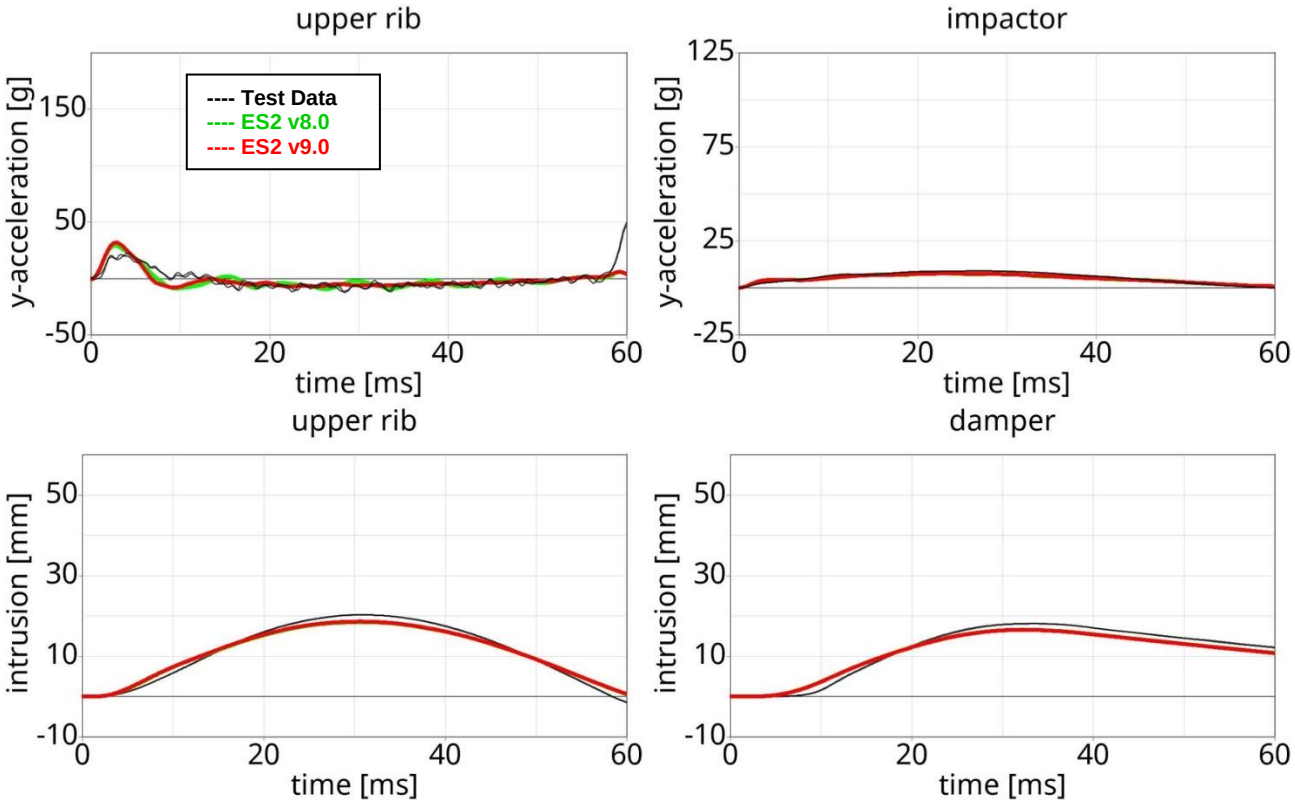
Figure 38: ES-2 rib module test setup 4

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

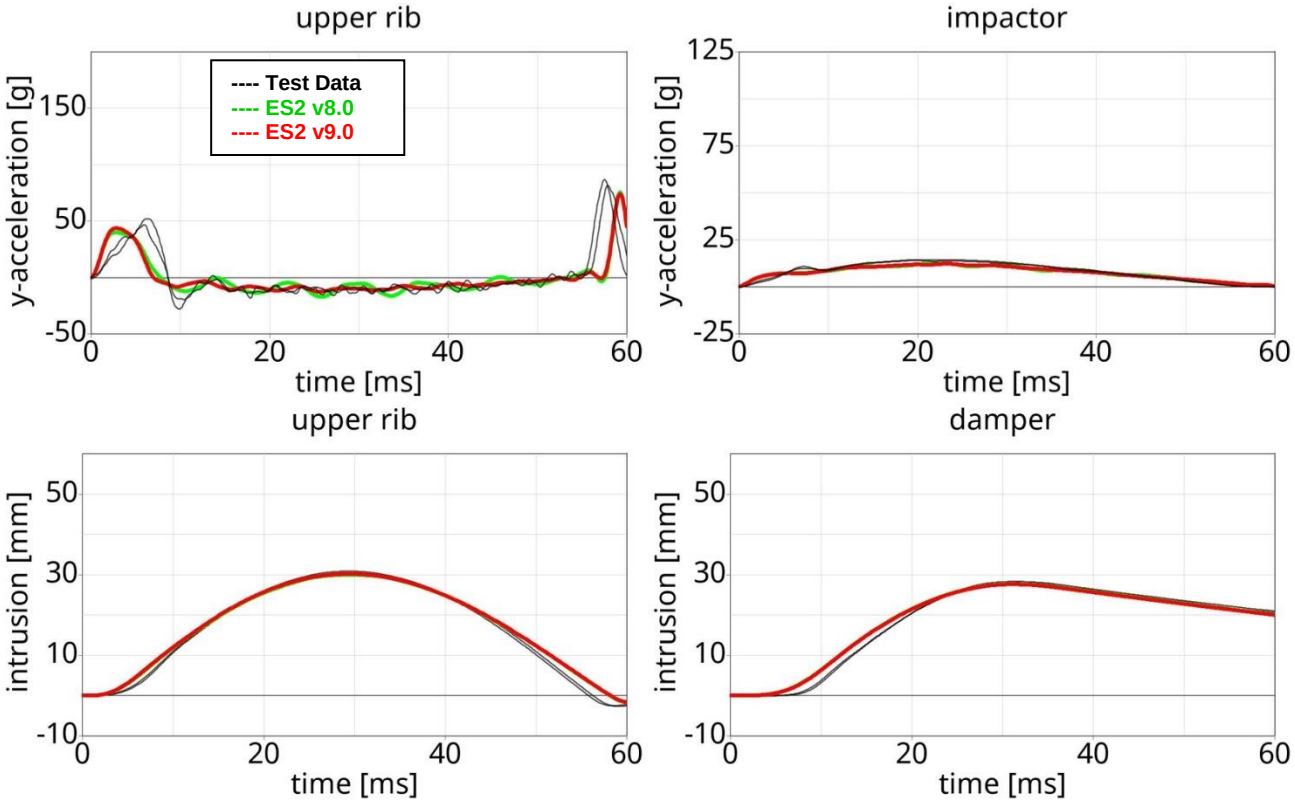
11.2.25 Test setup 4: velocity 1



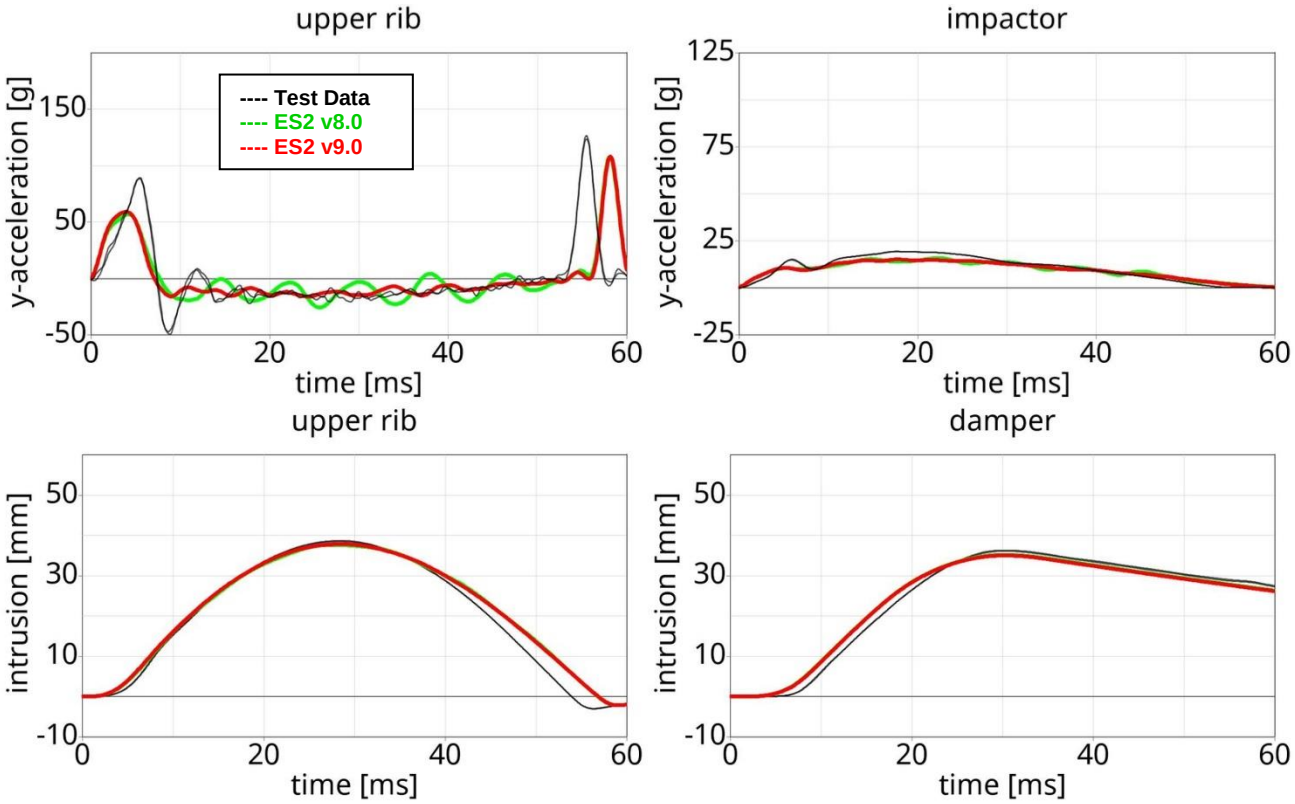
11.2.26 Test setup 4: velocity 2



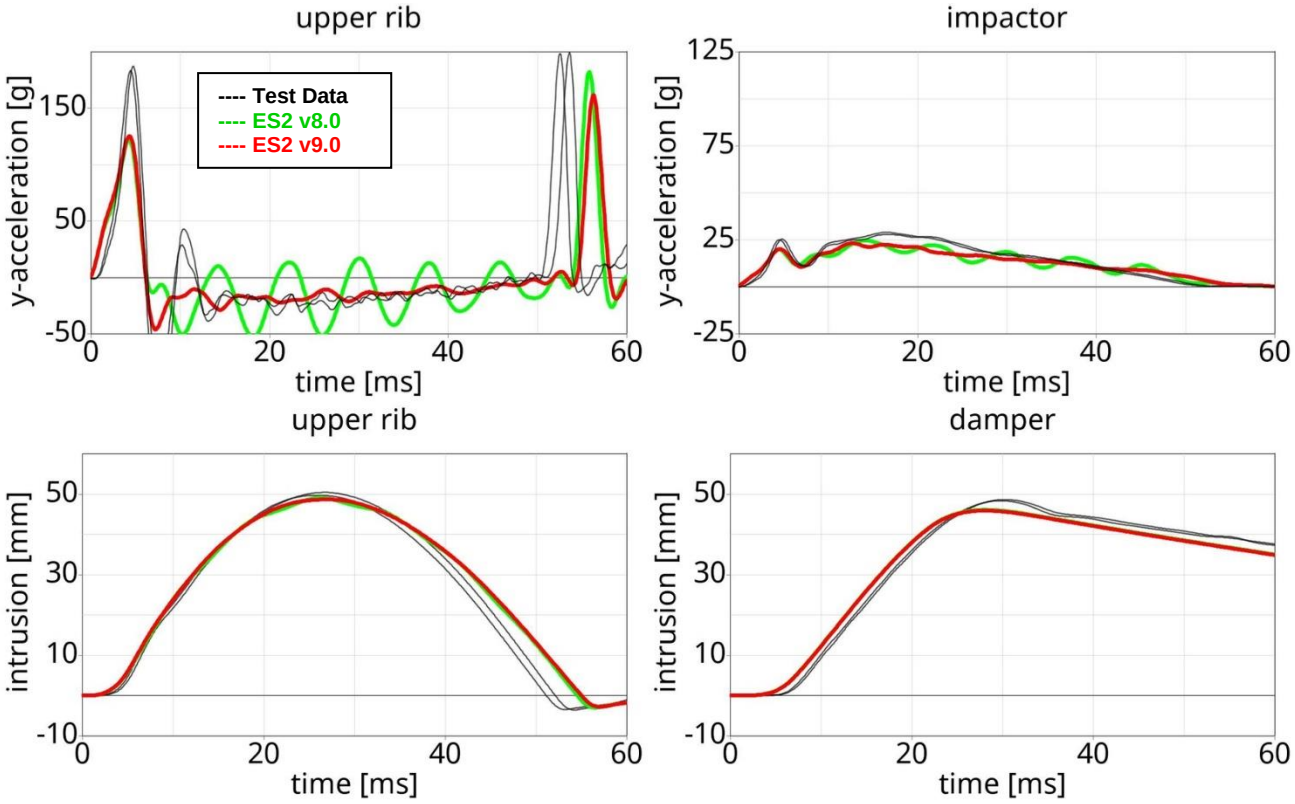
11.2.27 Test setup 4: velocity 3



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

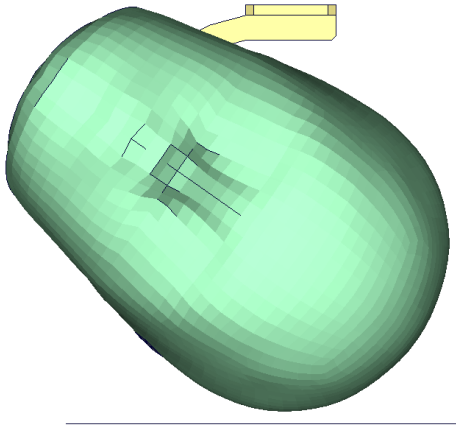
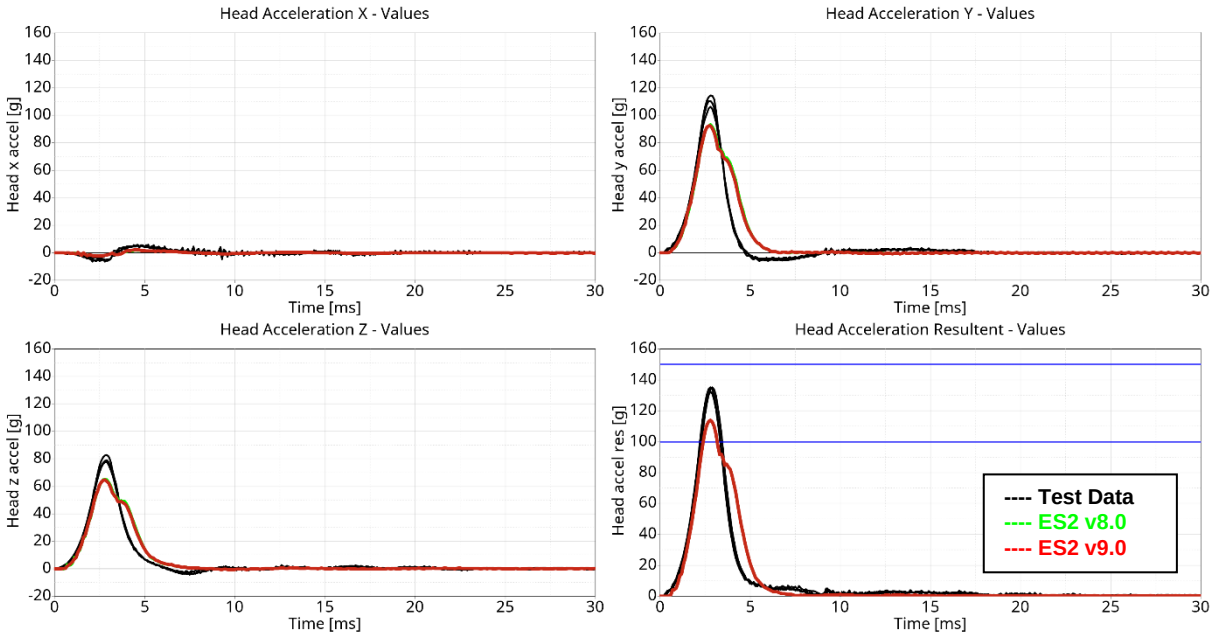


Figure 39: ES-2 head drop test setup

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.

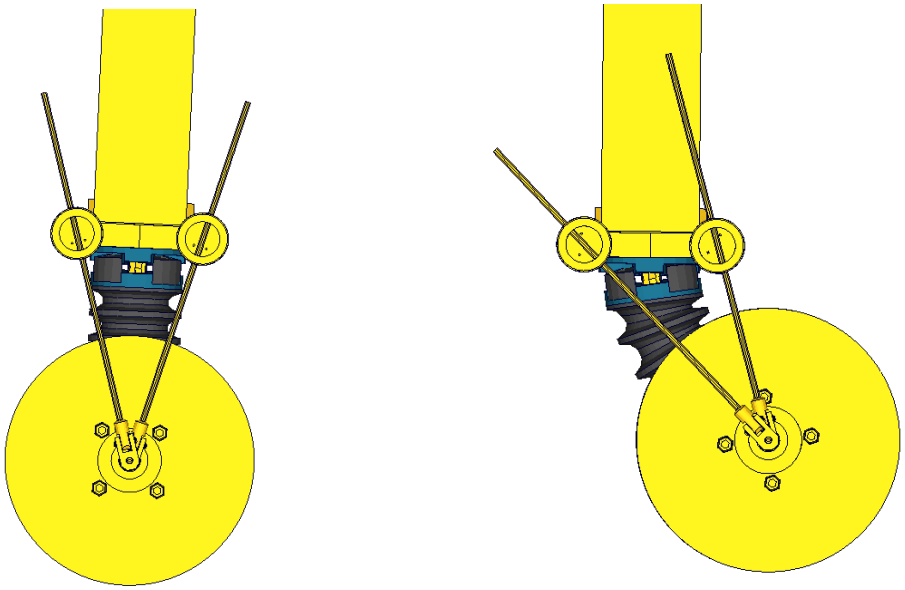
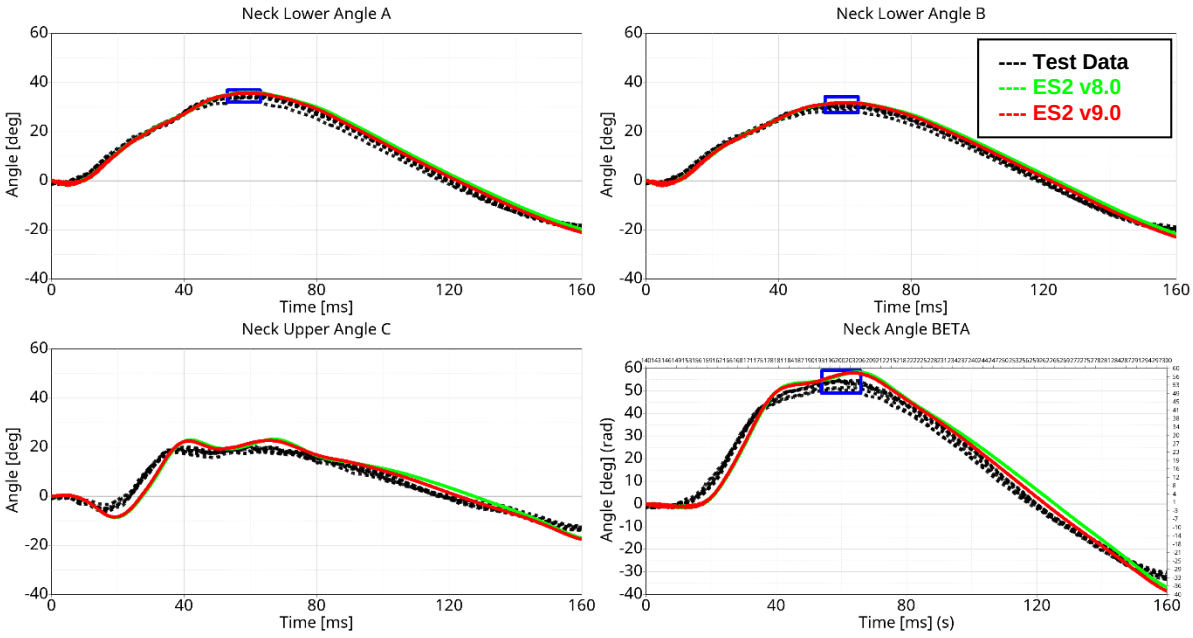


