Far Side Sled Test MADYMO Validation

Cristina Echemendia and Kennerly Digges

The George Washington University

April 2009

OBJECTIVE

The objective of the study is to validate TNO'S Human Facet Model for far side impacts based on the far side PMHS sled tests performed by Pintar (Pintar 2007) to evaluate far-side countermeasures. And to relate the head excursions of these simulations to damage extent in a side impact to establish a safety rating.

BACKGROUND

Historical data shows that head injuries are one of the most common injuries in far side crashes as the occupant's head travels across the vehicle striking the intruding door on the opposite side. Tests performed with PMHS reproduced the occupant kinematics of a far side impact with a laterally accelerated sled test (Pintar 2007). These tests evaluated the performance of different countermeasures such as seat belt configuration, belt geometry among others. In most cases the common (outboard) 3 point seatbelt slips from the occupant shoulder letting the head and torso freely travel to the opposite side of the vehicle. However, these tests show that the geometry of the seat belt is an important in the effectiveness of the seat belt performance.

Presently there are no anthropomorphic test devices specifically designed for evaluating human kinematics for far side impacts. Studies have shown that modified WorldSID and THOR dummies reproduce the kinematics of cadavers in far side impacts (Pintar 2007).

TNO's 50^{th} percentile Human Facet Model was used for this study. This model was chosen because it is important to have a representative response of the human biomechanics. Compared to other TNO Dummy models (Alonso 2007) the Human Facet Model is the one with the most biofidelic response and therefore used in this analysis. The TNO Human Facet model showed good correlation in the kinematics with a human cadaver test under a far-side crash configuration (Alonso 2007). The Human Facet Model was validated by Alonso (Alonso 2007) for far-side crashes through duplicating the cadaver test performed by Fildes (Fildes, et al., 2002).

The Human Facet Model (HFM) consists of multi-body models but they have a more advanced multi-body and rigid surface finite element technology. Inertial properties are also incorporated into the rigid and deformable bodies. The facets are generally the outer surface of the model and are represented by meshes of shell-type elements with no mass. These facets are connected to rigid or deformable bodies. This allows a more complex interaction than simple force-deflection interaction. Structural deformation of flexible parts, such as ribs is represented by deformable bodies which give a more biofidelic response.

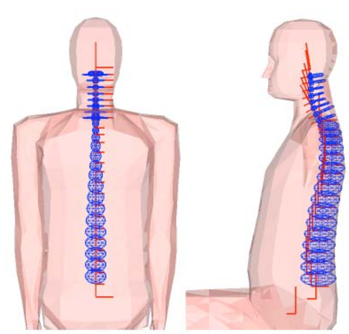

Figure 1 -TNO's Human Facet Model (TNO Automotive-AM, 2005)

METHODOLOGY

MaDyMo Simulations were performed to reproduce the cadaver far-side sled testing performed by Pintar (Pintar 2007). These simulations were only done for the outbound seat belt configurations.

The interaction between the seat belt and the complex shoulder area is critical for the simulation. The Human Facet Model was modified to better represent this shoulder area by adding rigid ellipsoids as previously done by Douglas [Douglas 2007]. A sphere with a radius of 0.053 m represents the shoulder and a sphere with a 0.045m radius represents part of the upper arm near the shoulder. A Multi-Body (MB) and Finite Element (FE) Kinematic contact was used to in the interaction between the seat belt and these ellipsoids representing the shoulder area.

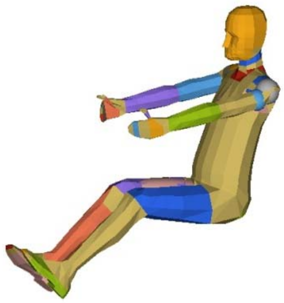

Figure 2 -Modified Human Facet Model

The Human Facet Model was positioned in a sled modeled after the sled used by Pintar. Contact interactions between the sled and the Human Facet Model were defined. The sled was laterally accelerated to 30kph and 11kph corresponding to the accelerations used in the PMHS tests. Also the belt was adjusted having two different D-ring positions. These tests were also modeled with and without belt pretension.

RESULTS

Pintar studies explored different belt configurations, varying the type of seat belt (inbound/outbound) and the belt geometry among other countermeasures. The seat belt height and D-Ring position to the rear was varied in these tests. The descriptions of these configurations are explained in Table 1 and Table 2. Tests 10, 11 and 22 according to Pintar's PMHS test were simulated with MADYMO. (Pintar 2007). These three tests had two different D-ring positions; all of them were at a Mid level height. Tests 10 and 11 had a Forward D-ring position, while test 22 had a Back D-ring position. Tests number 11 and 22 were performed at a 30kph speed and test 10 at 11kph.

