Modeling Neck Compression in Rollovers

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Objective

Simulate the Jordan Rollover System with MADYMO to evaluate the performance of the HIII and Human Facet Models.

Background

Jordan Rollover System (JRS) is a dynamic rollover test device. The vehicle is mounted on two towers with an axis running through the center of gravity of the vehicle. The test rig with a mounted vehicle is shown in Figure 1. In the recommended dynamic test, the vehicle initial position is as follows: 5 degree pitch, 10 degree yaw, 190 degrees per second rotation rate and 10 cm drop height. As the vehicle is dropped, a roadbed moves horizontally under the vehicle at 24km/h. The direction of roll is toward the passenger side and the initial roof impact occurs on the passenger side. However, the driver's side generally sustains the most roof damage.

Figure 1 -JRS Test Fixture with mounted vehicle

A 50th percentile Hybrid III Anthropomorphic Test Device (ATD) located at the driver position is used in the JRS tests record the drivers head and neck loads during the rollover. The roadbed is also instrumented to measure the forces exerted by the vehicle.

Methodology

<u>Vehicle-JRS Rig Setup</u>

A generic vehicle model was used to simulate the JRS test in MADYMO. The vehicle model has translational and sphere joints located at the center of gravity (CG). The sphere joints allow us to give the pitch, yaw and roll movement to the vehicle while the translational joints determine the linear motion of the vehicle in the x, y, z directions. The vehicle initially has no pitch and in the first few milliseconds, the vehicle is positioned into the 5 degree pitch. It is also rotated towards the driver side to achieve the initial 10 degree yaw. After the vehicle is positioned at the test initial position 190 degree per second roll-pulse starts to take place.

Roof Intrusion

The results of several physical JRS tests performed by Friedman (Friedman, 2009) were evaluated. His results show that the 2006 Chrysler 300 sustained the highest injury numbers compared to the 2007 VW Jetta, 2007 Toyota Camry, 2006 Hyundai Sonata and 2006 Pontiac G6. The 2006 Chrysler 200 reached compressive neck loads (Fz) of 5598 Newtons. This test also presented a Maximum Crush Speed of 12.07 kph, an Upper Neck Nij of 1.80 and a Lower Neck Nij of 1.44.

The 2006 Chyrsler 300 test was selected as the comparison test for the MADYMO simulations. The Roof Crush versus Roll Angle plot, shown in Figure 2, is provided by Friedman (Friedman, 2009) and it was used in the roof intrusion during the MADYMO Simulation. In Figure 2, LWR is the force exerted on the road by the vehicle's roof divided by the vehicle's weight. SWR is the roof load to vehicle weight ratio being considered for the FMVSS 216 upgrade.