Figure 40: ES-2 neck calibration test setup

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

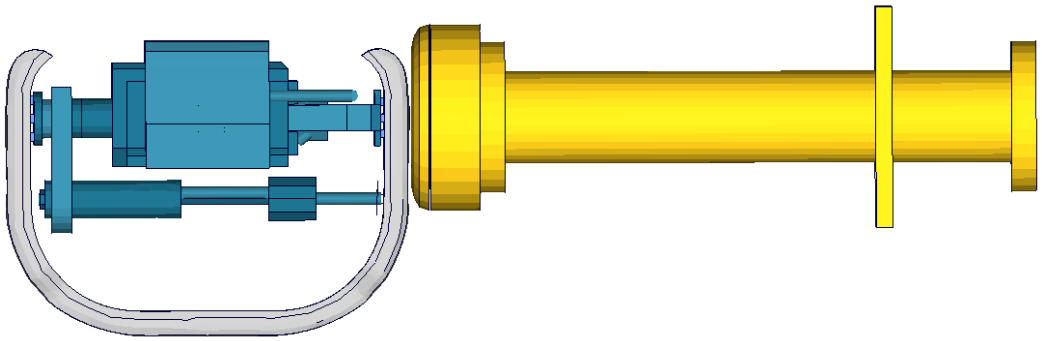
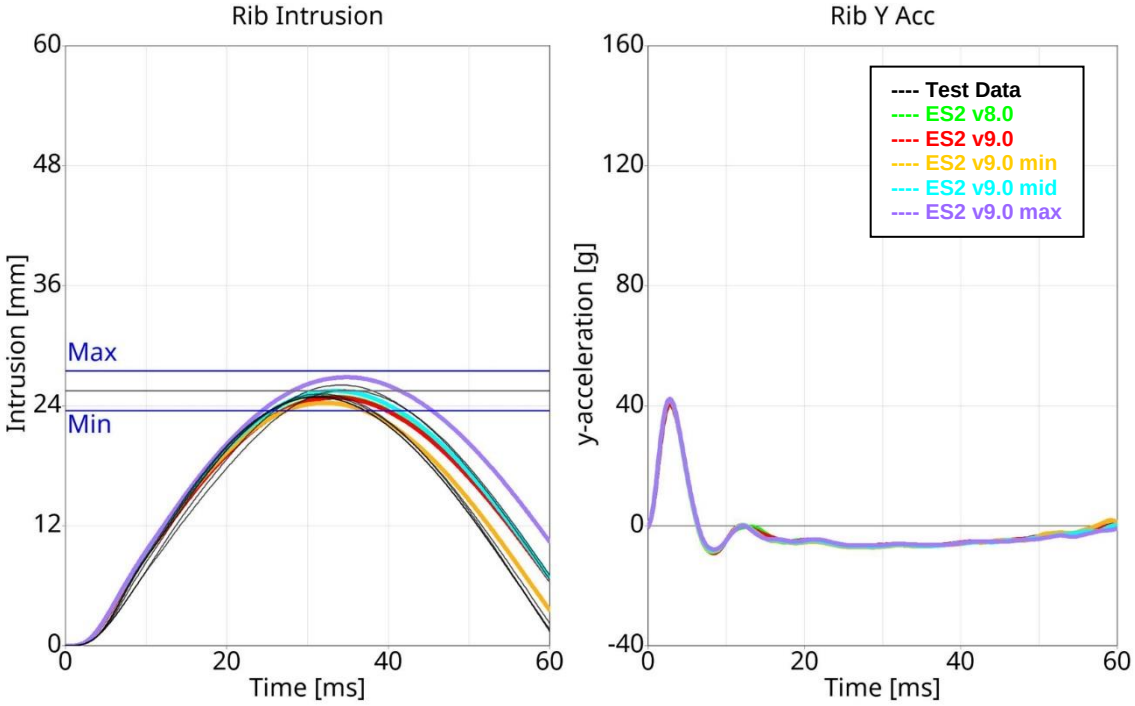
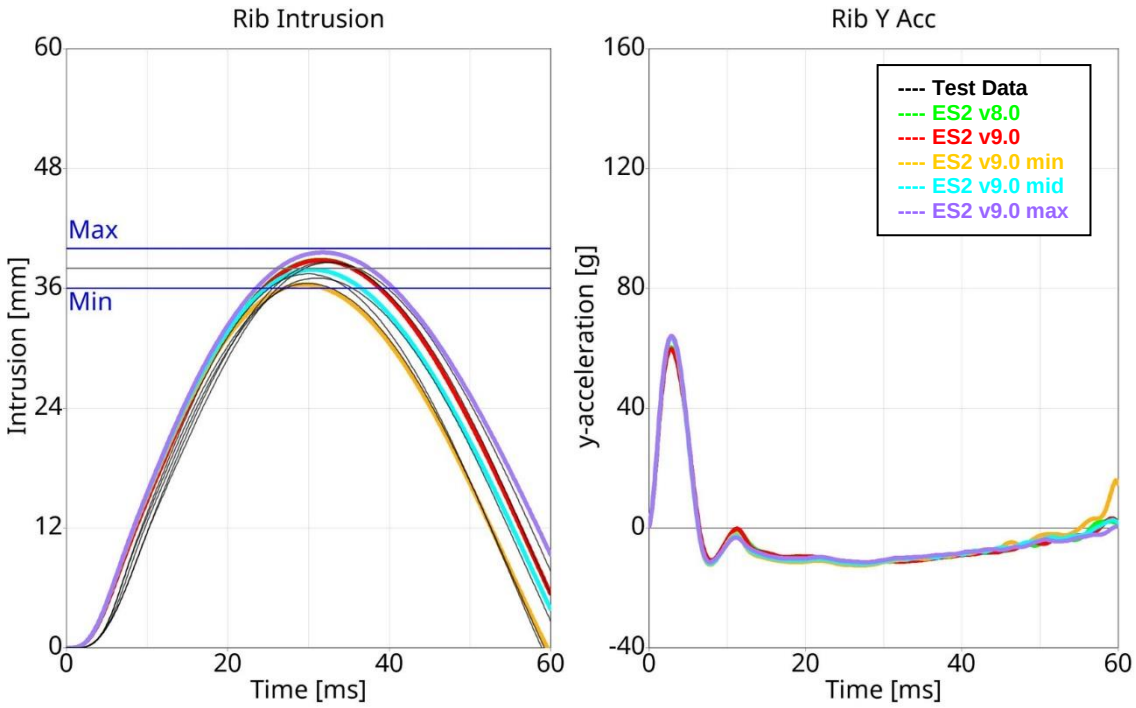


Figure 41: ES-2 rib calibration test setup

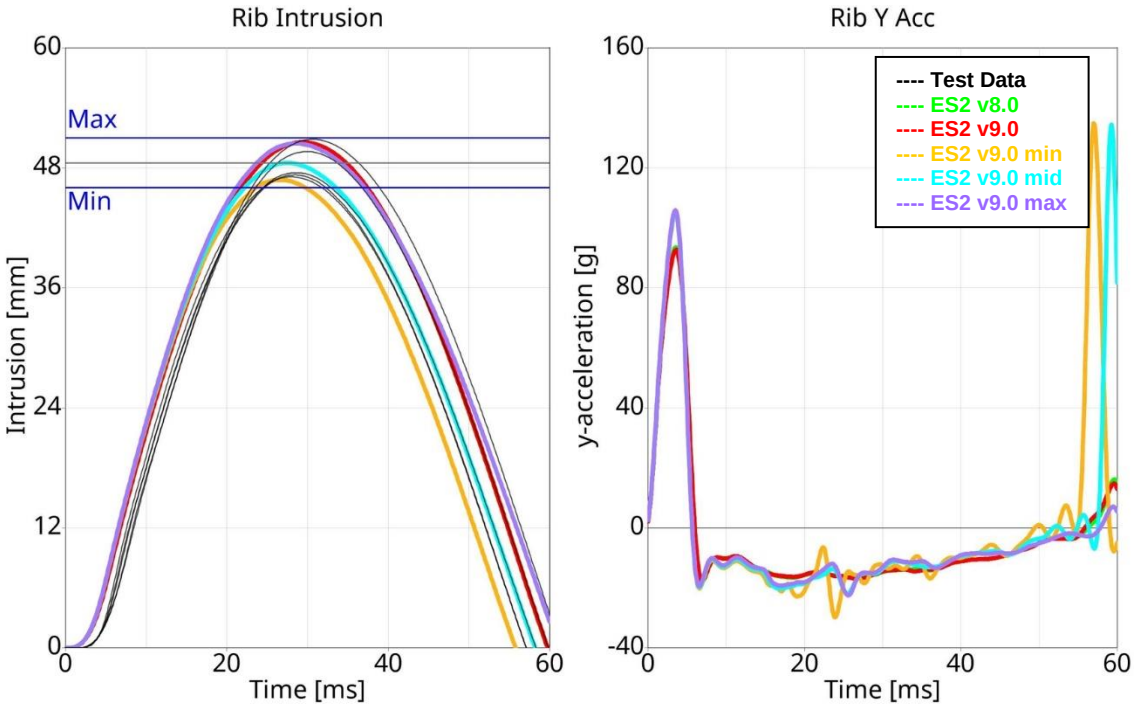
12.3.1 Results low velocity



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.

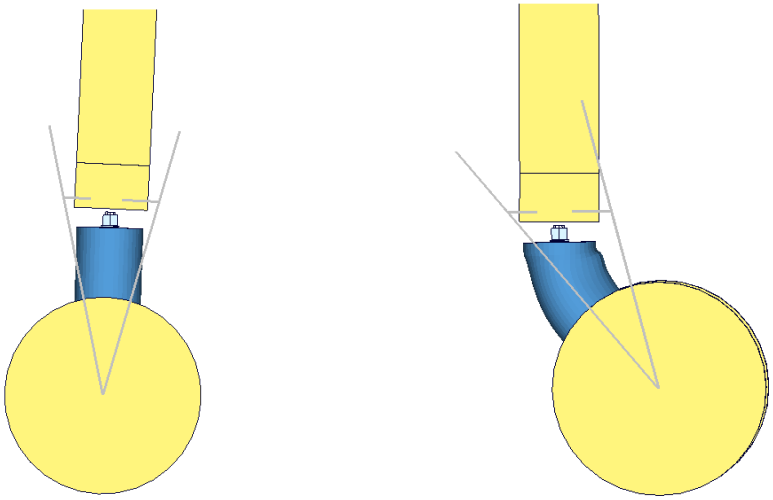
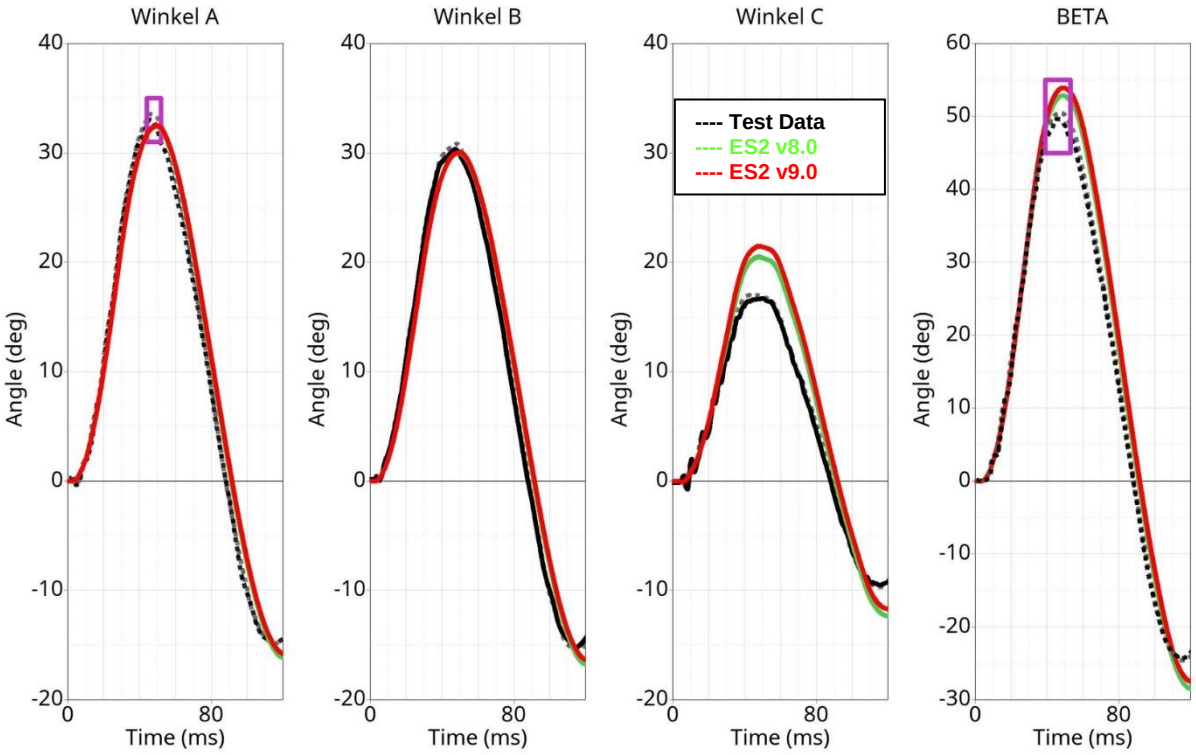


Figure 42: ES-2 lumbar spine calibration test setup

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

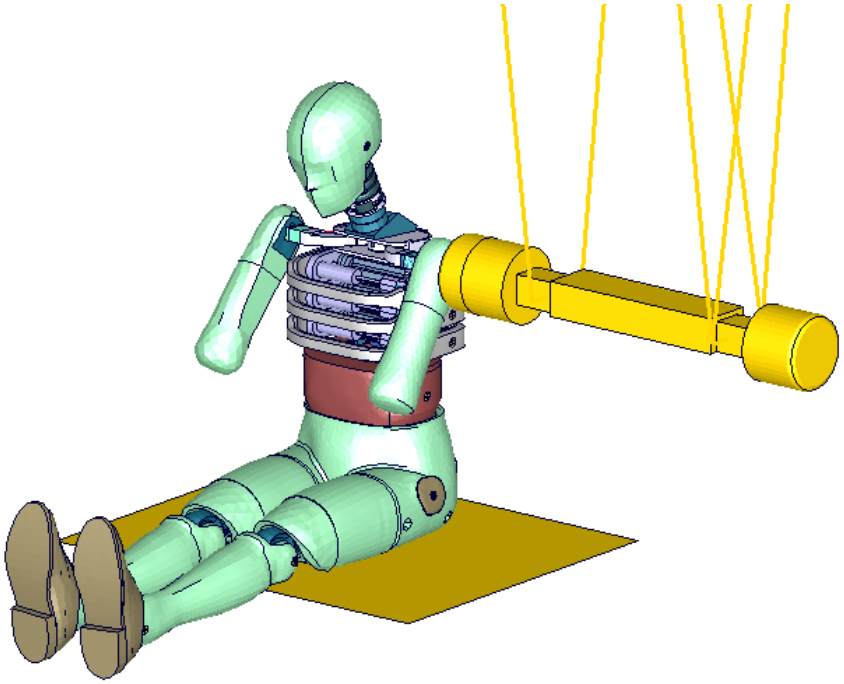
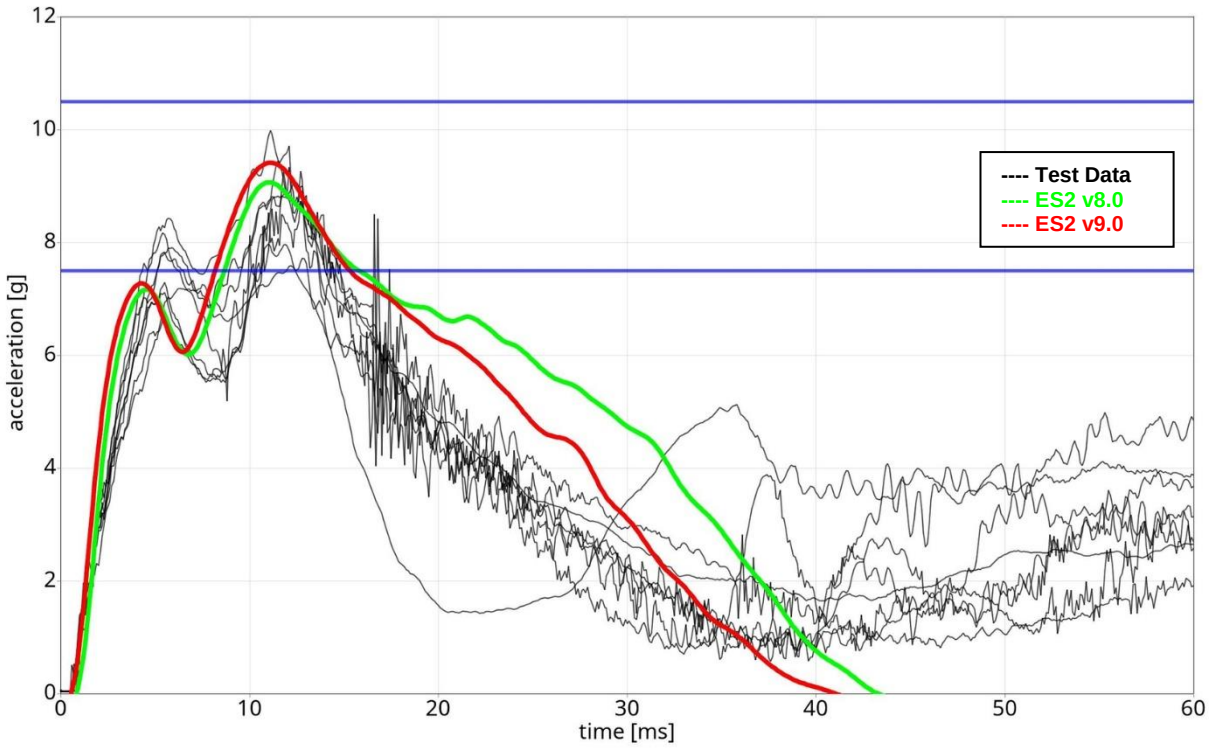


Figure 43: ES-2 shoulder certification test setup

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.

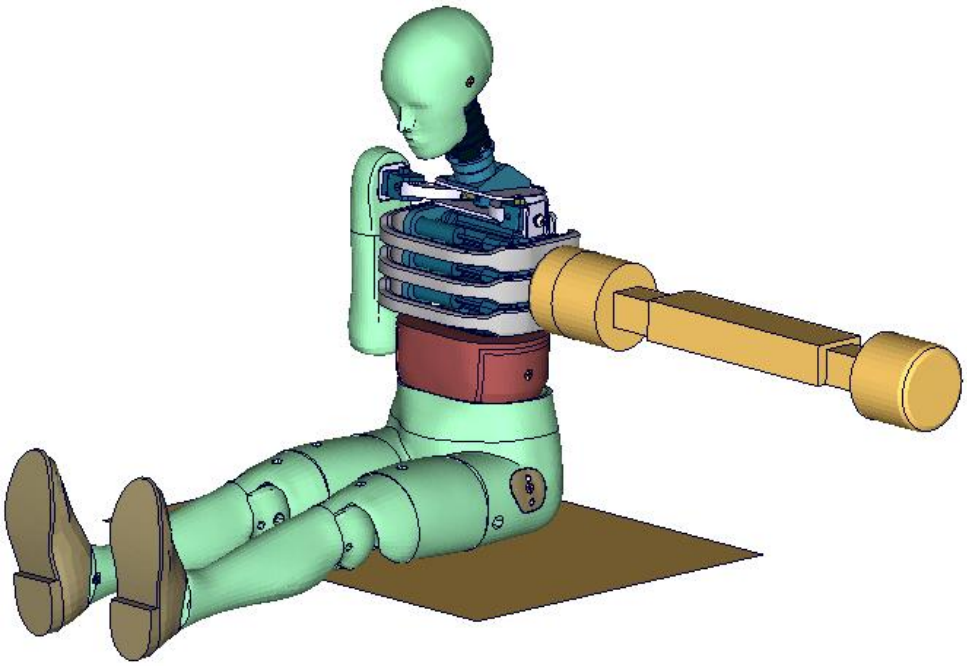
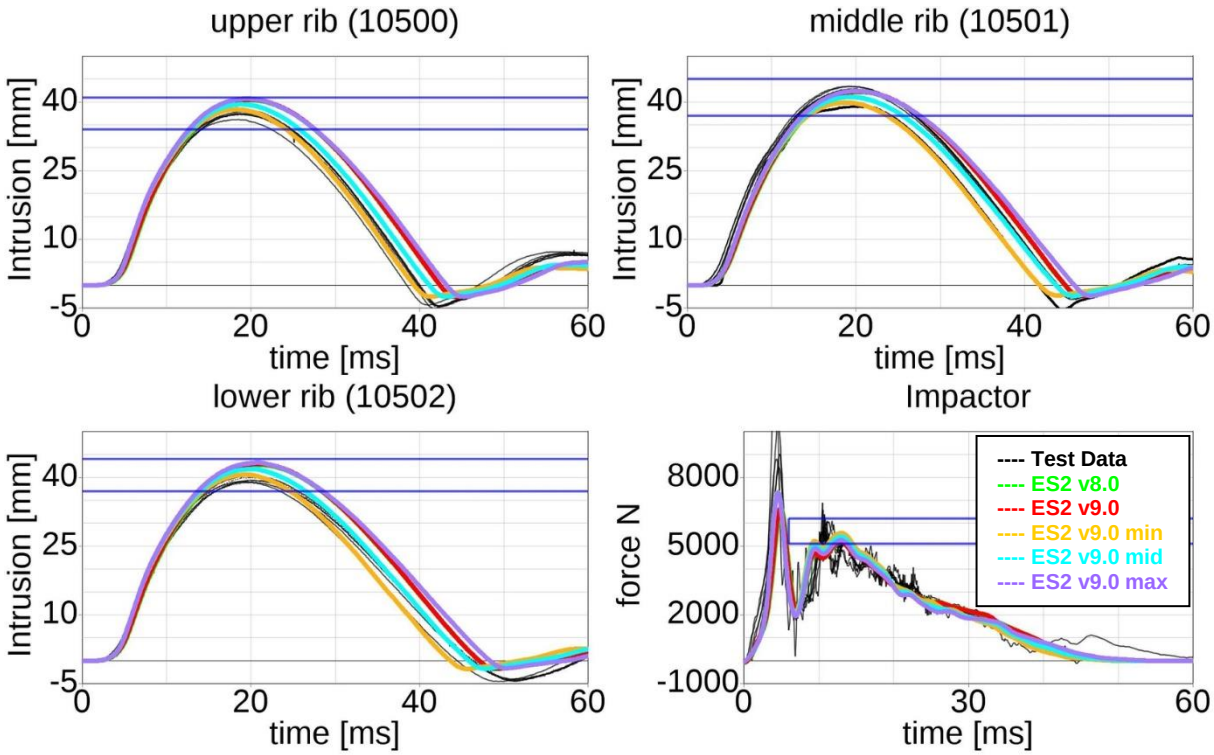