Table 1 -Belt Configuration Description – D-Ring Height Position

D-Ring Height Position	Description
LOW	D-ring anchor horizontal with top of shoulder
MID	D-ring 90 mm above shoulder
HIGH	D-ring 150 mm above shoulder

Table 2- Belt Configuration Description D-Ring Rear Position

D-Ring Back Position	Description
Back	D-ring 120 mm behind mid-point of shoulder
Forward	D-ring 30 mm behind mid-point of shoulder

The left side of Table 3 shows the test configurations explored according to Pintar (Pintar 2007). The results column shows if the belt slipped during the test or not. On the right hand side of the table the MaDyMo simulations results are presented as well, pointing out the configurations where the belt slipped or not.

The sled tests simulations with the human facet model showed that in the tests performed with the D-ring at a mid-height and back position, the seat belt did not slipped from the shoulder. The PMHS test with the same belt position had no belt slippage. Simulations done with the D-ring at a mid-height and forward position and at a low-height and back position presented belt slippage. The belt slipped from the shoulder, then got caught in the upper arm between the shoulder and the elbow. The PMHS test with the D-ring at a mid-height and forward position also showed the belt slipping.

Table 3- Tests on horizontally accelerated sled (far side @ 30kmph) with outbound seat belt.

PMHS Sled Test Results (Pintar 2007)	PMHS	5	4	4
	Config ID	22	10	11
	Pulse	30kph	11kph	30kph
	Result	NO SLIP	SLIP	SLIP
Belt Configuration	D-Ring Height	MID	MID	MID
	D-Ring Rear	BACK	FORWA RD	FORWA RD
	Pretension	No	No	No
MADYMO Results	30kph	NO SLIP		SLIP
	11kph		SLIP	

The same tests configurations were also simulated using a belt pretensioner. The belt pretensioner allowed 72 mm of belt travel and it was activated 10ms after time zero. The belt pretensioner did not prevent the belt from slipping from the shoulder in the mid-height and forward position tests. It did reduce the head excursion in the lateral direction 44 mm. The belt did not slip in the test with the D-ring at mid-height and back position similar to the test without pretensioning. It also reduced the head excursion by 61 mm.

These results show that while pretensioning helps reduce head excursion up to 61 mm, preventing the belt from slipping from the shoulder has a better benefit. According to these results the belt geometry is important to prevent the belt from slipping. Having the seat belt engage the occupant can reduce the head excursion up to 185 mm without a pretensioner and up to 202 mm with a pretensioner.

Table 4 in Appendix A shows the Maximum Head excursion in the x, y, z axis for the three different D-ring configurations with and without pretensioner. We can see that the Mid-Back D-ring position always presents a lower head excursion in the lateral direction. The head excursion in the PMHS test number 22 (mid-back D-ring position) also showed a lower value in head excursion.

The Y vs. Z head excursion at 30 kph simulations and PMHS tests are shown in Figure 3. From the graphics we can see how that the tests with pretensioner compared to the same configuration without pretension show a lower lateral head excursion.

The PMHS head excursions are also shown. We can see that the difference between test 22 (mid-back d-ring position) is not much lower than test 11 (Mid-Forward D-Ring position) even though test 22 did not slip and test 11 did slip. This can be attributed to the differences in PMHS anthropometry.

The PMHS tests were done with different cadavers, which were different in gender, weight, height, age, etc. A quantitative comparison cannot be done to compare the simulations against the PMHS tests but the simulations reproduce the trend of the kinematics.

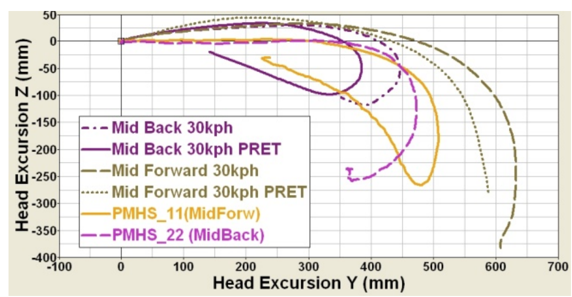

Figure 3- Human Facet Model Y-Z Head excursion with and without pretensioner (tests @ 30kmh) and PMHS tests.