Figure 44: ES-2 thorax certification test setup

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

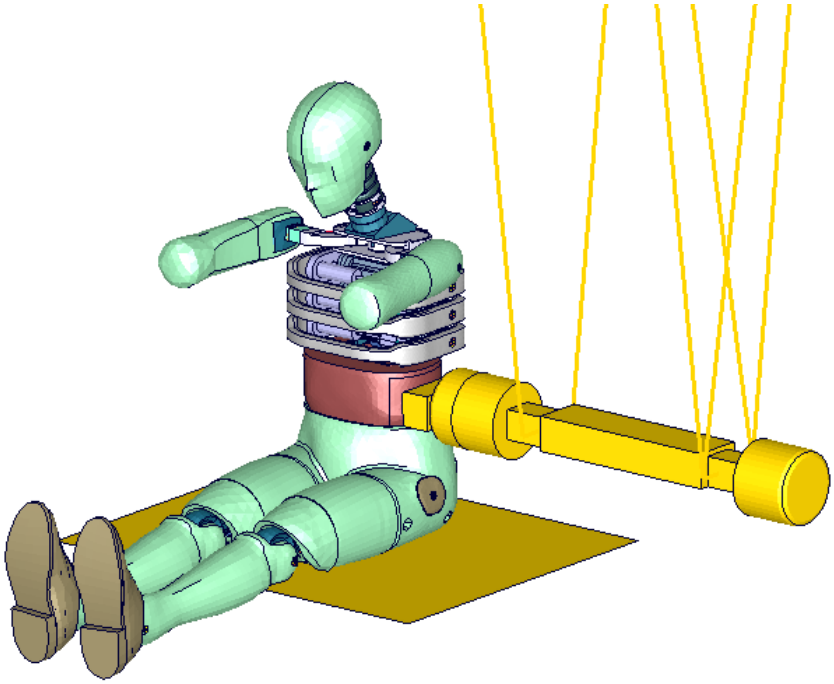
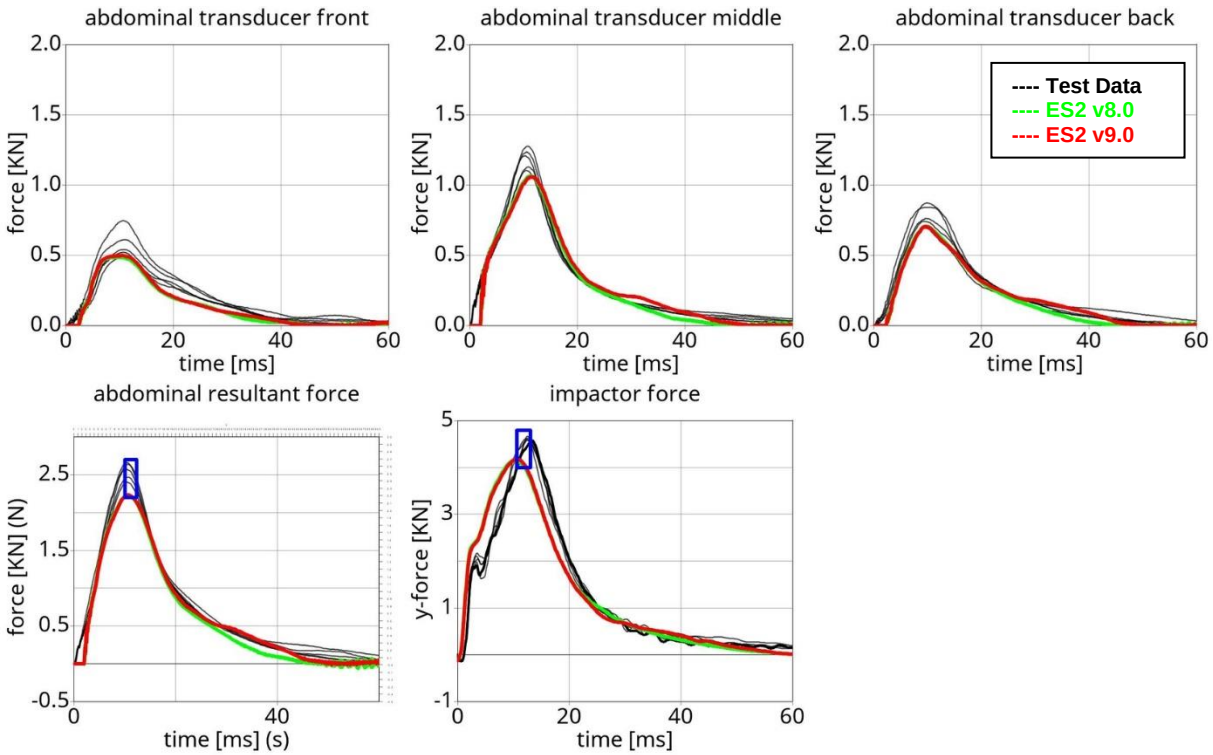


Figure 45: ES-2 abdomen certification test setup

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

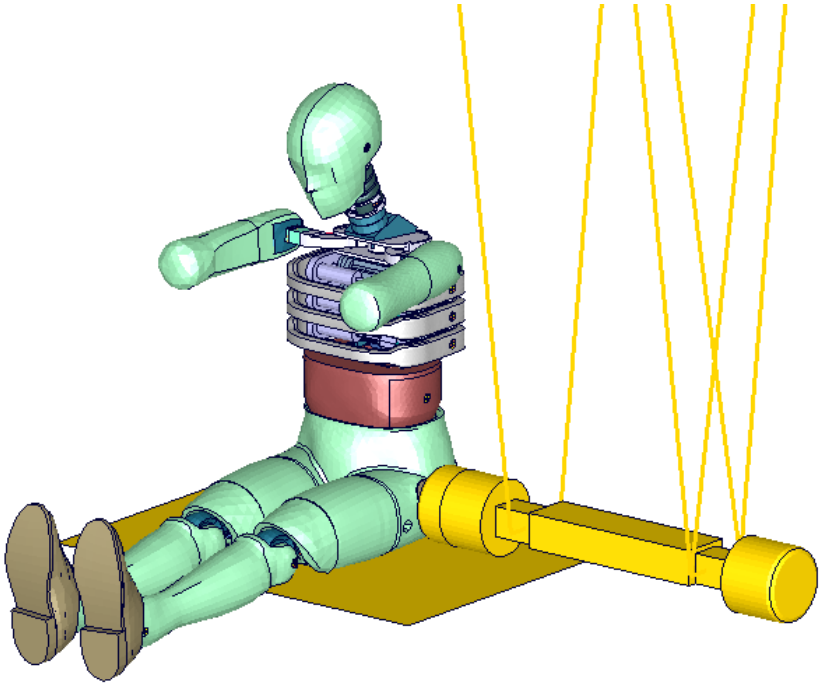
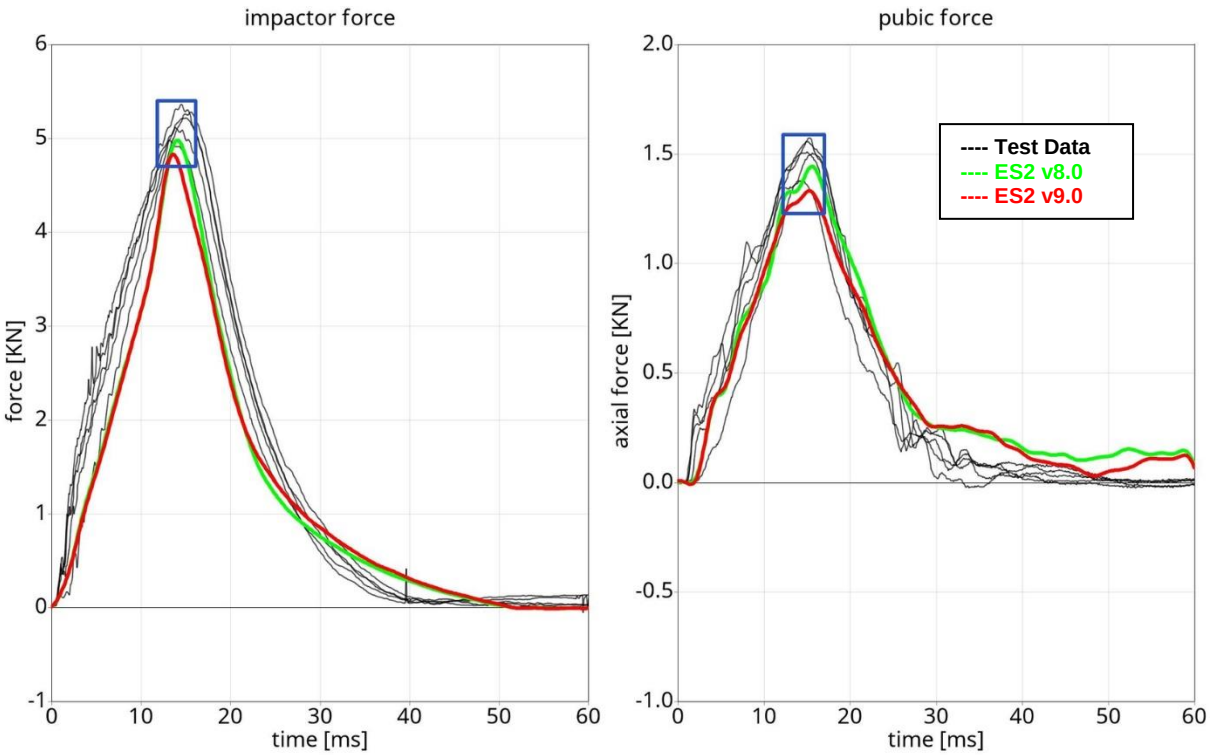


Figure 46: ES-2 pelvis certification test setup

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

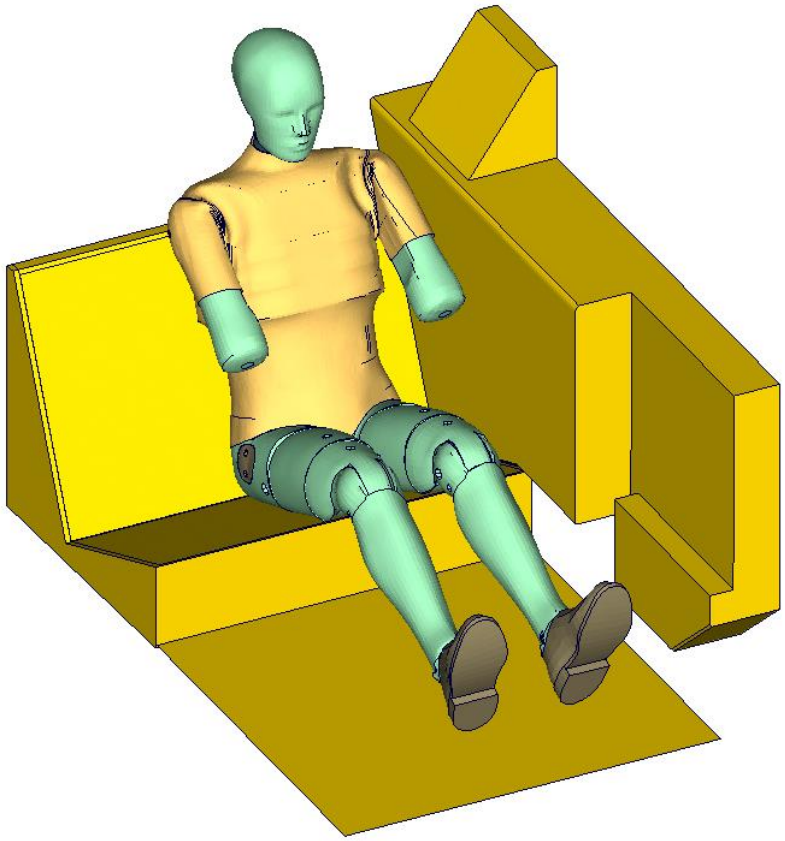
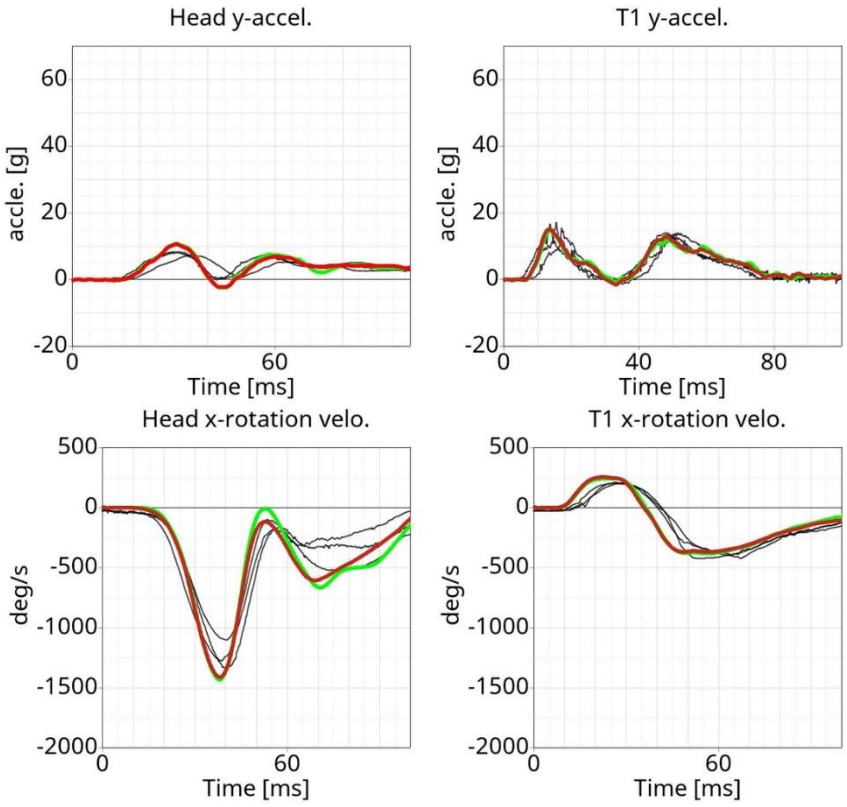
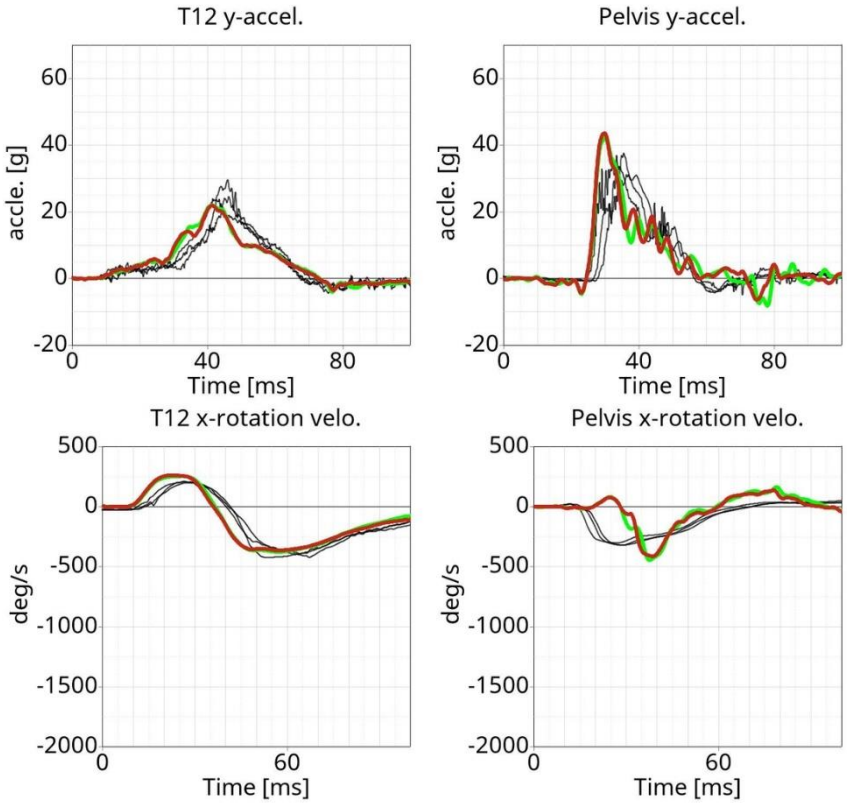


Figure 47: D1 plane barrier test setup

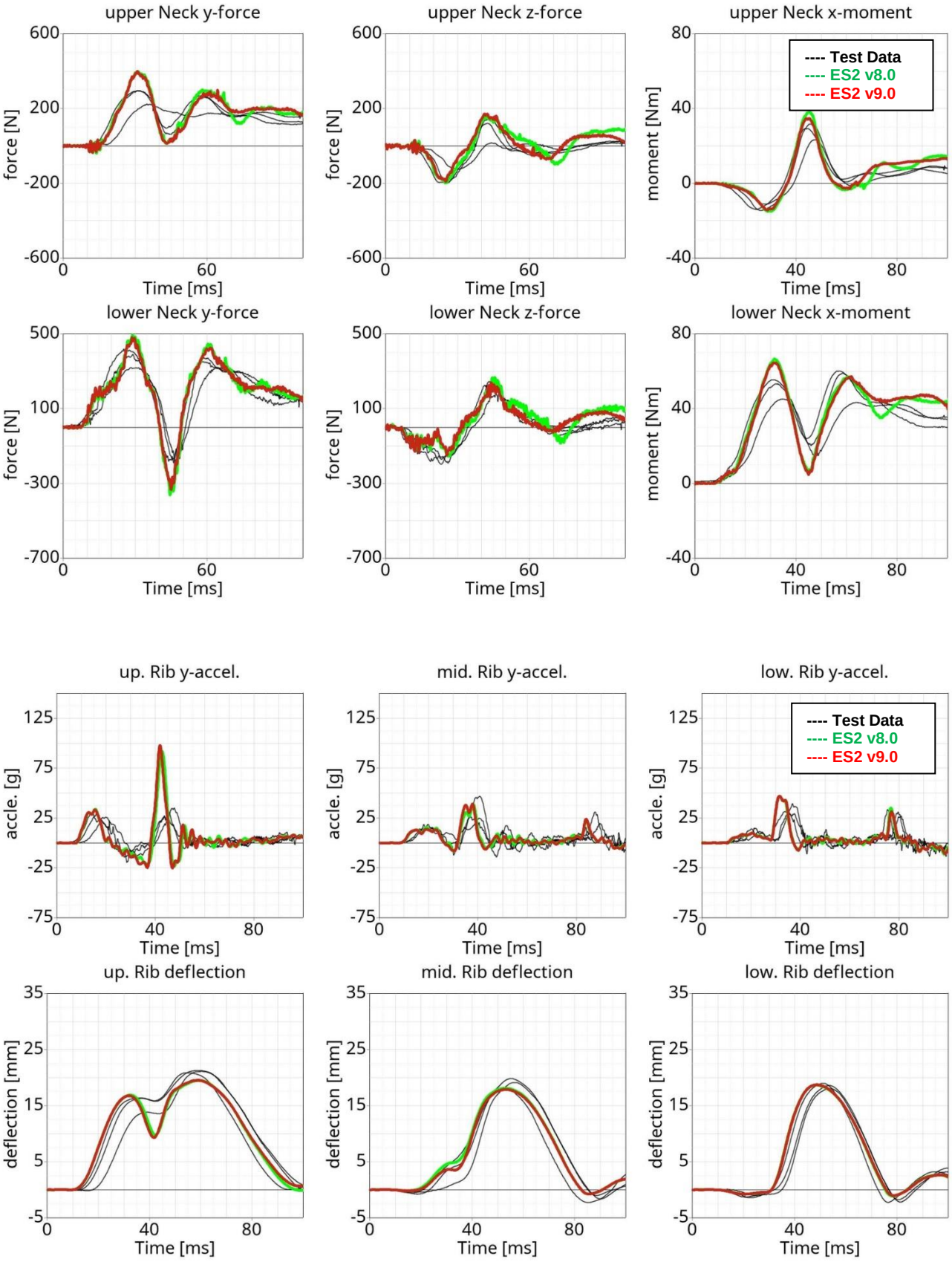
13.1.1 Results at low velocity impact

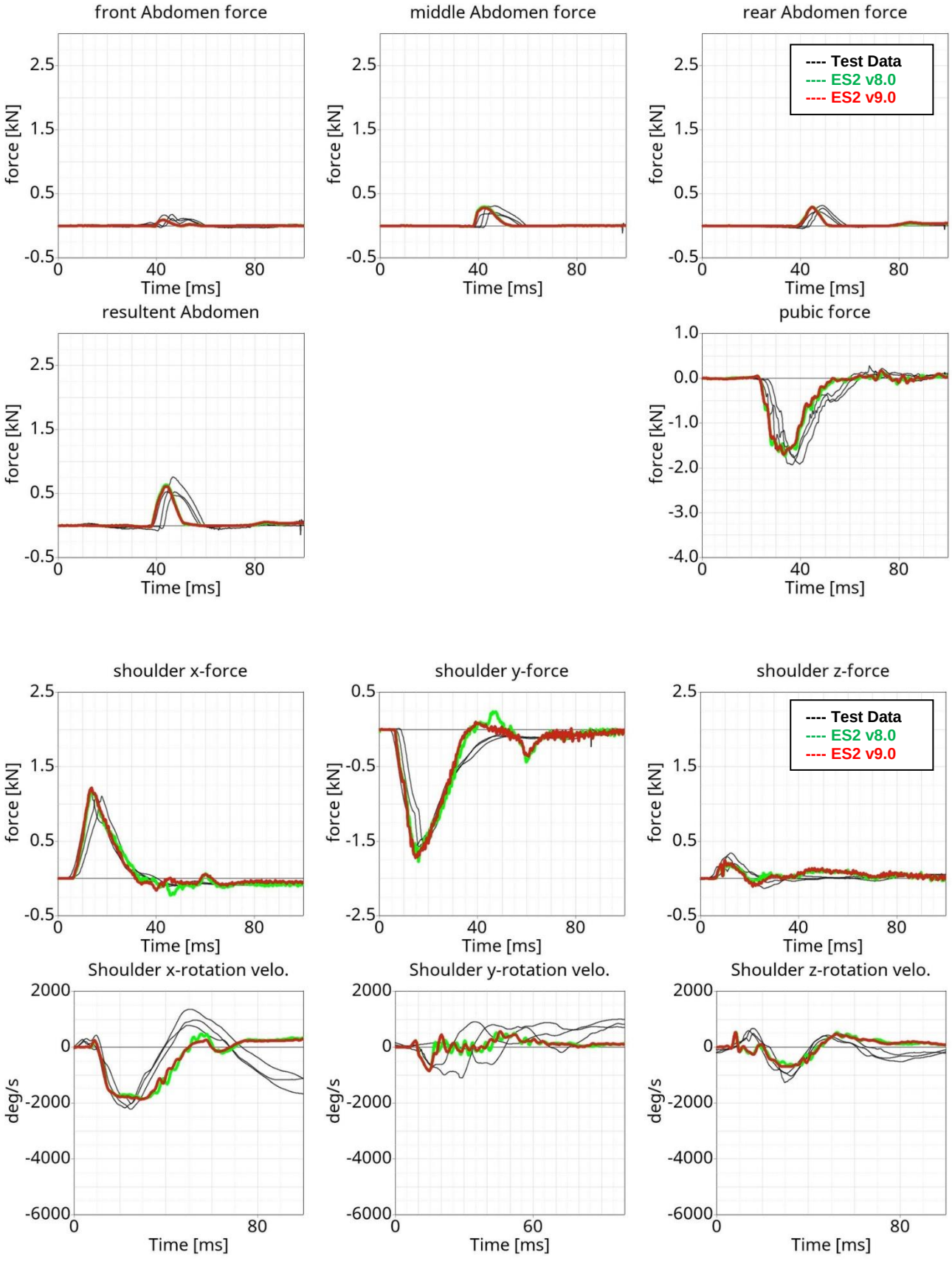


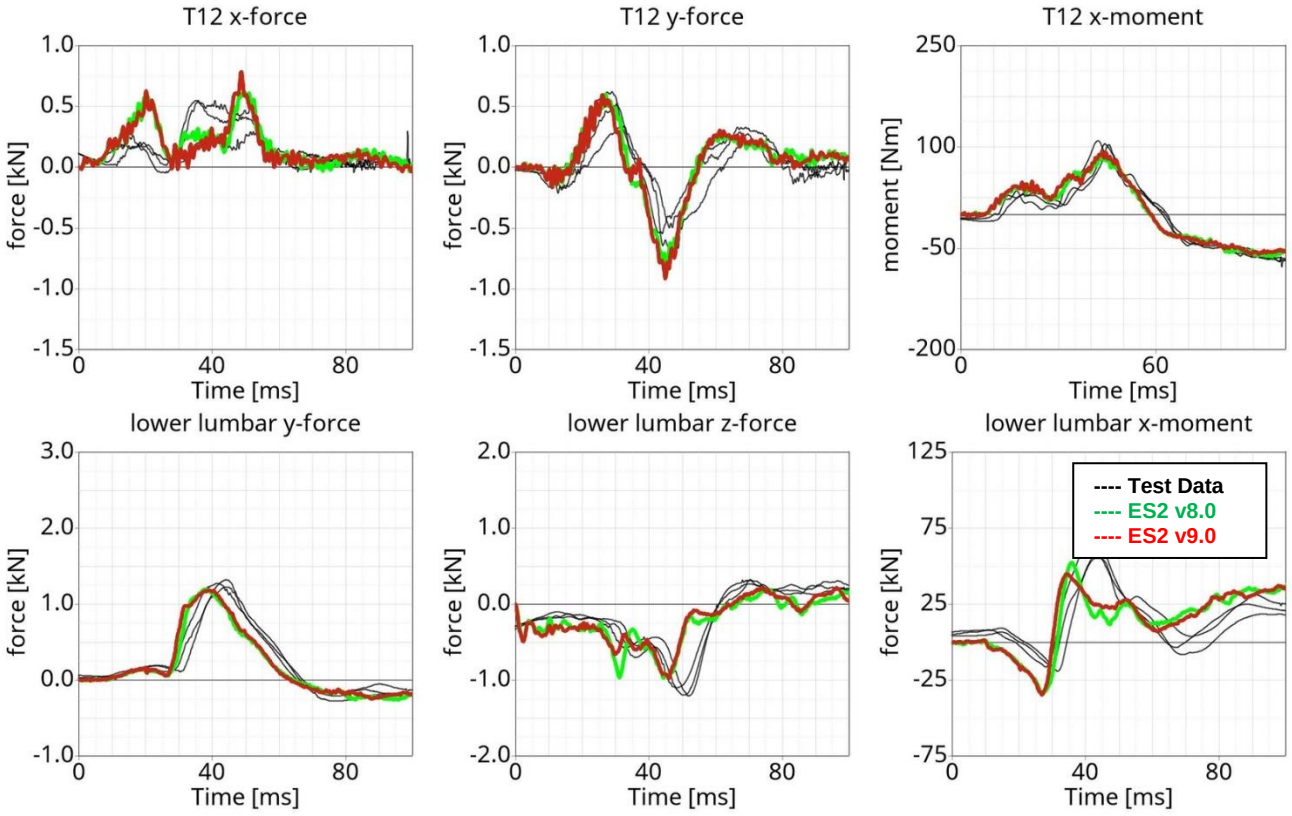
---- Test Data
---- ES2 v8.0
---- ES2 v9.0



---- Test Data
---- ES2 v8.0
---- ES2 v9.0


upper Neck y-force
force [N]
Time [ms]
upper Neck z-force
force [N]
Time [ms]
upper Neck x-moment
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
lower Neck y-force
force [N]
Time [ms]
lower Neck z-force
force [N]
Time [ms]
lower Neck x-moment
moment [Nm]
Time [ms]
up. Rib y-accel.
accle. [g]
Time [ms]
mid. Rib y-accel.
accle. [g]
Time [ms]
low. Rib y-accel.
accle. [g]
Time [ms]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
up. Rib deflection
deflection [mm]
Time [ms]
mid. Rib deflection
deflection [mm]
Time [ms]
low. Rib deflection
deflection [mm]
Time [ms]


front Abdomen force
middle Abdomen force
rear Abdomen force
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
resultent Abdomen
pubic force
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]


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 v8.0
---- ES2 v9.0

13.2 Configuration D3: Barrier with pelvis bumper

Boundaries:

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

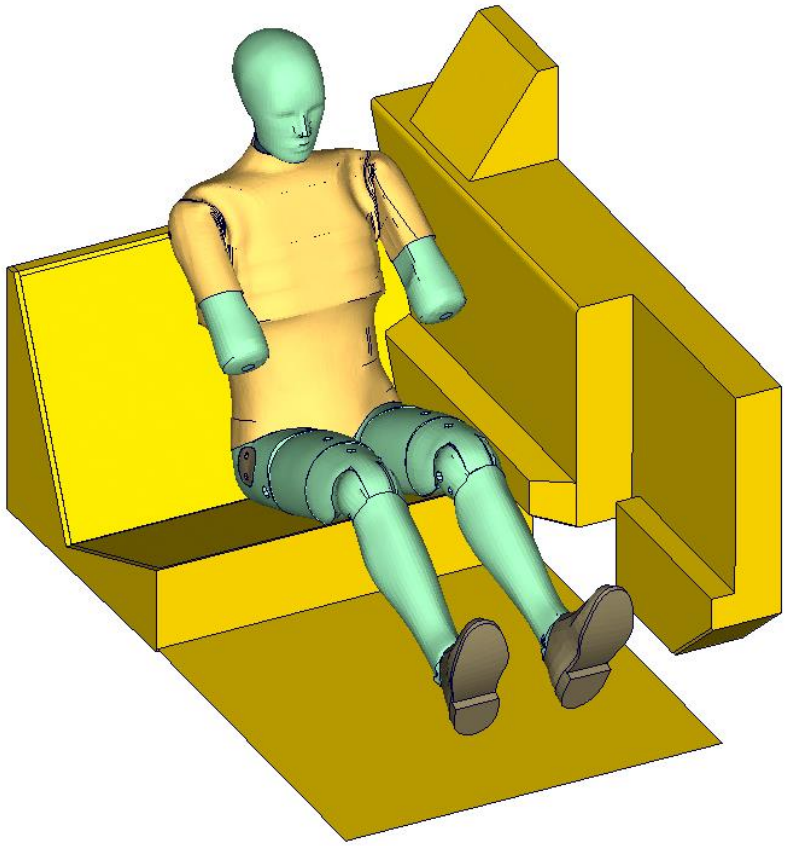
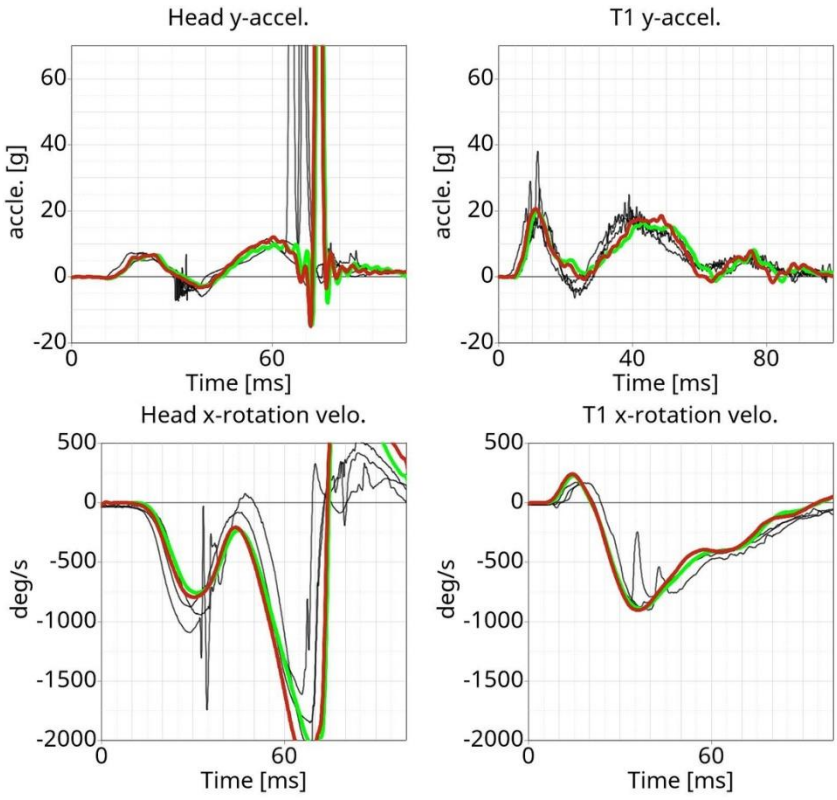
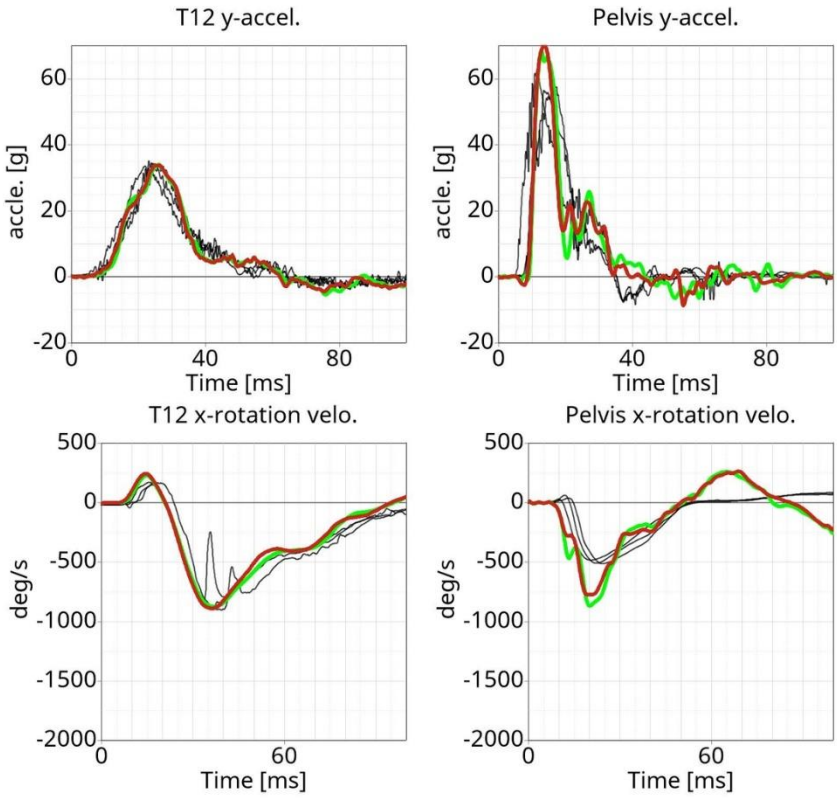


Figure 48: D3 barrier test setup

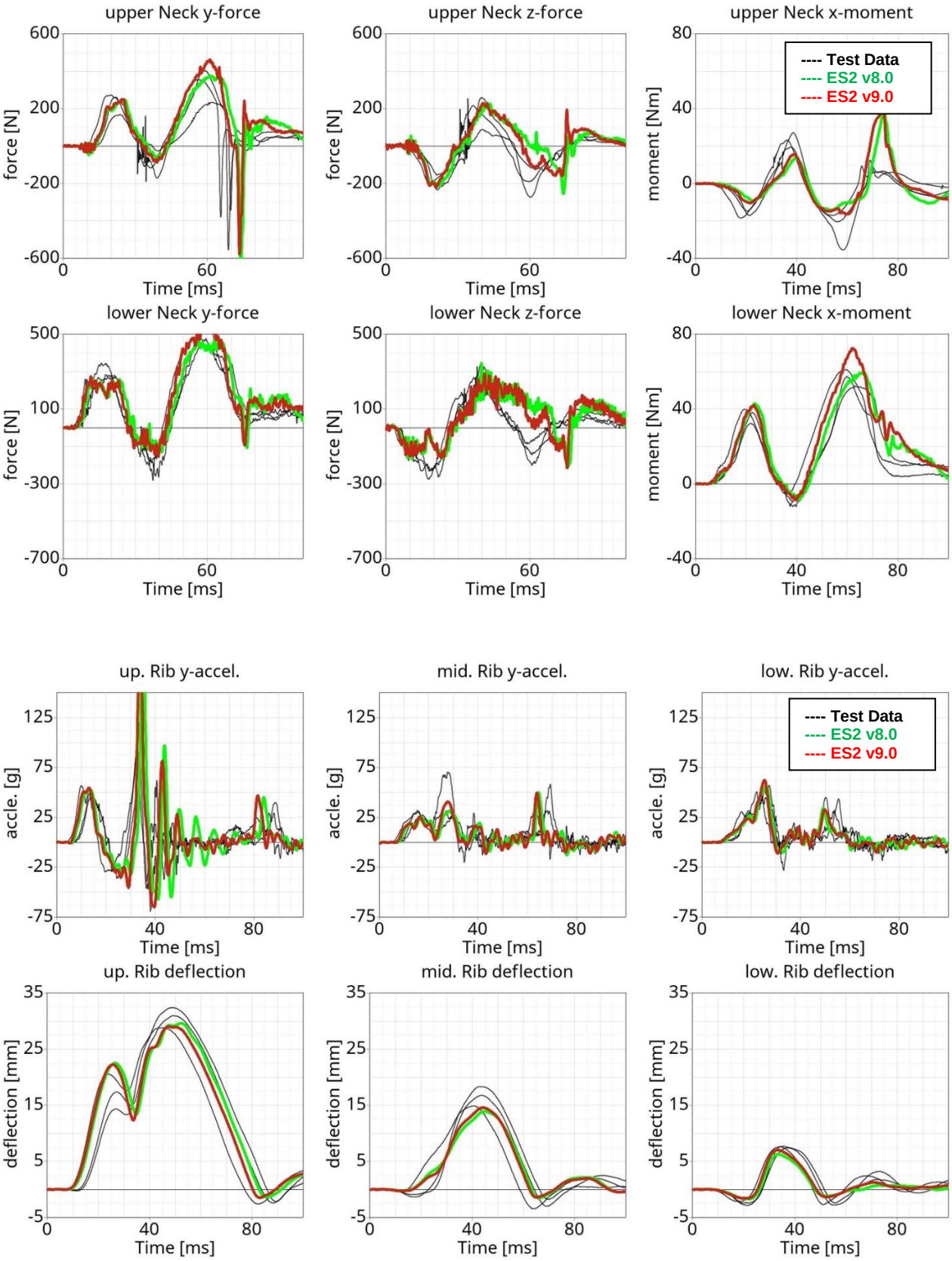
13.2.1 Results at high velocity impact

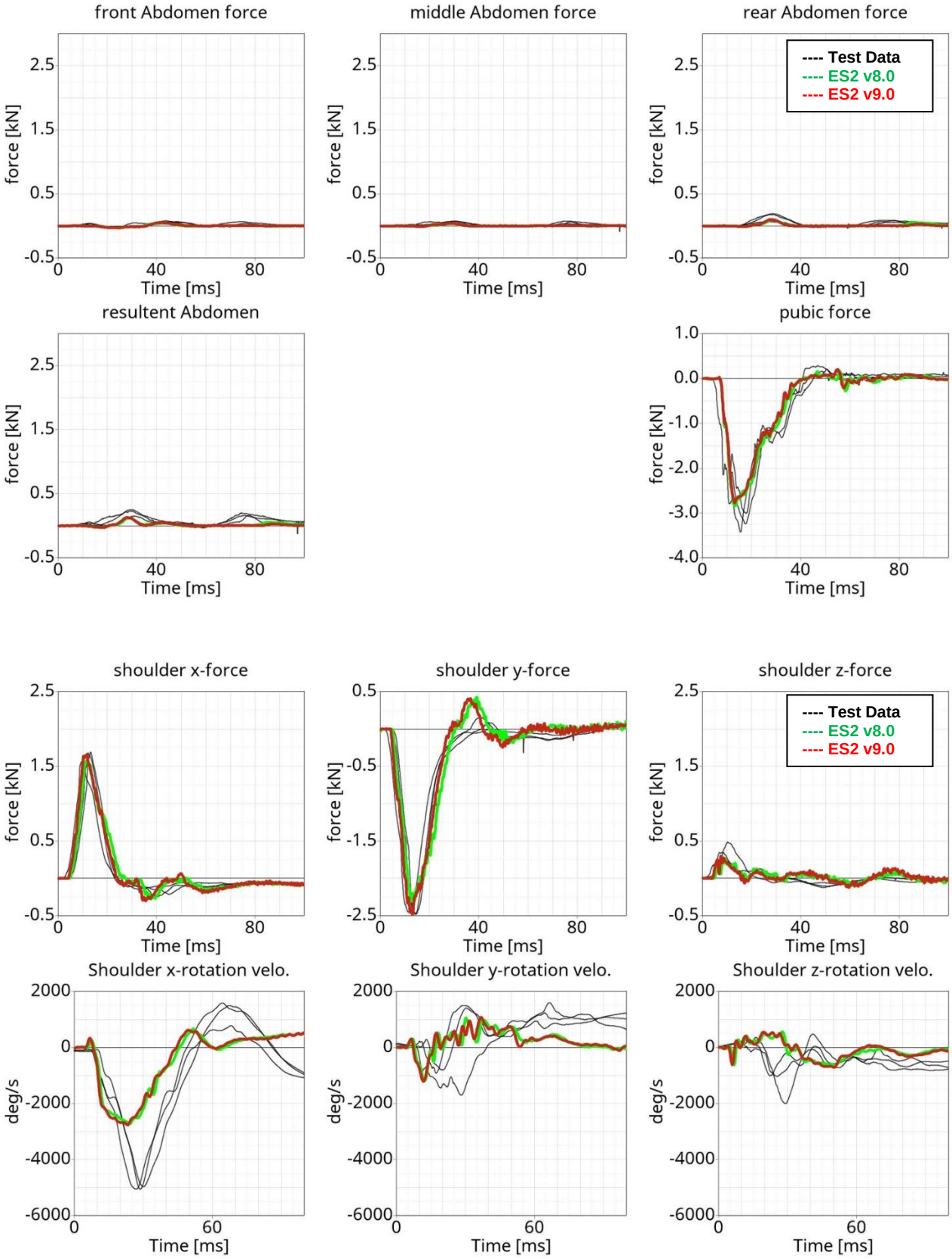


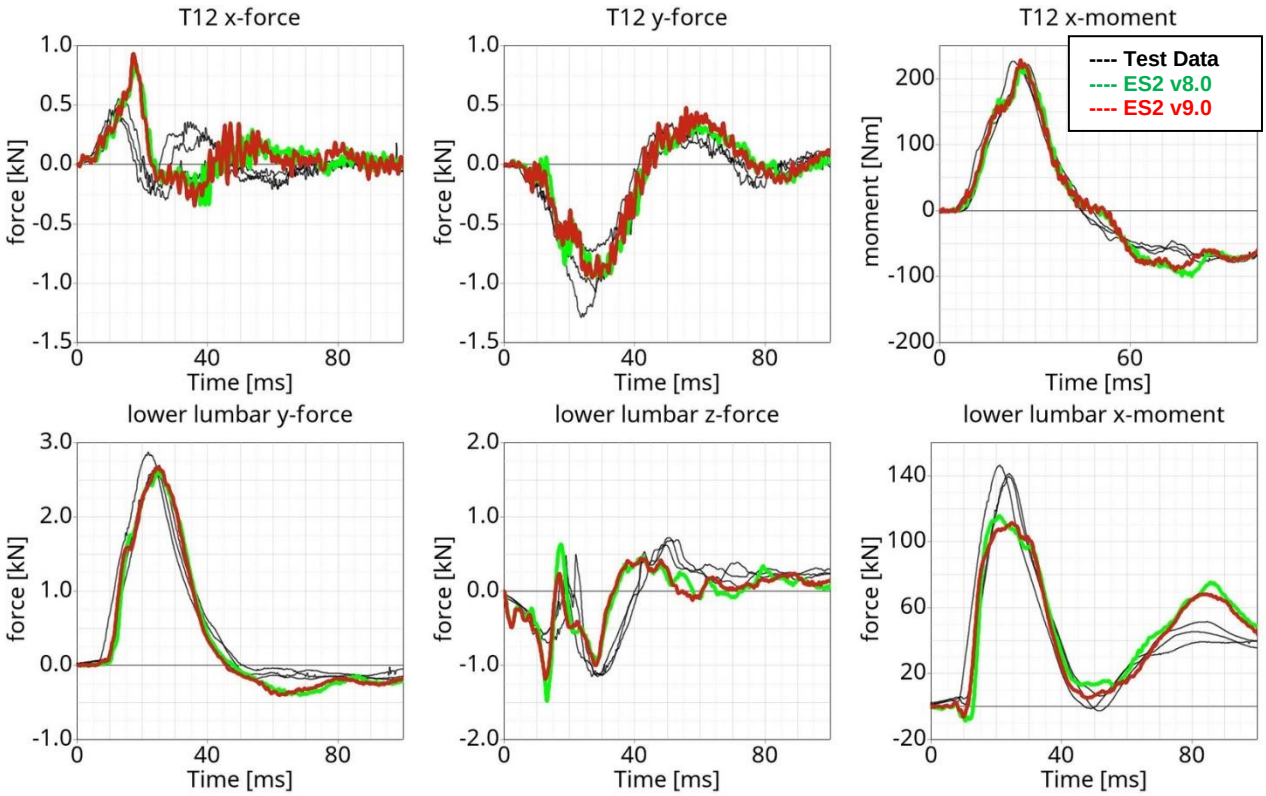
---- Test Data
---- ES2 v8.0
---- ES2 v9.0