The PMHS tests 3D kinematics was captured using a motion tracking system. Reflective targets were placed in multiple areas of the body such as head, pelvis, T1 and T12. These targets were then digitized. Comparing the head position of the Human Facet Model and the digitized motion analysis in Figure 4 we see that the head initially tilts at 100ms. It continues tilting and turning upward at 200ms. The Human Facet Model follows this same motion confirming that this model is a good model to evaluate the far side impact kinematics.

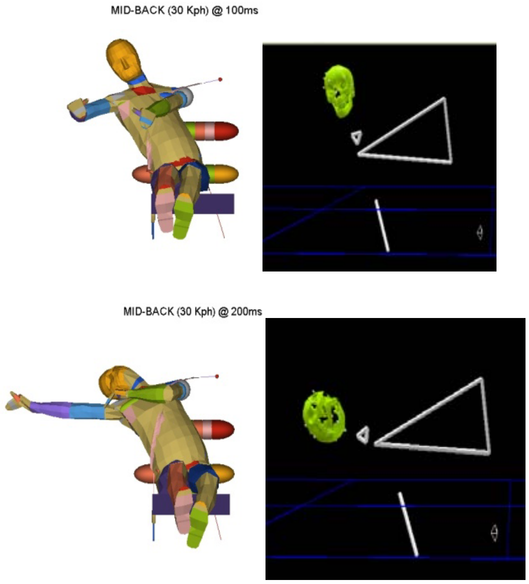

Figure 4-Human Facet Model and PMHS Motion Analysis on Far Side Sled tests @ 100ms (above) and @ 200ms (below)

After the results of the validation were successful, the same sled tests with the different belt geometry and configuration were simulated at different accelerations to evaluate the belt performance. The NCAP and IIHS lateral pulse were used.

Results show that the tests performed with the Mid-Back D-Ring position with and without pretension have the lowest head excursion and that the belt engaged the shoulder of the occupant. Whereas the Mid-Forward D-Ring position with and without pretension belt slipped of the shoulder of the occupant resulting in a higher head excursion.

These results were consistent with the sled tests performed at 30kph and confirming that the belt performance can be consistent at different lateral acceleration environments.

Table 5 in Appendix A show the summary of the results and head excursions for the sled tests performed with a NCAP and IIHS acceleration, with the different belt geometry and configurations.

CONCLUSIONS

Computer models are a convenient way of evaluating different variations on a common environment. The PMHS far side sled tests were modeled using MADYMO to evaluate different countermeasures. MADYMO human facet model has shown to successfully reproduce the PMHS kinematics in the far-side sled tests and the seat belt interactions.

The MADYMO modeling of the far side test environment has shown that reduction of head excursion can be achieved by appropriate belt geometry and pretensioning. A key to reducing the head excursion is the retention of contact with the shoulder. If the occupant's shoulder slips out of the belt the upper body is free to move laterally at increased velocity. Also this study confirms that the belt performance is consistent when the lateral acceleration is varied.

Appendix A – Head Excursion Results

Table 4-Maximum Head Excursion for Far Side Sled Tests

Belt Configuration				MADYMO HFM-Sled Tests - Pulse and Results							
D Ring Height Position	D Ring Back Position	Pretension	SLIP RESULT	Max Head Excursion X (mm)	Max Head Excursion Y (mm)	Max Head Excursion Z (mm)	Simulation Test ID	Test Pulse	Excursion with and without pretension	Comparison between belt slip and no slip (mm)
MID	BACK	No	**NO SLIP**	**-139.39**	**-446.55**	**-117.71**	**MID_BACK_30**		**-61.24**	
MID	FORWARD	No	**SLIP**	**26.29**	**-632.49**	**-381.82**	**MID_FORWARD_30**	**30kph**	**-44.23**	**-185.94**
MID	BACK	72mm	**NO SLIP**	**-190.27**	**-385.31**	**-98.53**	**MID_BACK_30_PRET**			
MID	FORWARD	72mm	**SLIP**	**-24.14**	**-588.26**	**-280.81**	**MID_FORWARD_30_PRET**			**-202.95**
MID	BACK	No	**NO SLIP**	**-36.99**	**-308.71**	**31.09**	**MID_BACK_11**		**-72.39**	
MID	FORWARD	No	**SLIP**	**1.34**	**-452.63**	**-67.78**	**MID_FORWARD_11**	**11kph**	**-104.4**	**-143.92**
MID	BACK	72mm	**NO SLIP**	**-104.67**	**-236.32**	**40.66**	**MID_BACK_11_PRET**			
MID	FORWARD	72mm	**SLIP**	**-34.81**	**-348.23**	**-51.48**	**MID_FORWARD_11_PRET**			**-111.91**