---- Test Data
---- ES2 v8.0
---- ES2 v9.0


upper Neck y-force
upper Neck z-force
upper Neck x-moment
lower Neck y-force
lower Neck z-force
lower Neck x-moment
up. Rib y-accel.
mid. Rib y-accel.
low. Rib y-accel.
up. Rib deflection
mid. Rib deflection
low. Rib deflection
force [N]
moment [Nm]
accle. [g]
deflection [mm]
Time [ms]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0


front Abdomen force
middle Abdomen force
rear Abdomen force
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
resultent Abdomen
pubic force
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]


T12 x-force
force [kN]
Time [ms]
T12 y-force
force [kN]
Time [ms]
T12 x-moment
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
lower lumbar y-force
force [kN]
Time [ms]
lower lumbar z-force
force [kN]
Time [ms]
lower lumbar x-moment
force [kN]
Time [ms]

13.3 Configuration D4: Door barrier

Boundaries:

- Rigid barrier (Figure 49)
- Impact speed: High velocity
- Arms in 40 degree position
- Curb edge
- Orthogonal impact

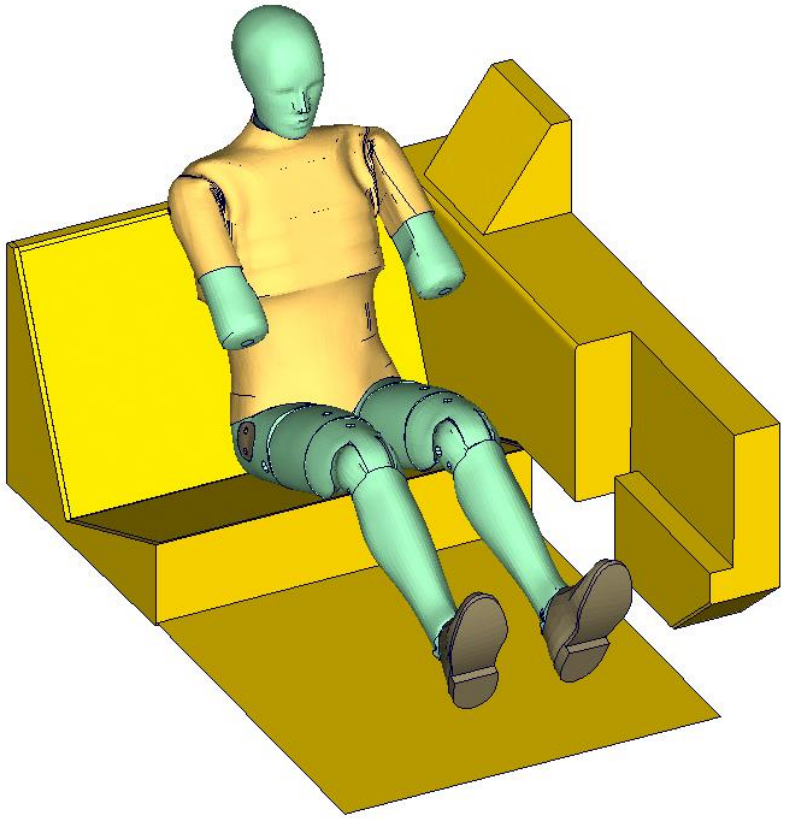
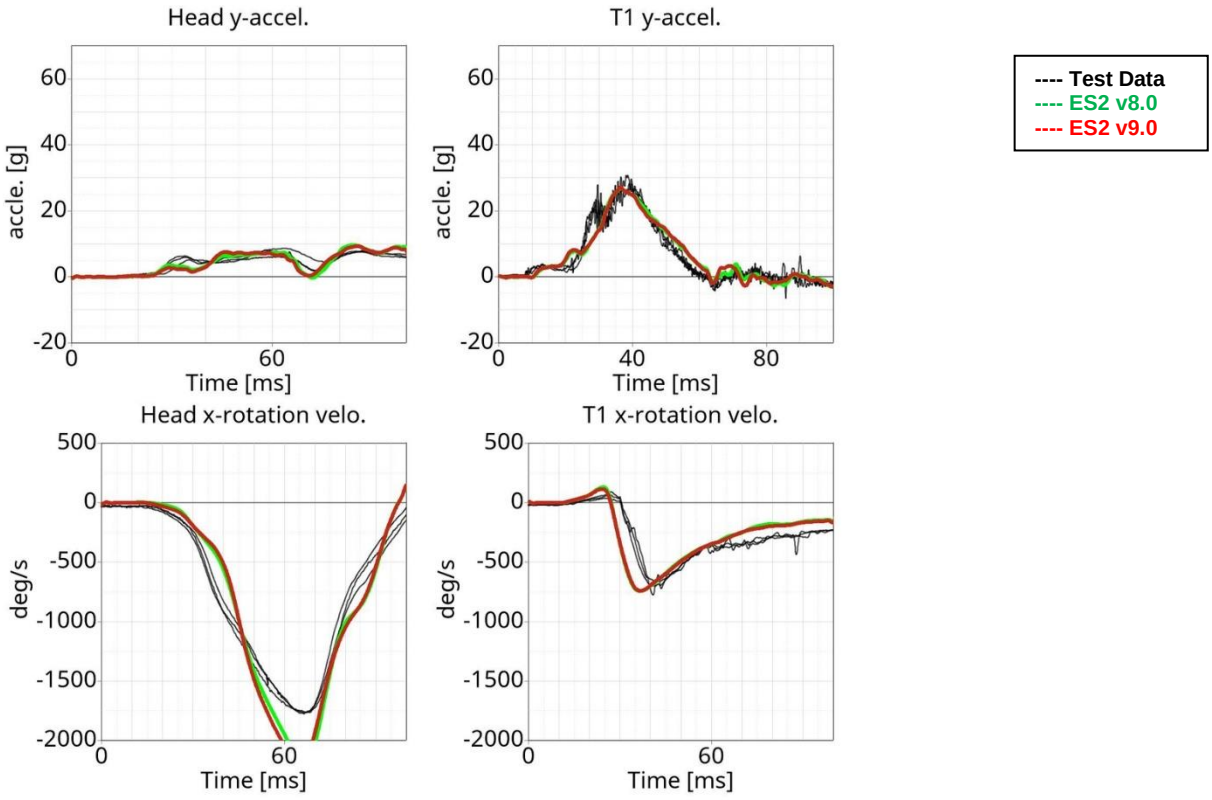
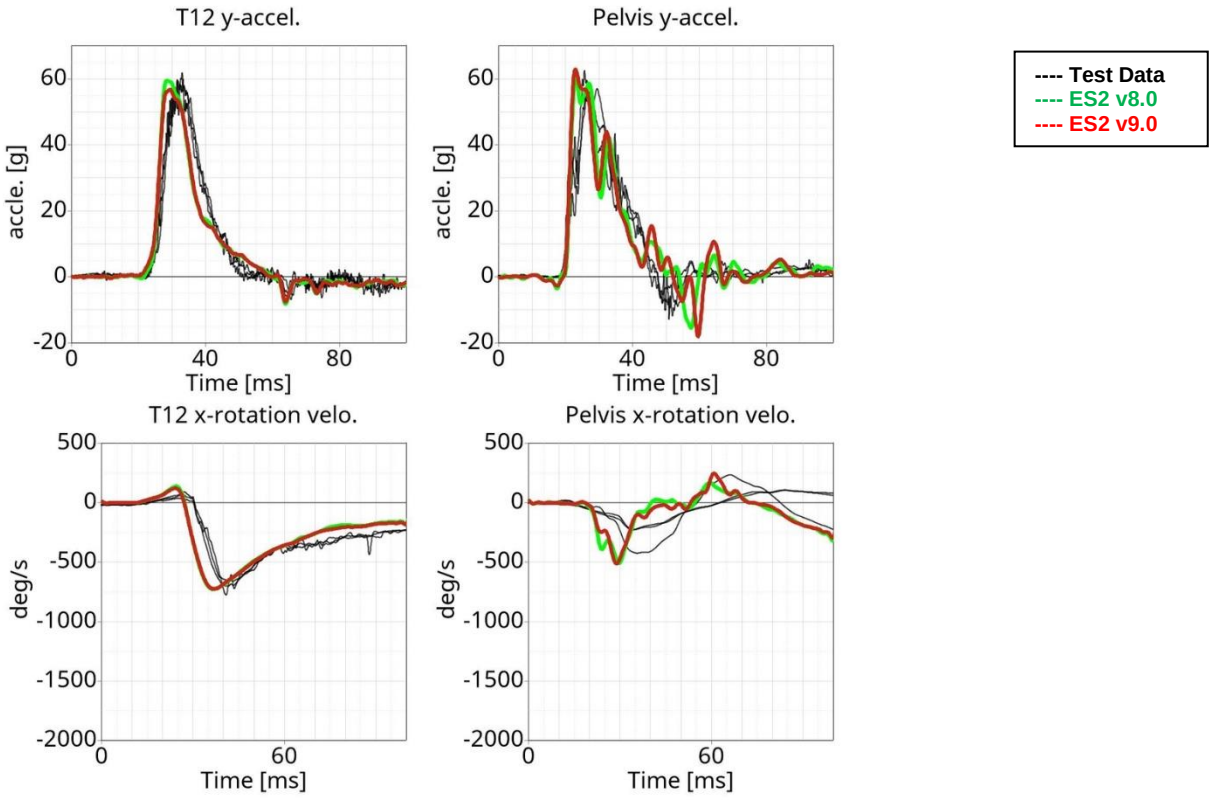
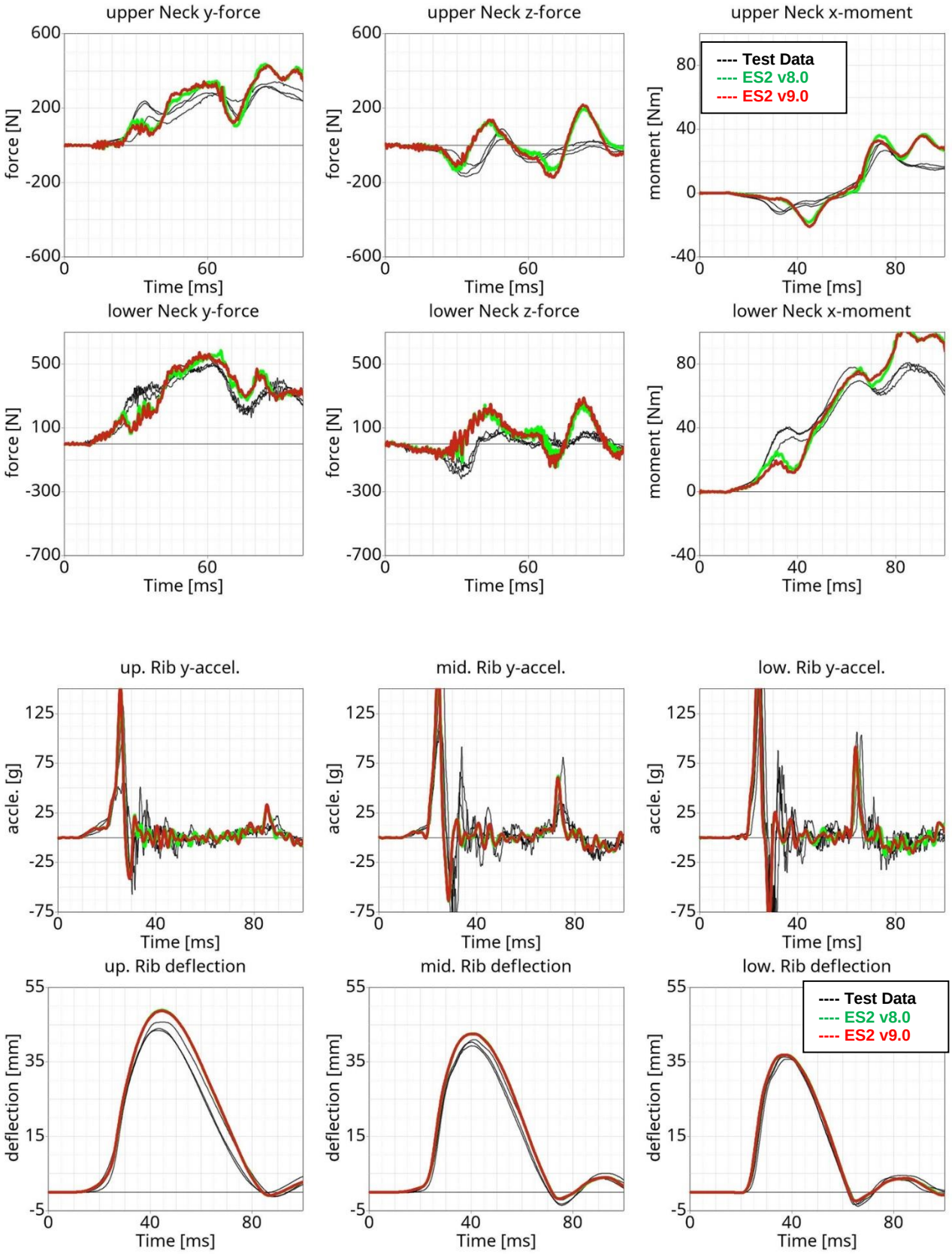


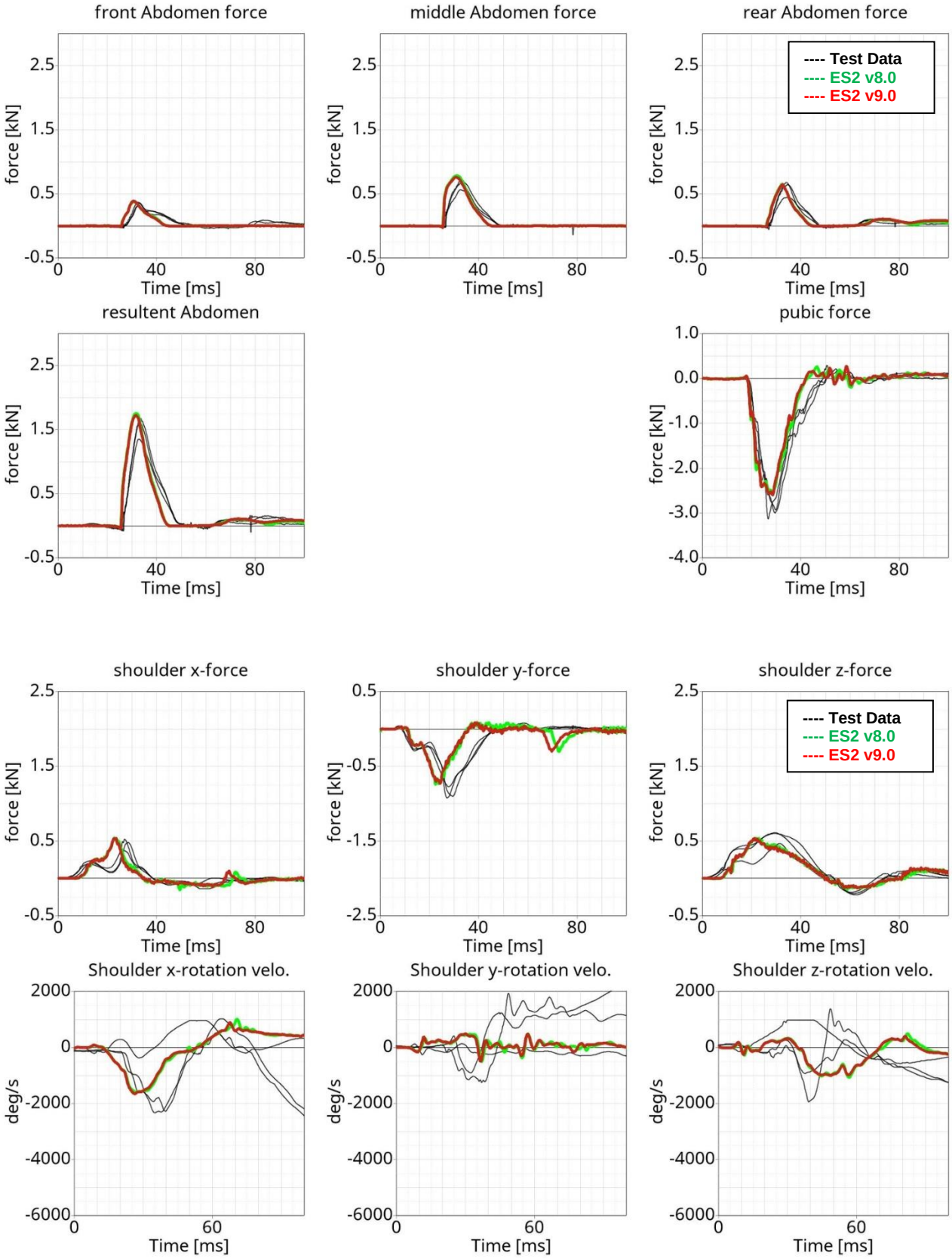
Figure 49: D4 door barrier test setup

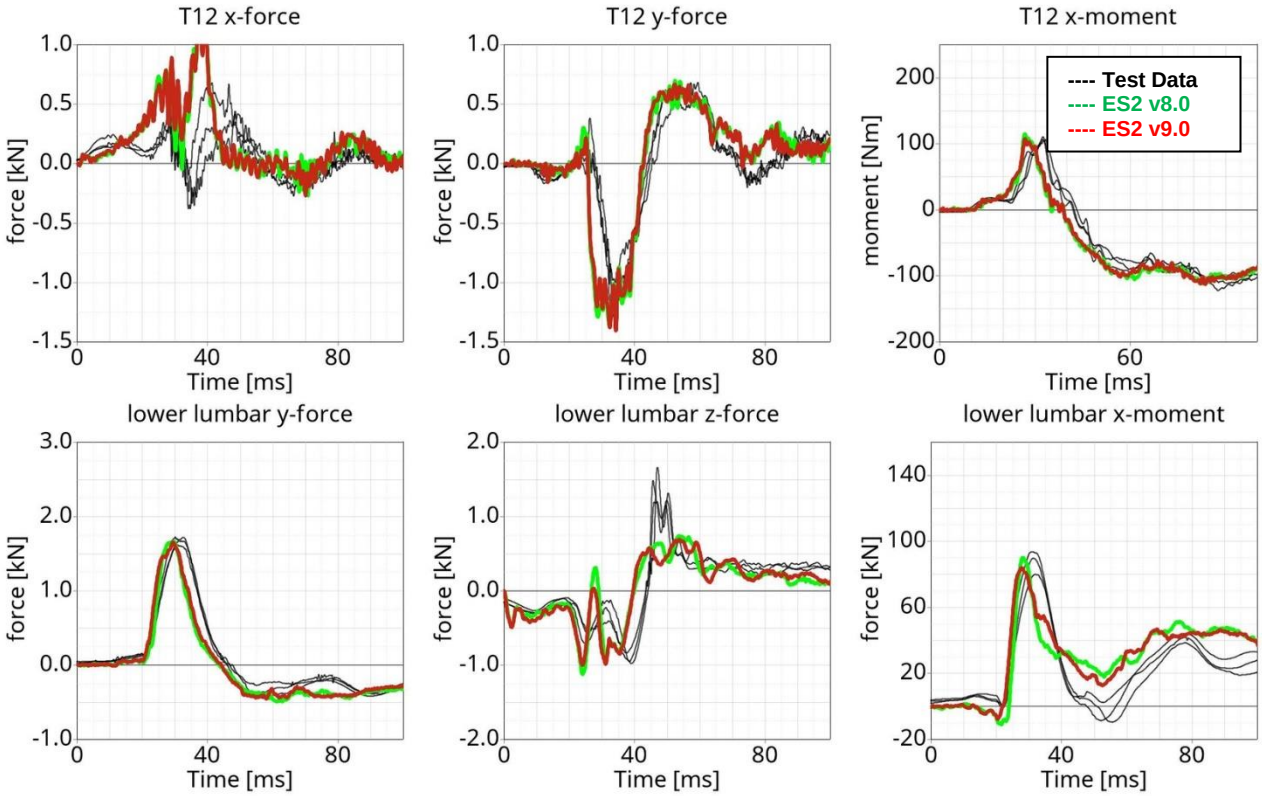
13.3.1 Results at high velocity impact






upper Neck y-force
force [N]
Time [ms]
upper Neck z-force
force [N]
Time [ms]
upper Neck x-moment
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
lower Neck y-force
force [N]
Time [ms]
lower Neck z-force
force [N]
Time [ms]
lower Neck x-moment
moment [Nm]
Time [ms]
up. Rib y-accel.
accle. [g]
Time [ms]
mid. Rib y-accel.
accle. [g]
Time [ms]
low. Rib y-accel.
accle. [g]
Time [ms]
up. Rib deflection
deflection [mm]
Time [ms]
mid. Rib deflection
deflection [mm]
Time [ms]
low. Rib deflection
deflection [mm]
Time [ms]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0


front Abdomen force
middle Abdomen force
rear Abdomen force
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
resultent Abdomen
pubic force
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]


T12 x-force
force [kN]
Time [ms]
T12 y-force
force [kN]
Time [ms]
T12 x-moment
moment [Nm]
Time [ms]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
lower lumbar y-force
force [kN]
Time [ms]
lower lumbar z-force
force [kN]
Time [ms]
lower lumbar x-moment
force [kN]
Time [ms]

13.4 Additional tests 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

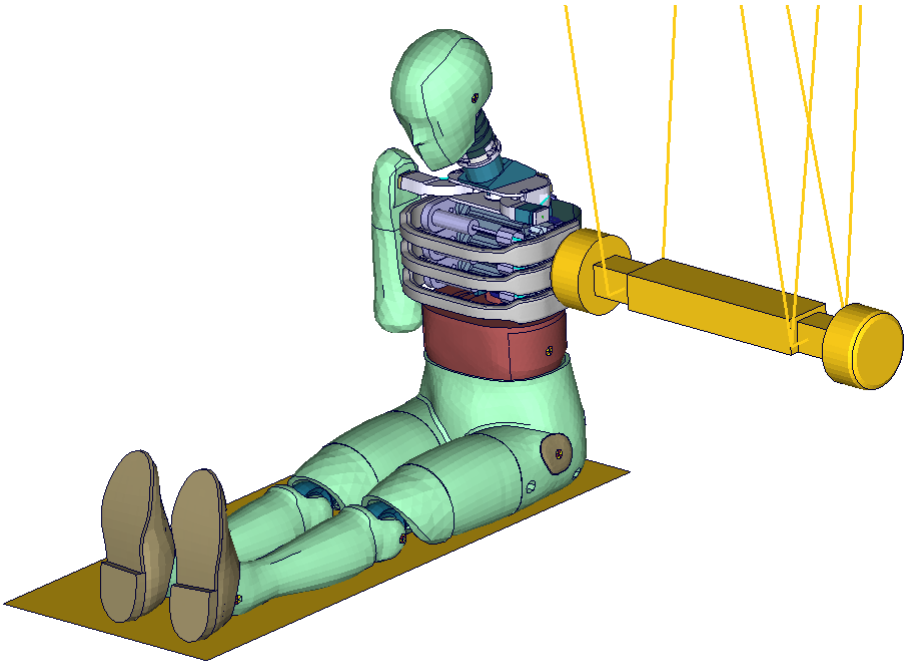
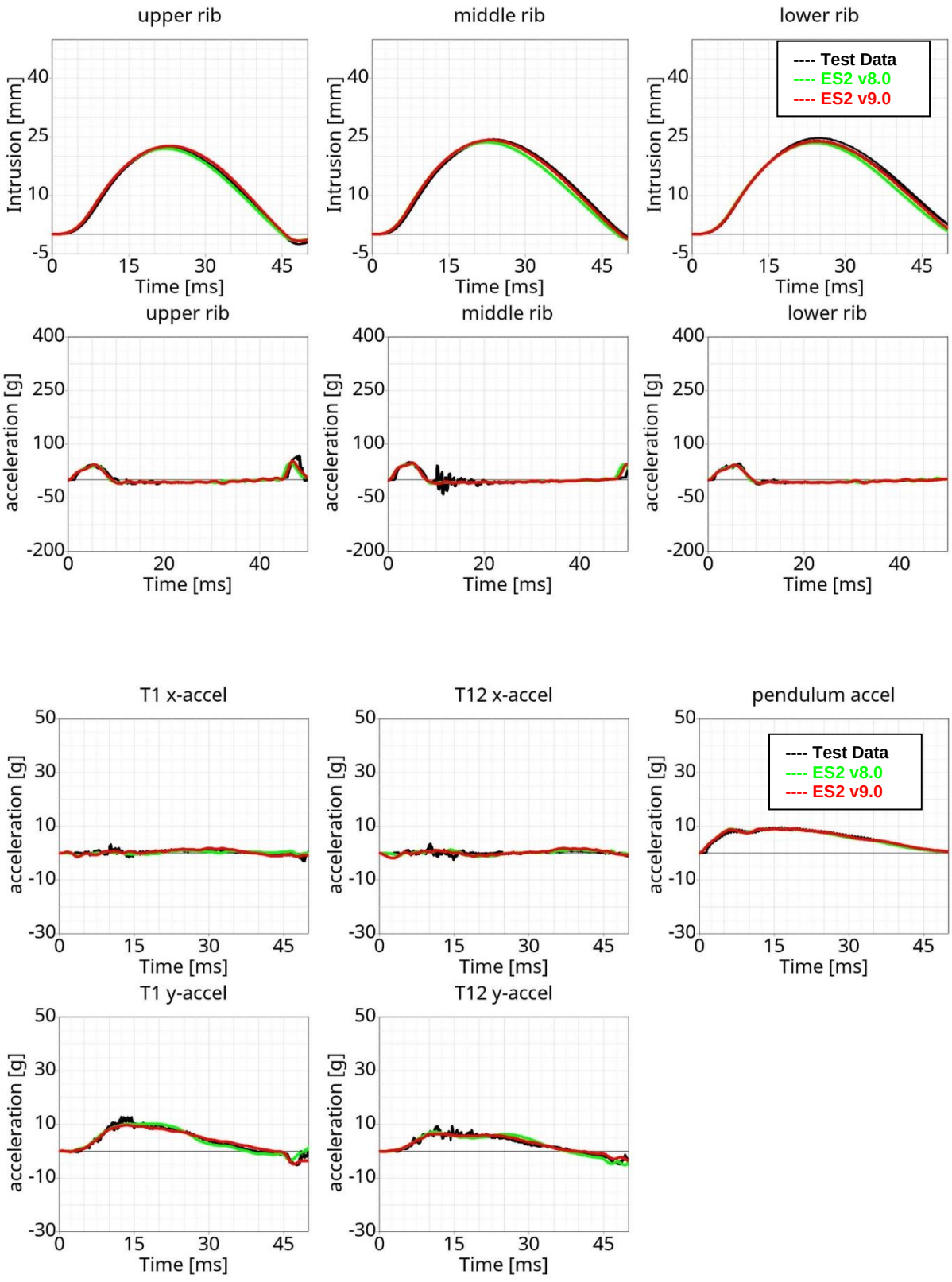
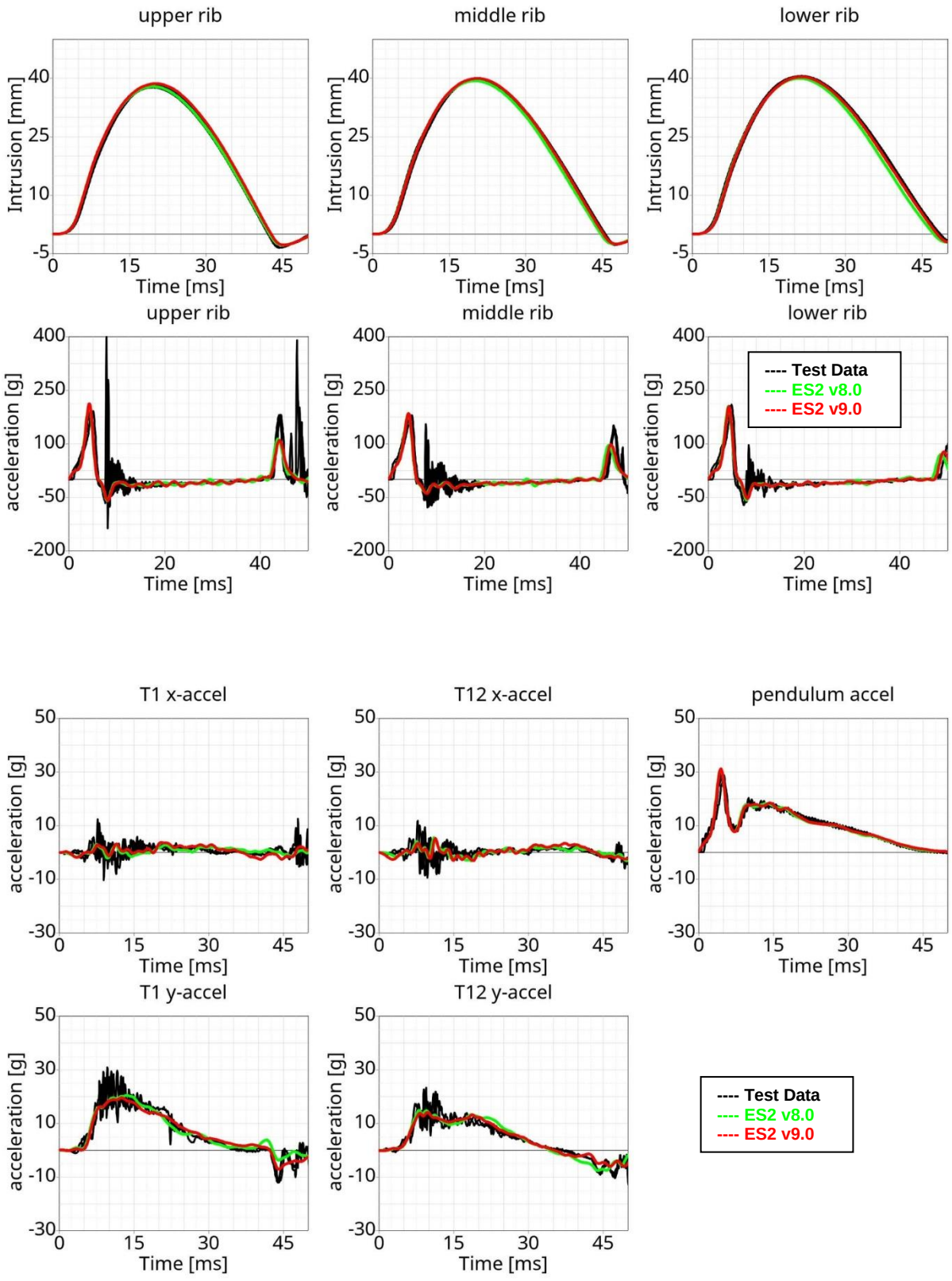


Figure 50: Pendulum impacting the ribs at 90 degrees; without arm and jacket

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

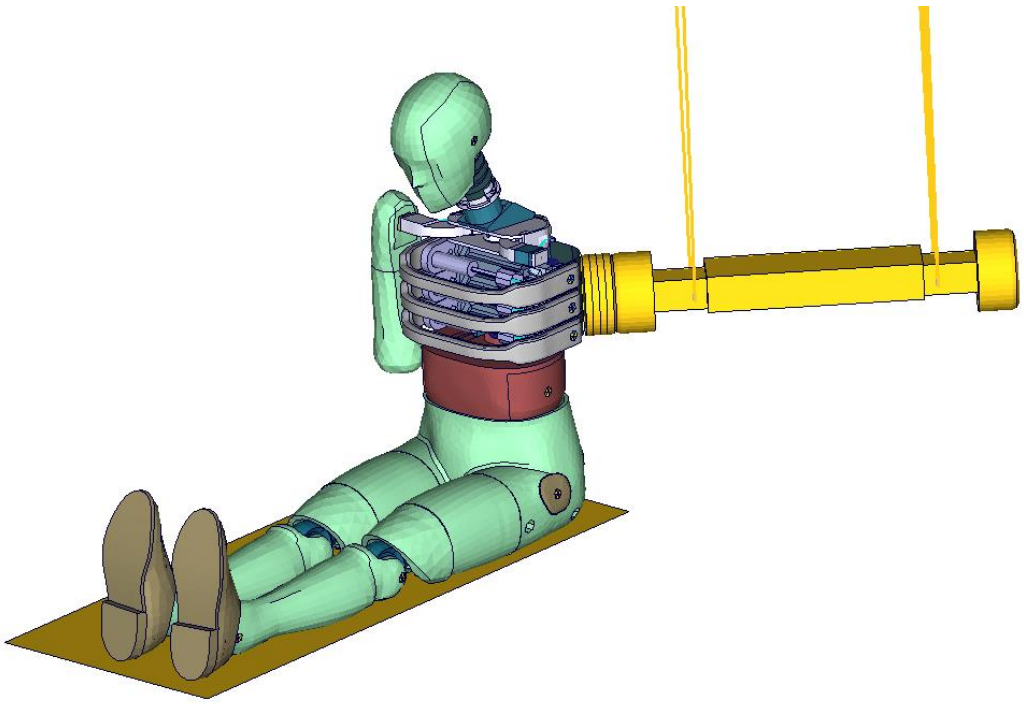
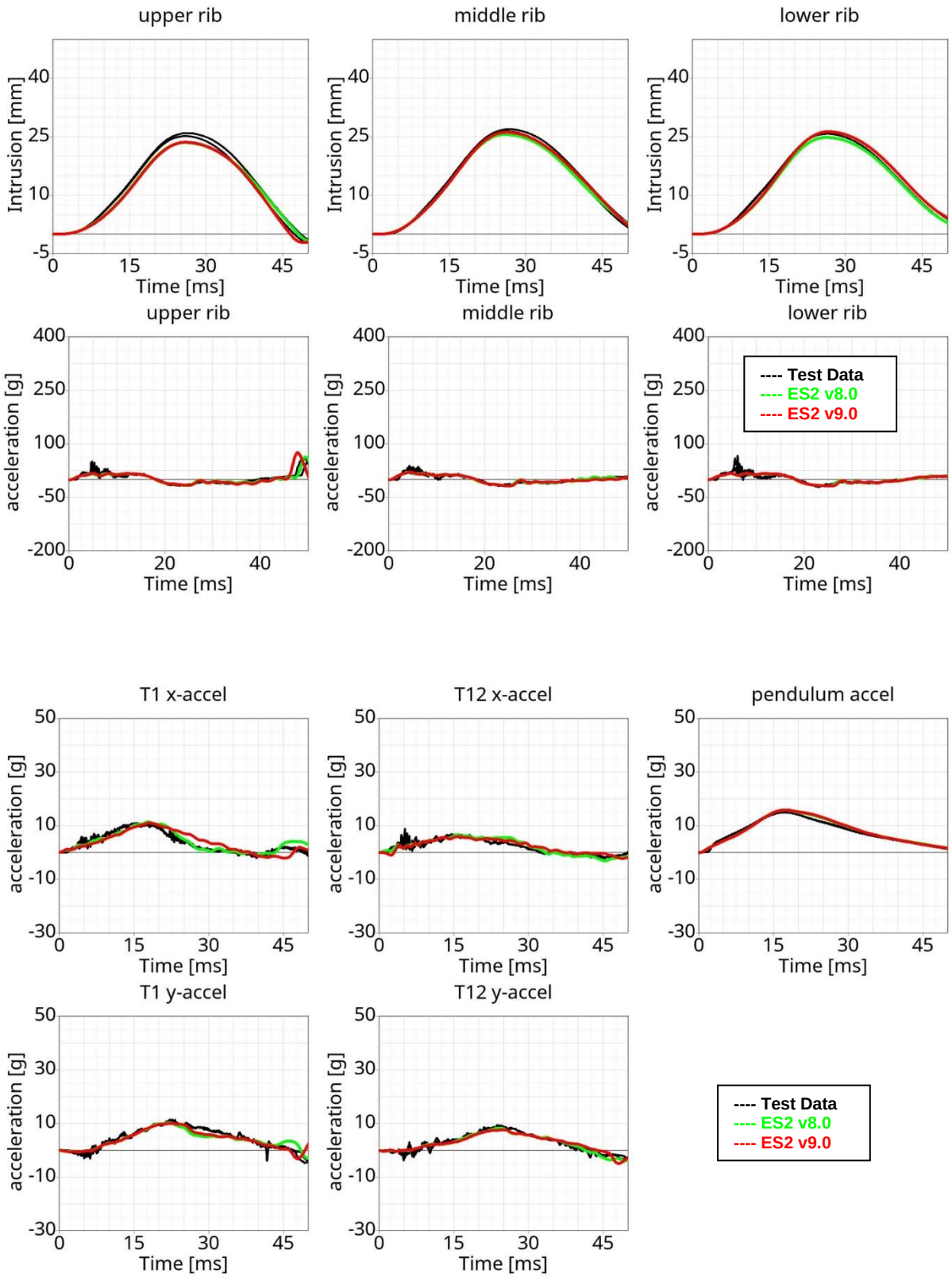
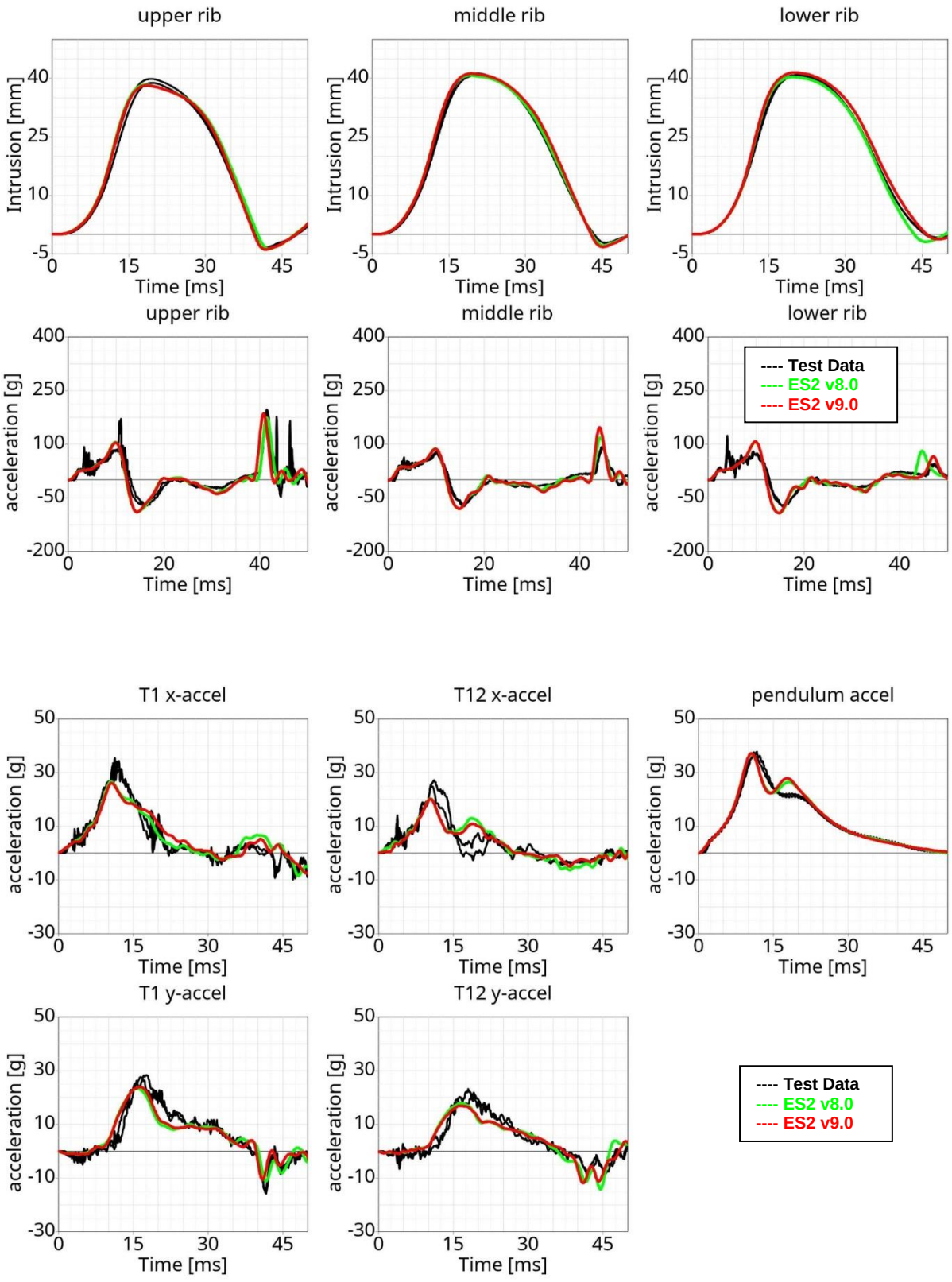