Table 5-Maximum Head Excursion for Far Side Sled Tests with NCAP and IIHS accelerations

Belt Configuration			MADYMO HFM-Sled Tests - Pulse and Results								
D Ring Height Position	D Ring Back Position	Pretension	SLIP RESULT	Max Head Excursion X (mm)	Max Head Excursion Y (mm)	Max Head Excursion Z (mm)	Simulation Test ID	Test Pulse	Delta V Lateral	Head Excursion with and without pretension	Comparison between belt slip and no slip
MID	BACK	No	NO SLIP	-138.93	-399.62	-99.4	MID_BACK_NCAP	**NCAP**	**23 kph**	-73.85	
MID	FORWARD	No	SLIP	16.55	-590.58	-298.01	MID_FORWARD_NCAP			-71.38	-190.96
MID	BACK	72mm	NO SLIP	-182	-325.77	-75.33	MID_BACK_NCAP_PRET				
MID	FORWARD	72mm	SLIP	-19.95	-519.2	-184.19	MID_FORWARD_NCAP_PRET				-193.43
MID	BACK	No	NO SLIP	-142.22	-394.59	-82.2	MID_BACK_IIHS	**IIHS**	**21 kph**	-74.77	
MID	FORWARD	No	SLIP	20.23	-590.37	-286.78	MID_FORWARD_IIHS			-60.77	-195.78
MID	BACK	72mm	NO SLIP	-181.14	-319.82	-67.99	MID_BACK_IIHS_PRET				
MID	FORWARD	72mm	SLIP	-22.19	-529.6	-195.05	MID_FORWARD_IIHS_PRET				-209.78

Appendix B – Head Excursion Graphics

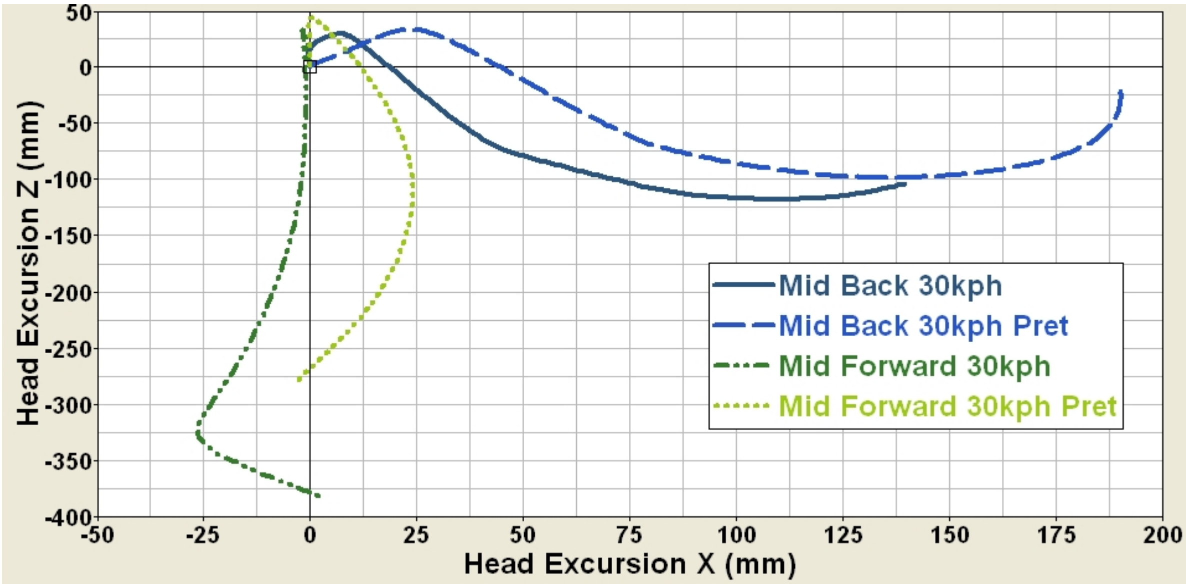

Figure 5 -Human Facet Model X-Z Head excursion with and without pretensioner (tests @ 30kmh)