Figure 51: Pendulum impacting the ribs at 45 degrees; without arm and jacket

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

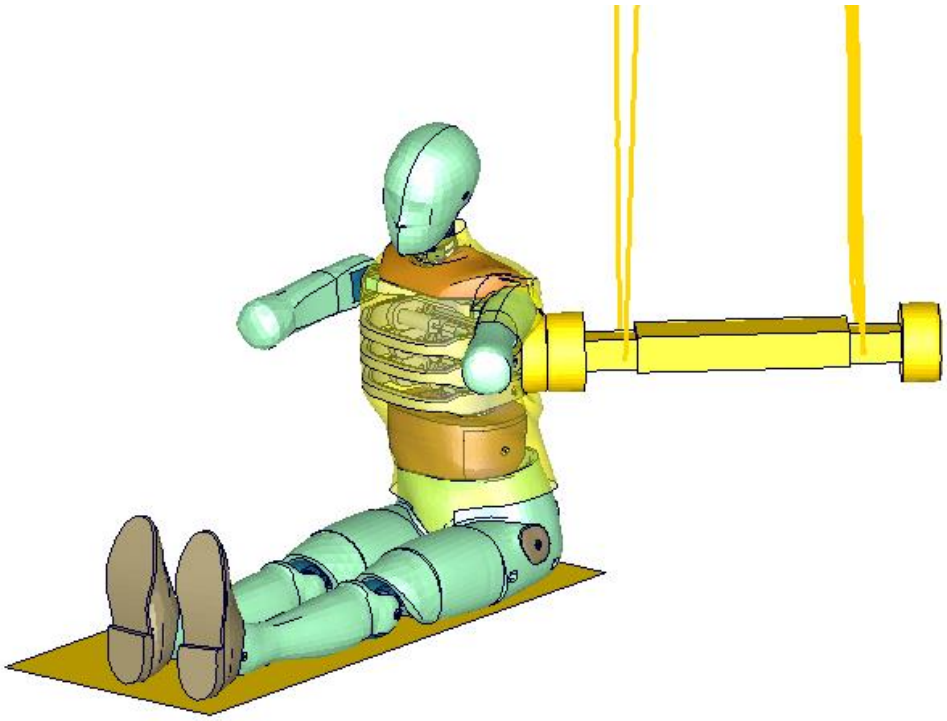
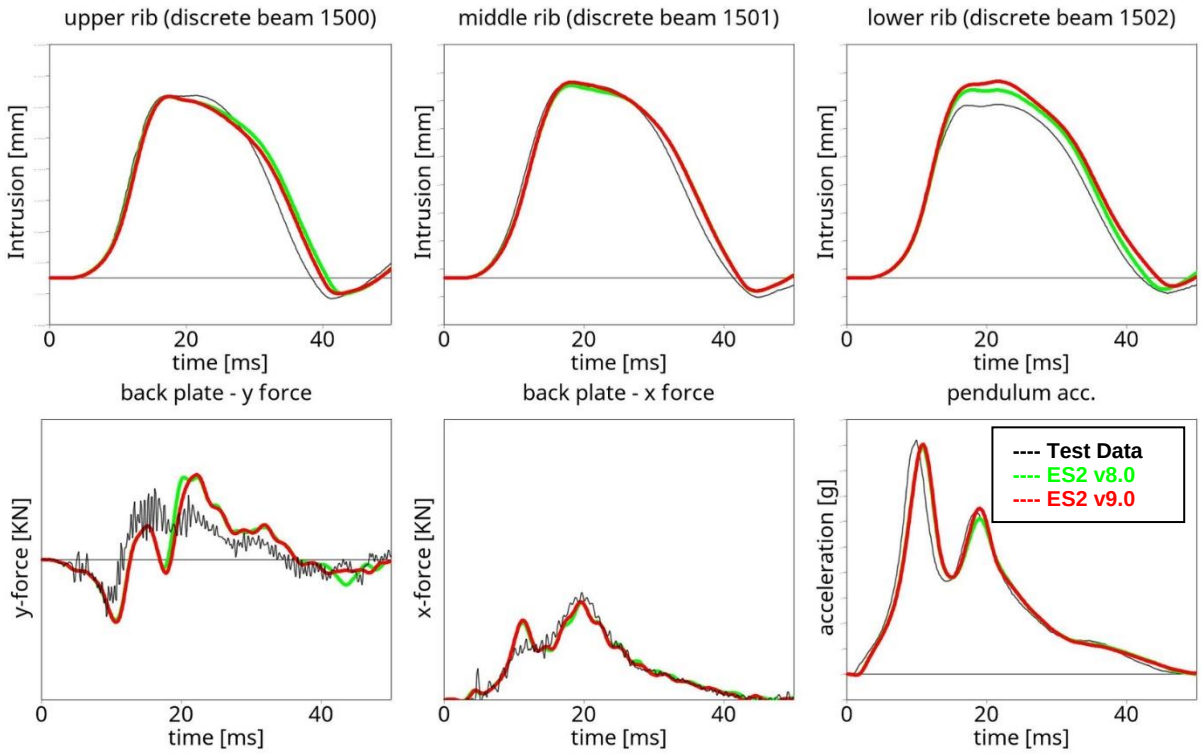


Figure 52: Pendulum impacting the ribs at 45 degrees; with arm and jacket

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]
acceleration [g]
---- Test Data
---- ES2 v8.0
---- ES2 v9.0

13.5 ARP-sled-tests with ES-2re

13.5.1 ARP-sled-test with armrest

Boundaries:

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

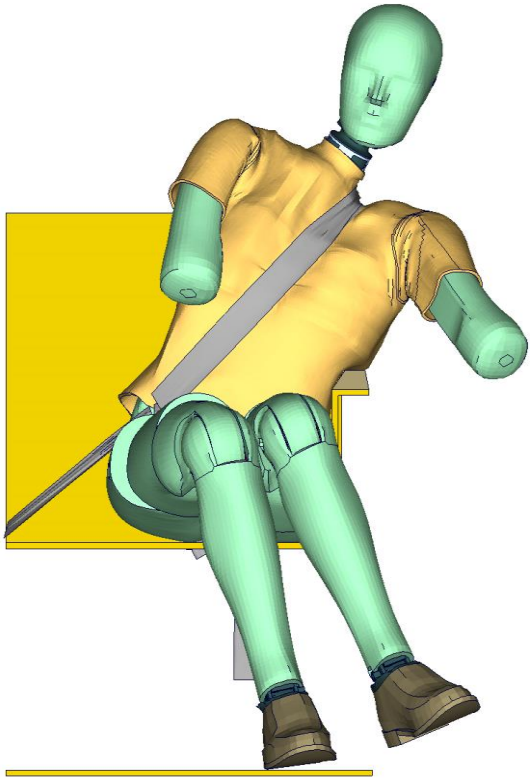
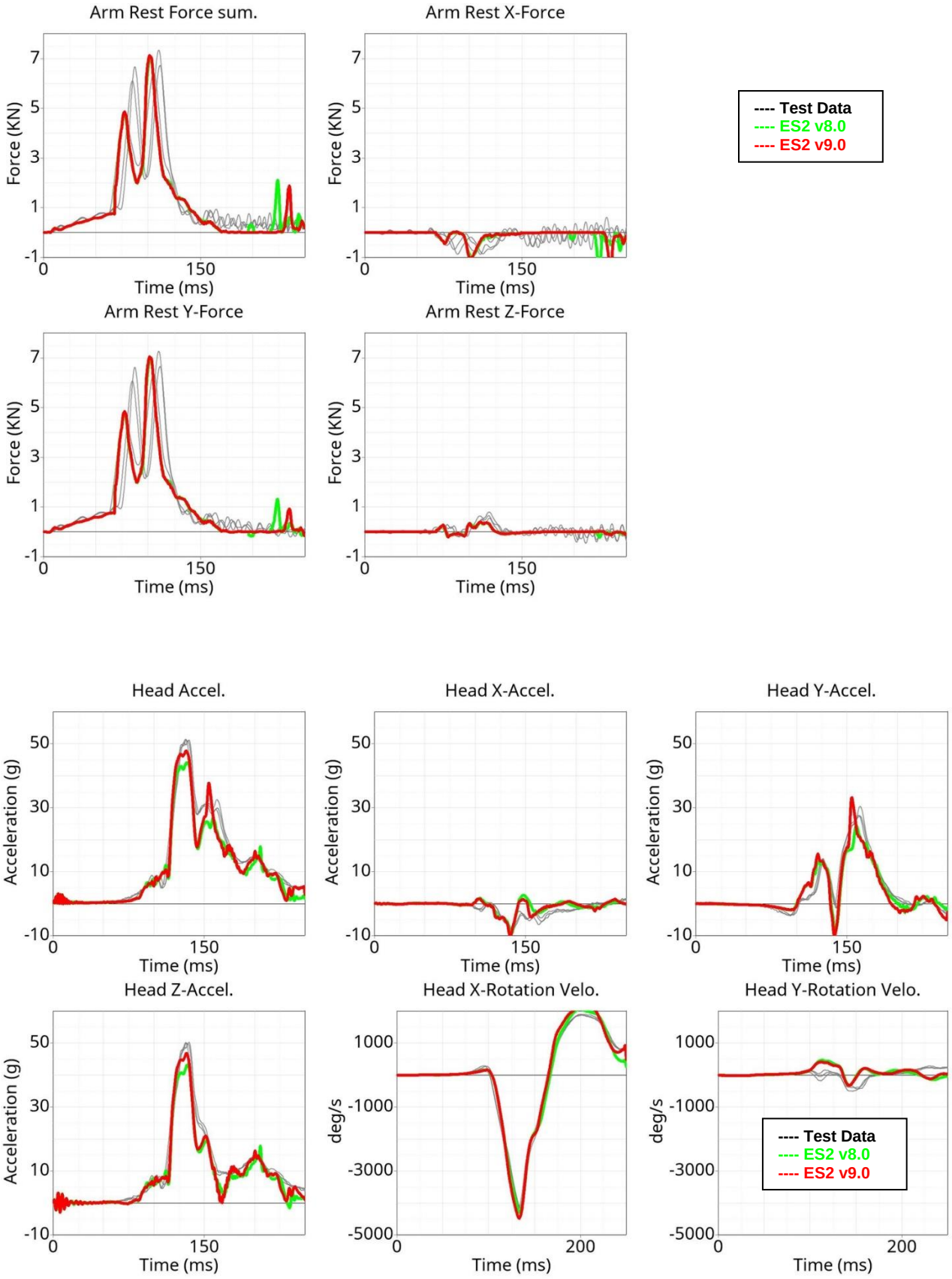
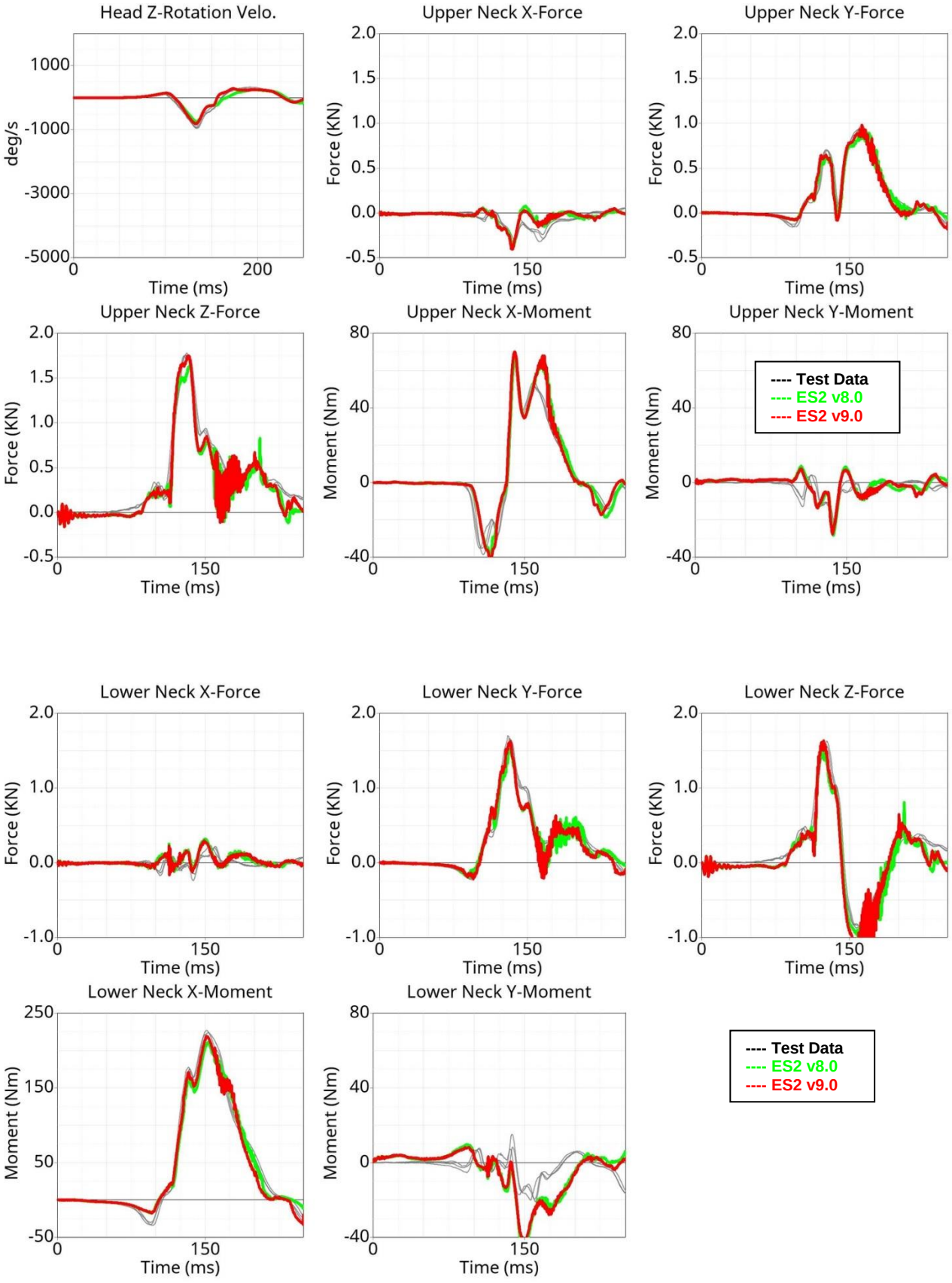
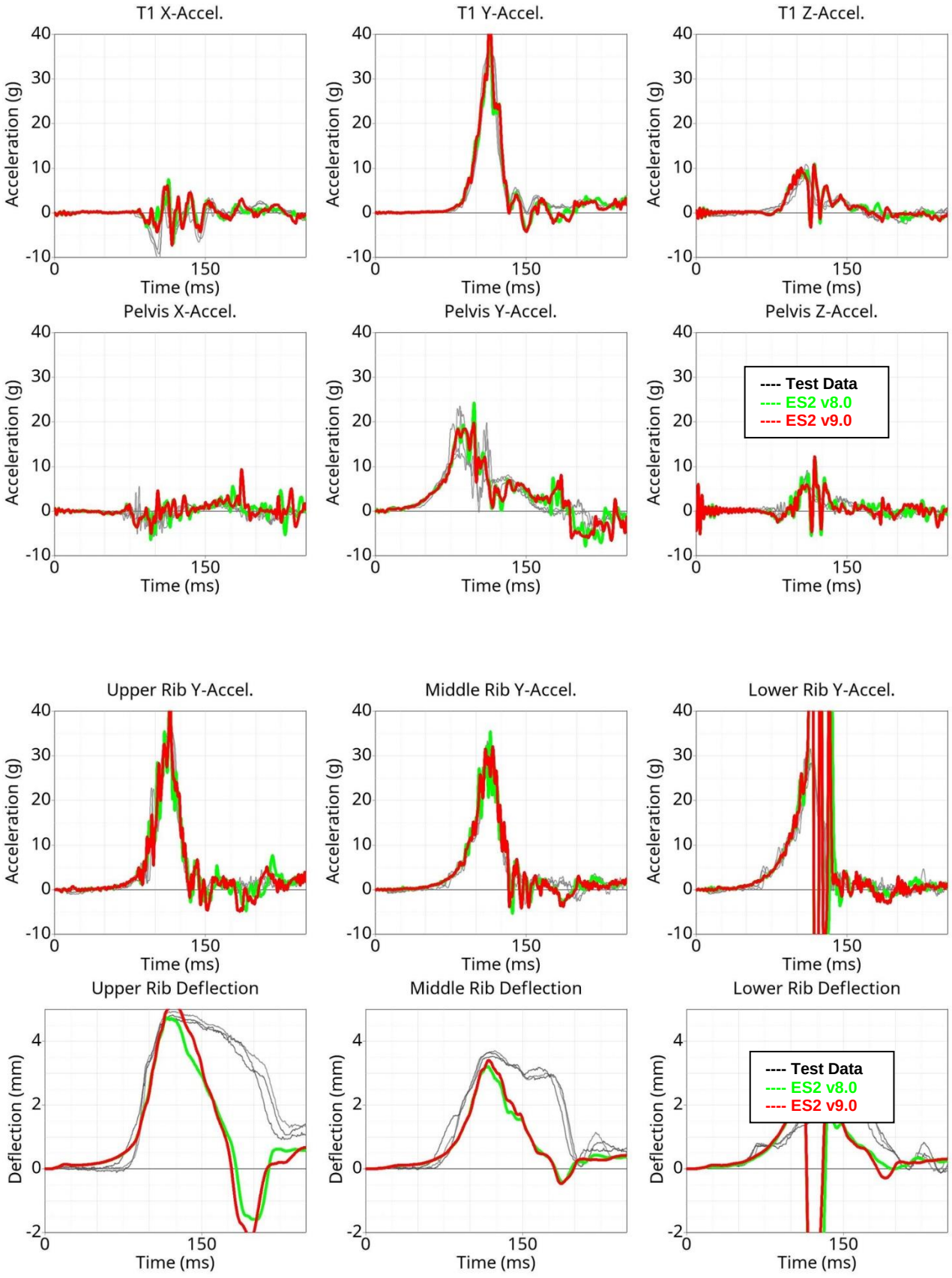


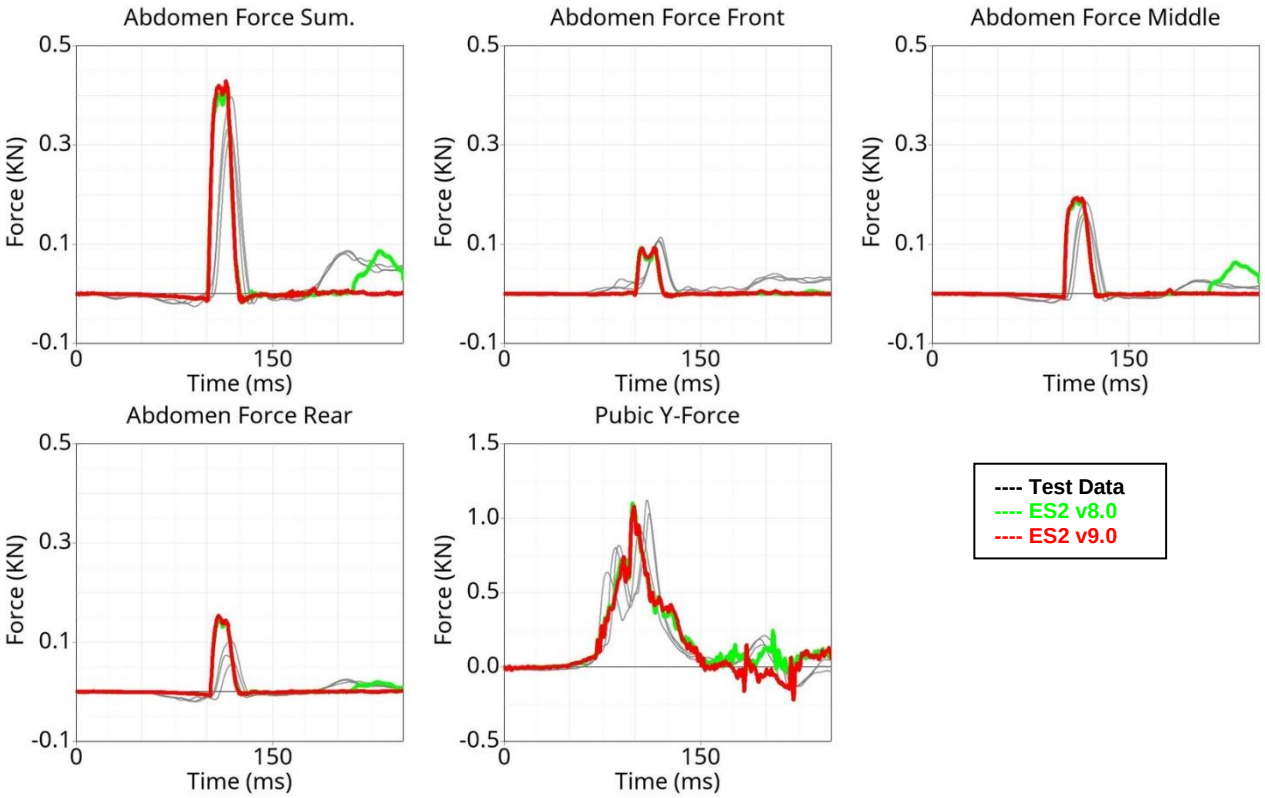
Figure 53: ARP-sled-test with armrest

Results with armrest




Head Z-Rotation Velo.
deg/s
1000
-1000
-3000
-5000
0
200
Time (ms)
Upper Neck X-Force
Force (KN)
2.0
1.5
1.0
0.5
0.0
-0.5
0
150
Time (ms)
Upper Neck Y-Force
Force (KN)
Time (ms)
Upper Neck Z-Force
Force (KN)
Time (ms)
Upper Neck X-Moment
Moment (Nm)
80
40
0
-40
Time (ms)
Upper Neck Y-Moment
Moment (Nm)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
Lower Neck X-Force
Force (KN)
1.0
0.0
-1.0
Time (ms)
Lower Neck Y-Force
Force (KN)
Time (ms)
Lower Neck Z-Force
Force (KN)
Time (ms)
Lower Neck X-Moment
Moment (Nm)
250
150
50
-50
Time (ms)
Lower Neck Y-Moment
Moment (Nm)
Time (ms)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0