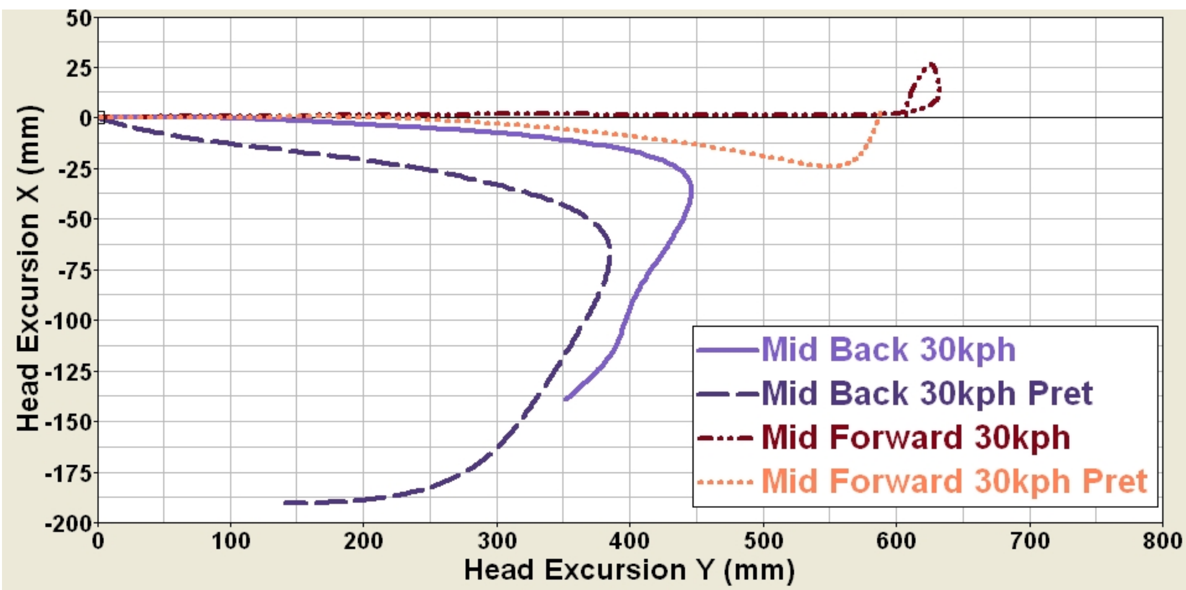

Figure 6-Human Facet Model Y-XHead excursion with and without pretensioner (tests @ 30kmh)

Appendix C – Neck Load Graphics

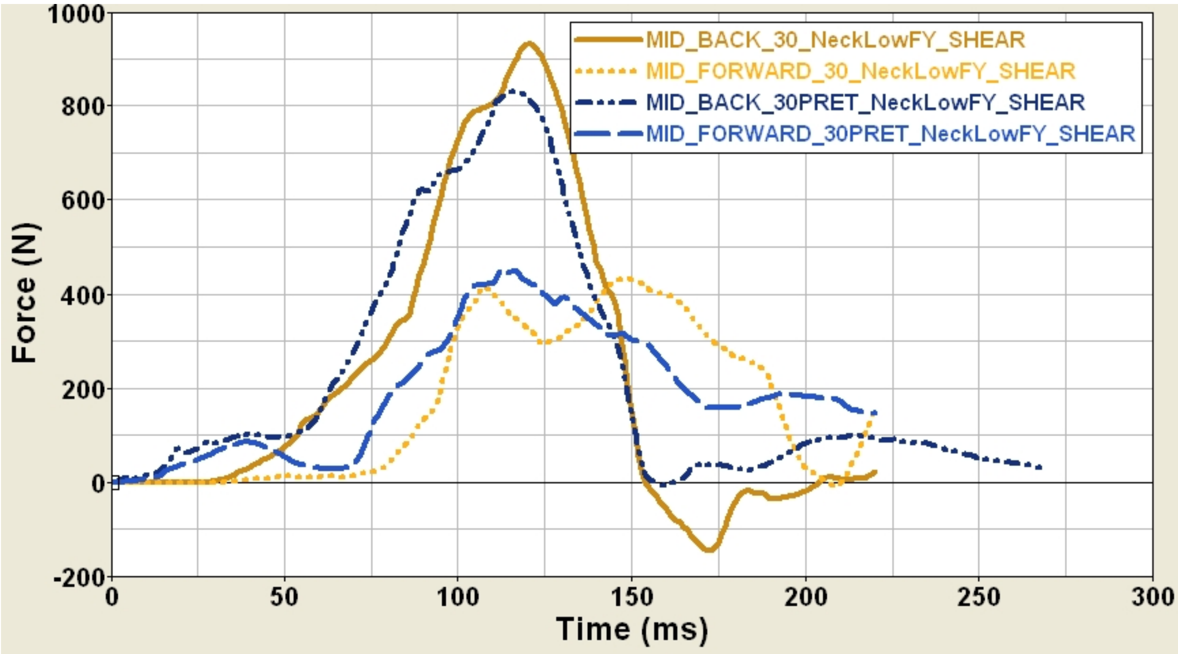

Figure 7-Human Facet Model Neck Shear Load (Fy) with and without pretensioner (tests @ 30kmh)

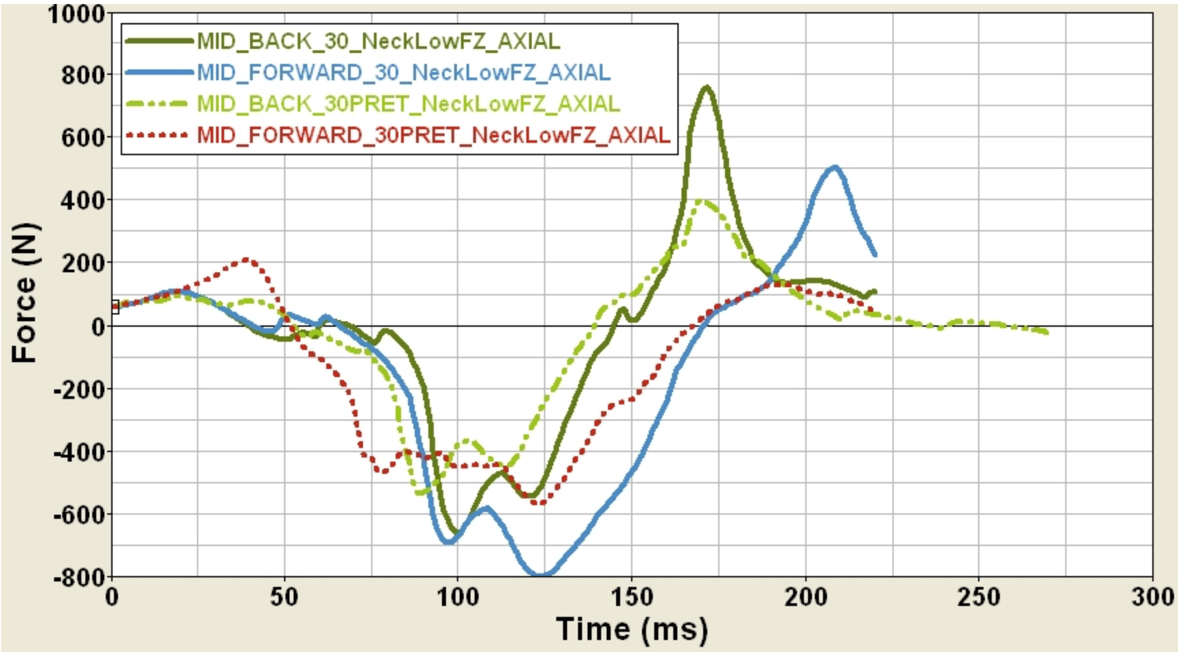

Figure 8-Human Facet Model Neck Axial Load (Fz) with and without pretensioner (tests @ 30kmh)