T1 X-Accel.
T1 Y-Accel.
T1 Z-Accel.
Pelvis X-Accel.
Pelvis Y-Accel.
Pelvis Z-Accel.
Upper Rib Y-Accel.
Middle Rib Y-Accel.
Lower Rib Y-Accel.
Upper Rib Deflection
Middle Rib Deflection
Lower Rib Deflection
Acceleration (g)
Deflection (mm)
Time (ms)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0


Abdomen Force Sum.
Abdomen Force Front
Abdomen Force Middle
Abdomen Force Rear
Pubic Y-Force
Force (KN)
Time (ms)
0.5
0.3
0.1
-0.1
1.5
1.0
0.0
-0.5
0
150
---- Test Data
---- ES2 v8.0
---- ES2 v9.0

13.5.2 ARP-sled-test without armrest

Boundaries:

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

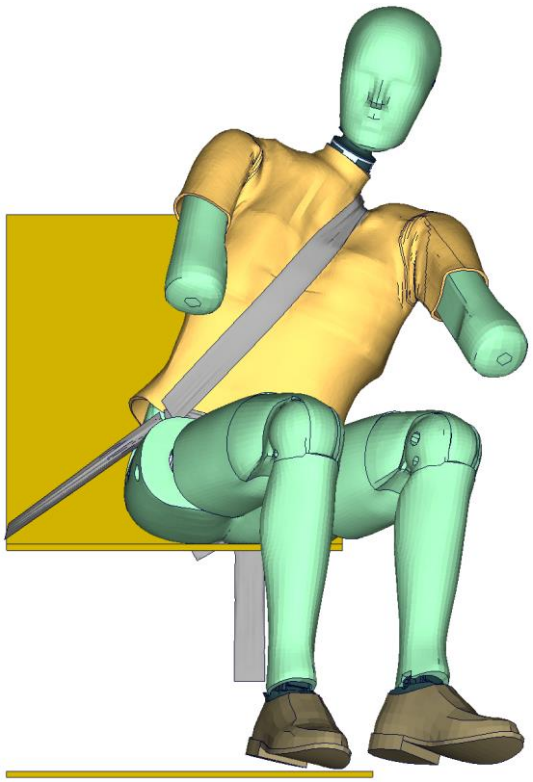
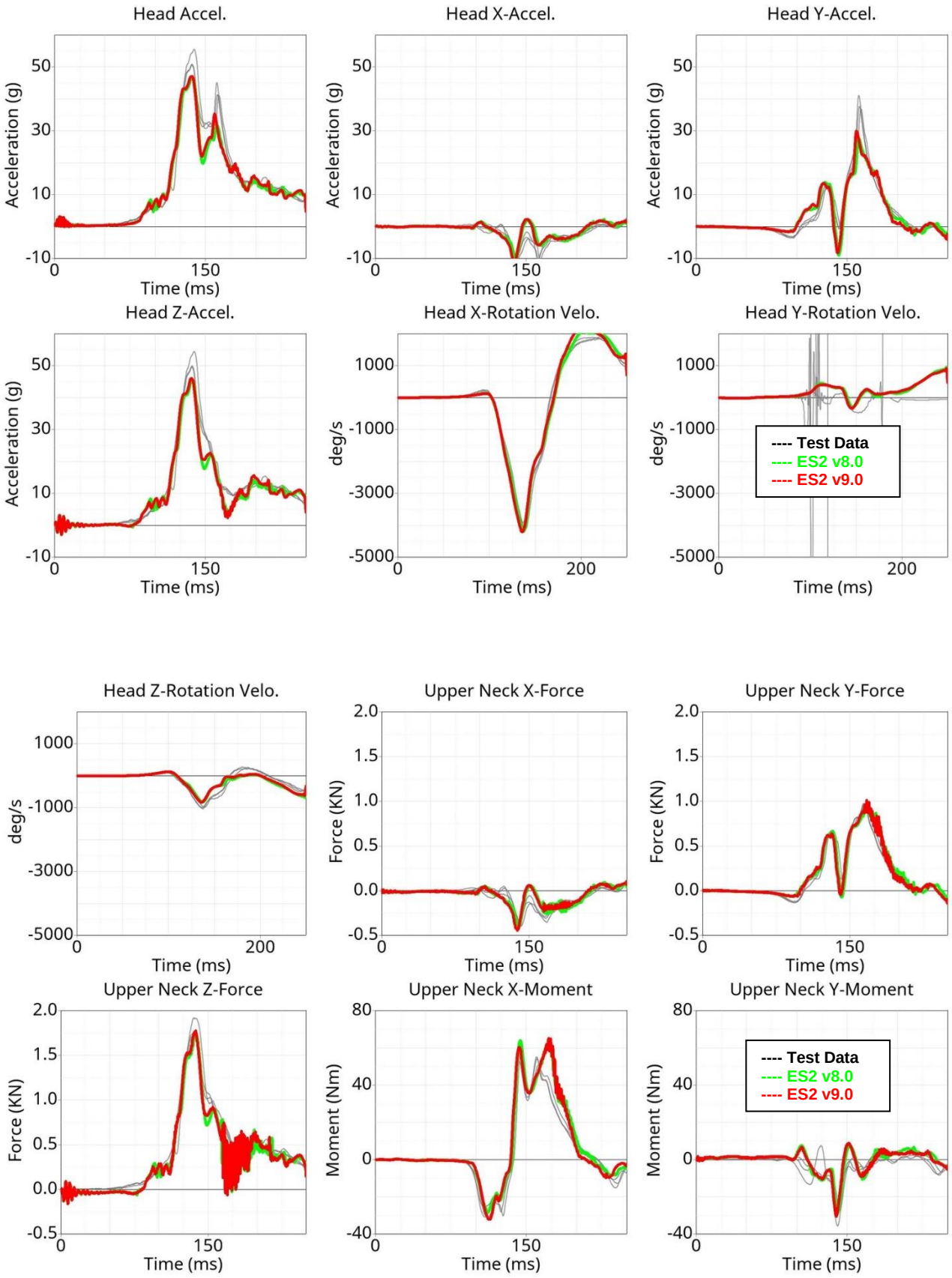
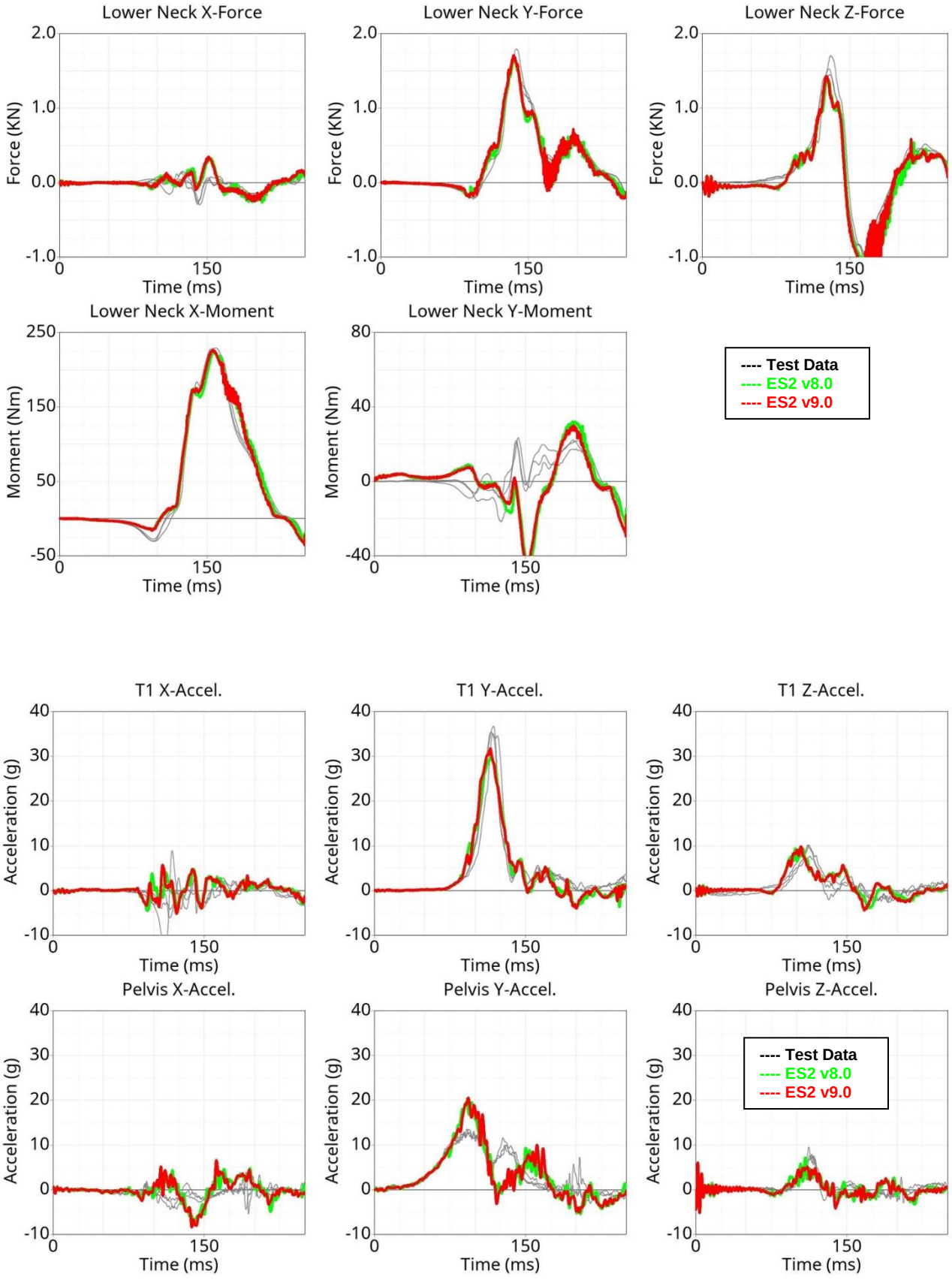
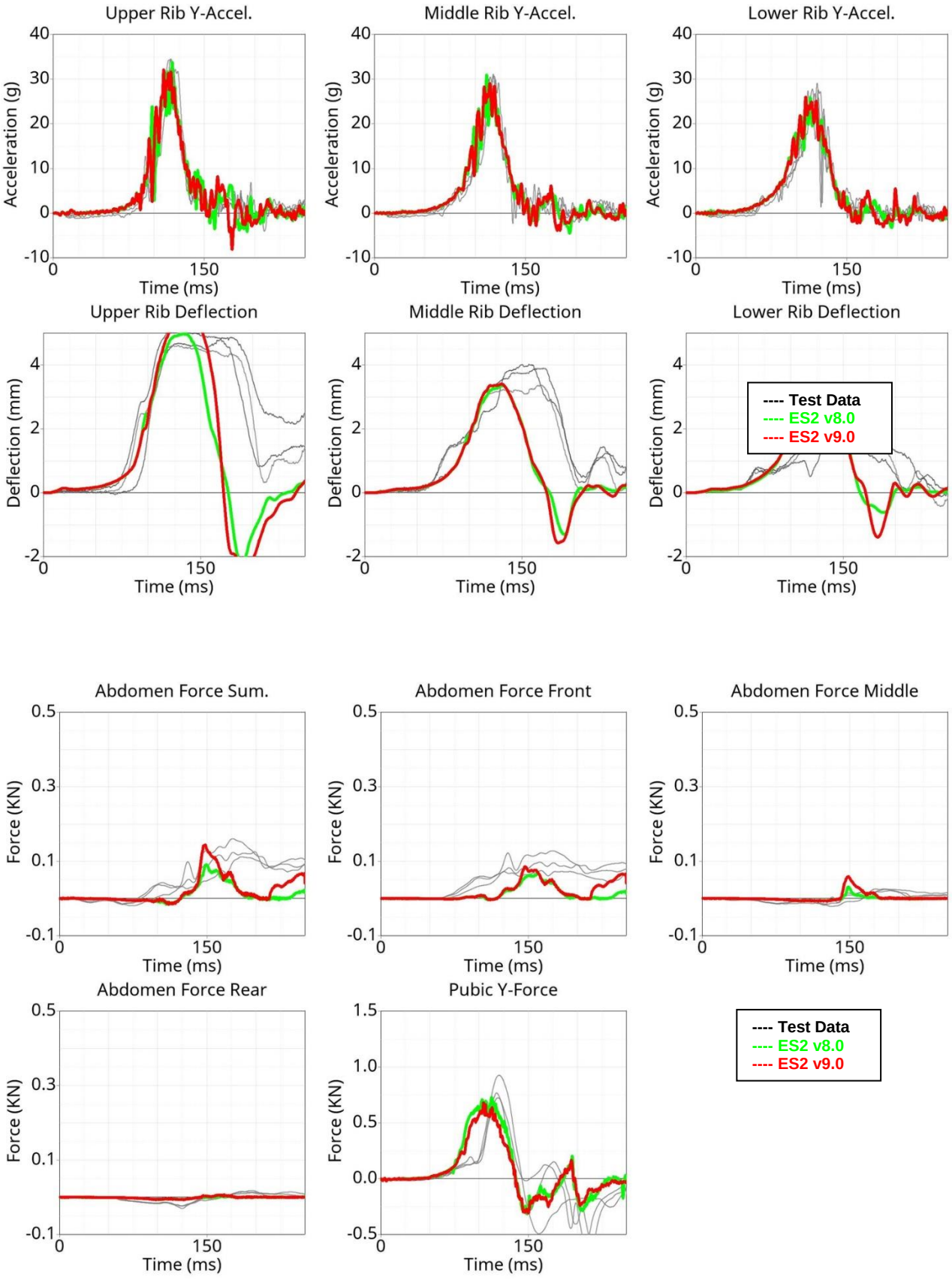


Figure 54: ARP-sled-test without armrest

Results without armrest




Lower Neck X-Force
Lower Neck Y-Force
Lower Neck Z-Force
Force (KN)
Time (ms)
Lower Neck X-Moment
Lower Neck Y-Moment
Moment (Nm)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
T1 X-Accel.
T1 Y-Accel.
T1 Z-Accel.
Pelvis X-Accel.
Pelvis Y-Accel.
Pelvis Z-Accel.
Acceleration (g)


Upper Rib Y-Accel.
Middle Rib Y-Accel.
Lower Rib Y-Accel.
Acceleration (g)
Time (ms)
Upper Rib Deflection
Middle Rib Deflection
Lower Rib Deflection
Deflection (mm)
---- Test Data
---- ES2 v8.0
---- ES2 v9.0
Abdomen Force Sum.
Abdomen Force Front
Abdomen Force Middle
Force (KN)
Abdomen Force Rear
Pubic Y-Force

14. CORA rating

To track the ongoing development of the ES-2/re dummy model CORA (CORelation & Analysis) is used. CORA was developed by the PDB (Partnership for Dummy Technology and Biomechanics). It can be used to evaluate time history signals from test and simulation. The methodology of CORA is visualized in Figure 55. It consists of two different ratings, the cross correlation rating and the corridor rating. With the two different approaches CORA tries to compensate the disadvantage of each approach for his own. The rating ranges from 0, which means very bad fit, to 1, which means very good fit.
For the corridor rating two different corridors are created surrounding the mean curve of the test curves. For this rating the values of each time step are compared. If the simulation curve value lies within the inner corridor of the mean curve the rating for this time step is 1. If it lays between the first and the second corridor it is interpolated between 1 and 0. If it lays outside of the second corridor the rating is 0. For the total corridor rating the mean of all time step ratings is calculated.
The cross correlation rating itself is divided into three separate ratings. The phase rating considers the time shift between the simulation and test curve. The size rating calculates the area under the curves and so compares the size. The shape rating checks the general shape of the two curves. The exact way of the ratings is documented within the CORA manual.

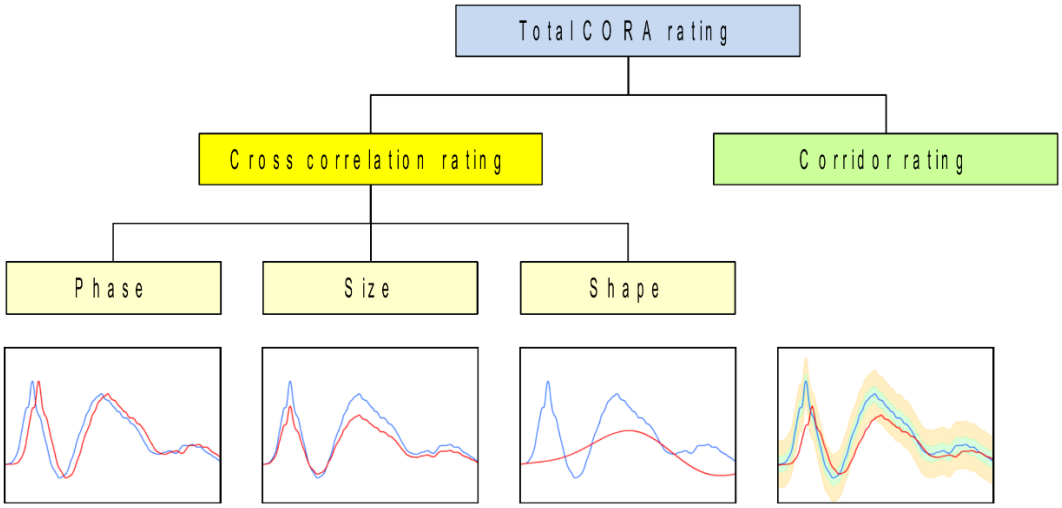


Figure 55: Methodology of the CORA rating (image out of PDB CORAplus_Manual)

For the CORA ratings different parameters have to be set. For the dummy CORA ratings all the parameters are the same for the different test scenarios. On the other hand the evaluated dummy output curves and the weighting of this curves is different between ARP sled test rating, PDB sled test rating and certification test rating. The considered output curves correspond to the defined outputs in the tests. The weighting of the curves was defined by consideration of some critical values and experience. It is important to use the defined settings for all the old dummy model versions and the new ones to keep the comparability.

Table 35 shows the improvement of the CORA rating from version 6 to the newest version 9 of the ES-2/re dummy for the barrier tests. There is a steady improvement since version 6. There were only little changes in performance for version 9, so the CORA rating is nearly the same compared to the previous version.

Dummy	D1-barrier	D3-Barrier	D4-Barrier	Total
ES-2re v9	0.746	0.754	0.749	0.750
ES-2re v8	0.747	0.748	0.752	0.749
ES-2re v7	0.723	0.733	0.759	0.739
ES-2re v6	0.734	0.714	0.746	0.731

Table 35: CORA rating barrier tests

Table 36 shows the CORA ratings for the ARP-sled test. The ARP-sled test is available since the version 8 of the dummy. This explains the large improvement of the CORA rating from version 7 to version 8.
The higher CORA rating for the ARP-sled test in comparison to the barrier test does not mean, that the dummy is better suited for the ARP-sled cases. Due to the difference in evaluated outputs channels for each sled test and the difference of the evaluation range between ARP-sled (250 ms) and barrier (100 ms) tests it does not make sense to compare the CORA rating of different testing setups with each other.

Dummy	with armrest	without armrest	Total
ES-2re v9	0.832	0.824	0.828
ES-2re v8	0.831	0.826	0.828
ES-2re v7	0.810	0.765	0.787
ES-2re v6	0.765	0.721	0.743

Table 36: CORA rating ARP-sled tests

Table 37 and Table 38 show the CORA rating of the certification tests. The total rating of the certification tests is nearly the same since version 7.

Dummy	Head	Neck	Rib	Lumbar
ES-2 v9	0.933	0.915	0.943	0.833
ES-2 v8	0.931	0.865	0.941	0.879
ES-2 v7	0.938	0.776	0.941	0.879
ES-2 v6	0.938	0.776	0.941	0.879

Table 37: CORA rating certification tests 1

Dummy	Abdomen	Pelvis	Shoulder	Thorax	Total
ES-2re v9	0.905	0.852	0.632	0.820	0.854
ES-2re v8	0.871	0.861	0.626	0.814	0.848
ES-2re v7	0.923	0.849	0.650	0.843	0.850
ES-2re v6	0.921	0.690	0.679	0.852	0.834

Table 38: CORA rating certification tests 2

All of the certification tests show very high CORA ratings with little differences between each dummy version. For the certification tests there are only a few output channels available, meaning only this channels have to show a good match. With the defined boundaries of the certification tests, the test outputs automatically have to have a good correlation with the hardware tests.

15. List of Figures