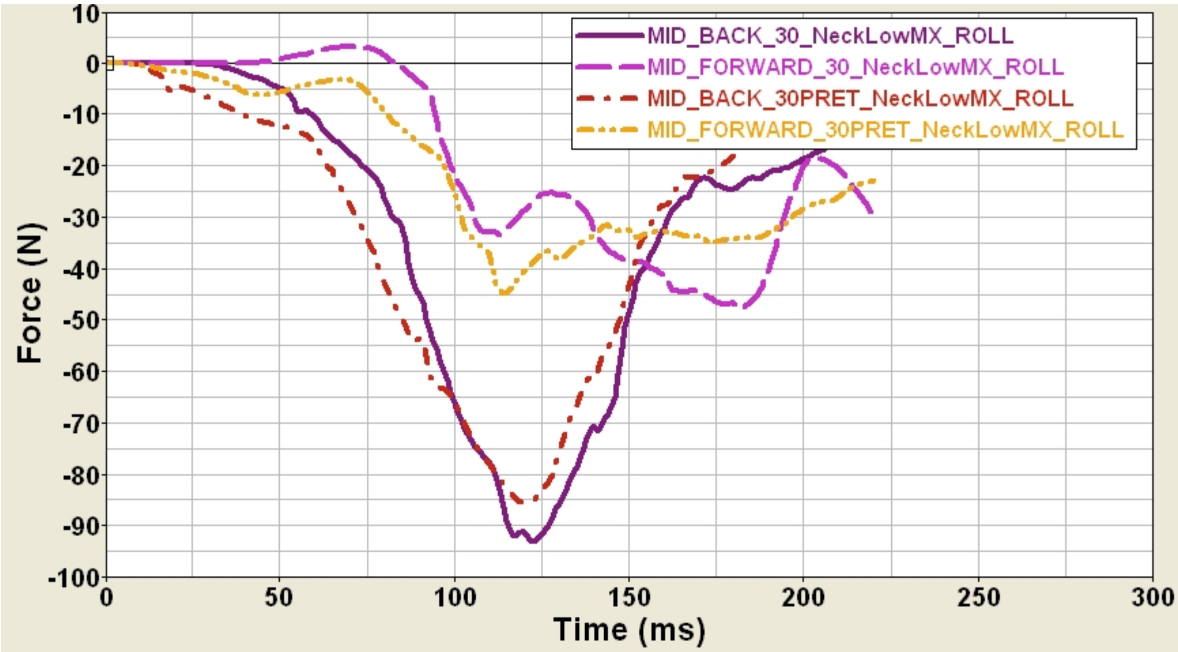

Figure 9-Human Facet Model Neck Lateral Bending Moment (MX) with and without pretensioner (tests @ 30kmh)

Appendix D –Sled Tests Kinematics

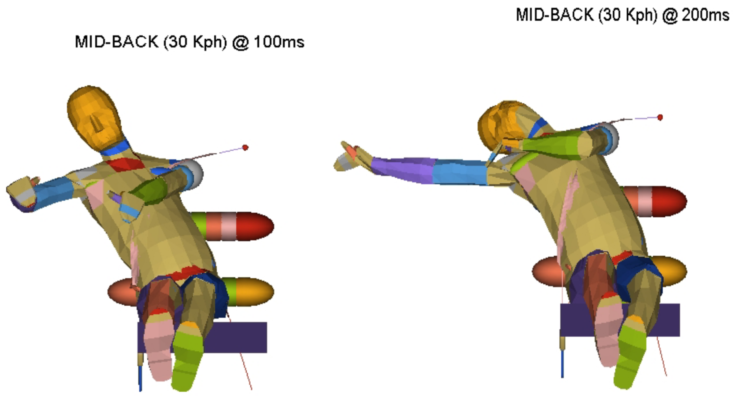

Figure 10 -Kinematics of 30kph Far Side Sled Test with Mid-Back Belt Configuration at 100ms (left) and 200ms (right)

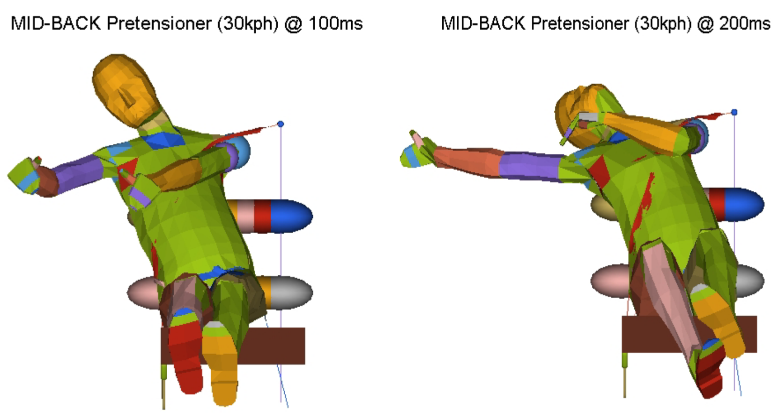

Figure 11-Kinematics of 30kph Far Side Sled Test with Mid-Back Belt Configuration and Pretension at 100ms (left) and 200ms (right)

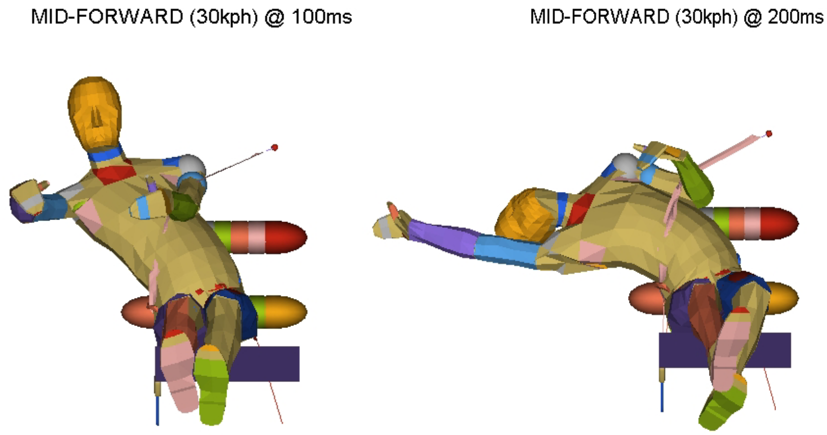

Figure 12-Kinematics of 30kph Far Side Sled Test with Mid-Forward Belt Configuration at 100ms (left) and 200ms (right)

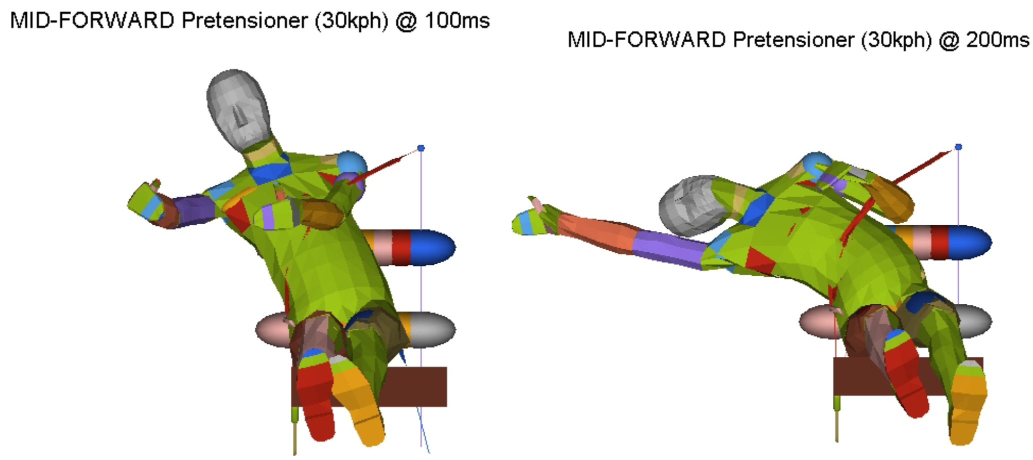

Figure 13-Kinematics of 30kph Far Side Sled Test with Mid-Forward Belt Configuration and Pretension at 100ms (left) and 200ms (right)

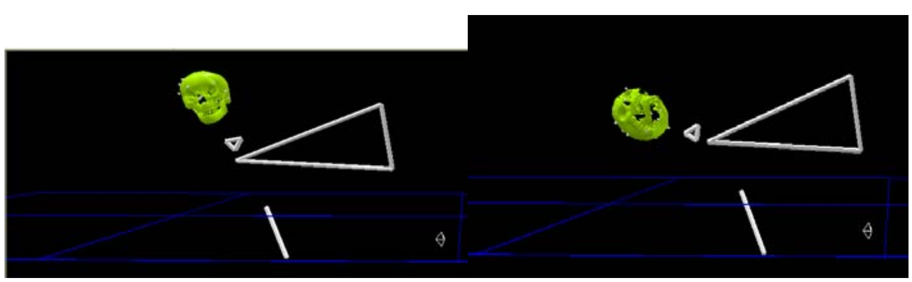

Figure 14-Motion Analysis of PMHS Far-Side Sled tests.

References

Pintar, F.A., Yoganandan, N., Stemper, B.D., Bostrom, O., Rouhana, S.W., Digges, K.H., Fildes, B.N. "Comparison of PMHS, WorldSID and THOR-NT Responses in Simulated Far Side Impact" Stapp Car Crash Journal Vol. 51 (October 2007)

Alonso, B,. MADYMO Human Facet Model Validation for Far-side, Report written to George Washington University- National Crash Analysis Center, October 2004

Alonso, B., Digges, K., Morgan, R., Far Side Impact Vehicle Simulations with MADYMO. SAE International 2007. 2007-01-0363

Douglas, C., Fildes, B., Gibson, T., Bostrom , O., and Pintar, F., "Modeling the Seat Belt to Shoulder-Complex Interaction in Far Side Crashes", Paper, 07-0296, *20th ESV Conference,* June 2007.

Douglas, C., Fildes, B., Gibson, T., Bostrom , O., and Pintar, F., "Factors Influencing Occupant to Seat Belt Interaction in Far Side Crashes", *51th Proceedings of the Association for the Advancement of Automotive Medicine"*, p319-342, October 2007.

TNO Automotive-HM. (2005). *MADYMO Human Models Manual. Version 6.3.*