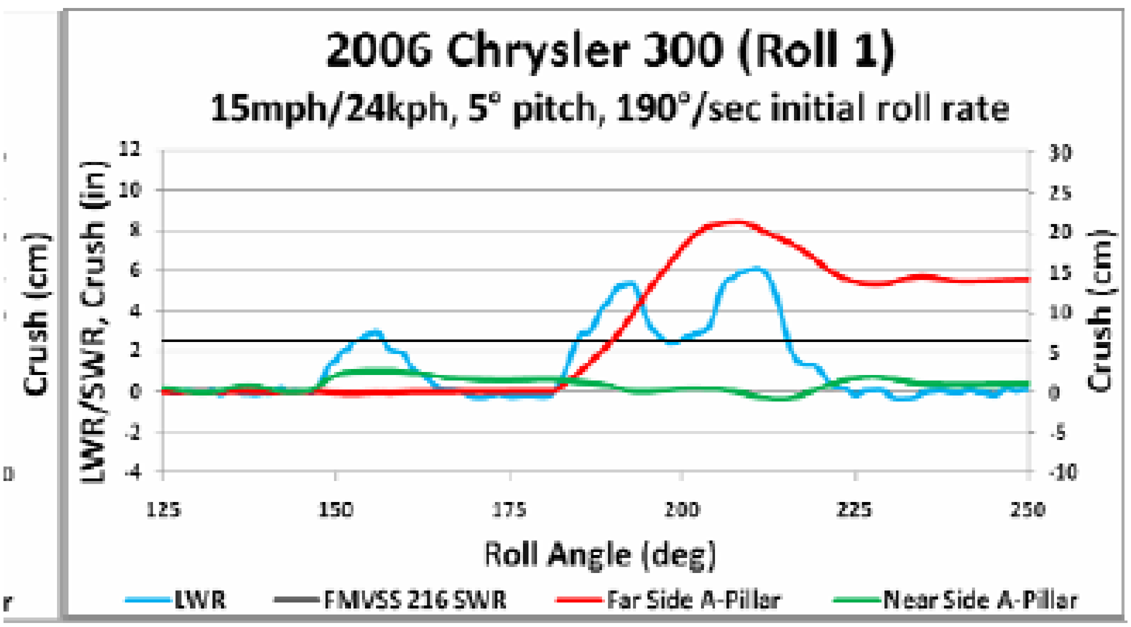


Figure 2- 2006 Chrysler 300 Roof Crush vs. Roll Angle (Friedman 2009)

Occupant Models

The Hybrid III dummy is widely used in the research of occupant safety in frontal impacts. The 50th percentile Hybrid III MADYMO model was used to compare the kinematics and the neck loads to a physical test. The Hybrid III MADYMO Model is an ellipsoid model. The inertial properties of the dummy are included in the specifications for the rigid bodies of the model. Ellipsoids, cylinders and planes are used to represent the geometry of the dummy. The deformation of the contact areas are represented by force-based contact characteristics attributed to the ellipsoids in the dummy.

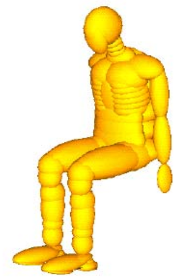


Figure 3– TNO's Hybrid III Ellipsoid Model (TNO Automotive-MM, 2005)

The 50th percentile human facet model was used to explore the degree to which this model is appropriate for evaluating neck injuries in rollovers. The human facet model has been used in far side impact studies where the kinematics of this model was validated against human cadaver tests (Echemendia 2009) (Alonso, 2004). This model has a combination of rigid bodies and facet surfaces that more compliant joints and surfaces.

The human facet model is made up of rigid bodies, flexible bodies 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 give a more biofidelic response. Each vertebra is represented by a rigid body connected by free joints. The free joints have a lumped joint resistance which represents translational and rotational resistance.

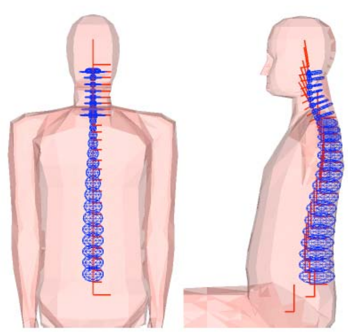


Figure 4- TNO's Human Facet Model (TNO Automotive-HMM, 2005)

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. Also other rigid ellipsoids were added in the abdomen, thorax and arm to prevent too much penetration between the facets of the Human Facet Model and the Finite element seat belt. A Multi-Body (MB) and Finite Element (FE) Kinematic contact was used to in the interaction between the seat belt and the ellipsoids representing the shoulder, abdomen, thorax and arm areas.

The Human Facet Model needs to start a simulation in an equilibrium state. Due to the flexibility of the spine and neck of the Human Facet Model, it requires a pre-simulation to settle the model into a seated position. This consists of placing the Human Facet Model in a seated position slightly above the seating surface and oriented properly with respect to its environment. Then a pre-simulation is performed where the model is subjected to a gravitational field only. This simulation will run for about 1 second. By that time the model has found an equilibrium state. The MADYMO Manual (TNO Automotive-HMM, 2005) presents different methods for placing the Human Facet Model and maintain it in an upright position. The method used was using cardan restraints that simulate the active muscle behavior of a human needed to resist the force of gravity.

Results

<u>Hybrid III</u>

The JRS test simulation was performed with the 50th percentile Hybrid III Model. The first way of comparing the simulation and the physical test is by comparing injury parameter results. The neck compressions in TNO's Hybrid III model reached 4223 N and 4678 Ni in the Lower and Upper neck respectively. Figure 5 shows the Force vs. Time graphic of TNO's Hybrid III neck compression at the time of roof intrusion on the first roll. The modeling neck compression results are about 15% lower than the physical tests reported by Friedman.

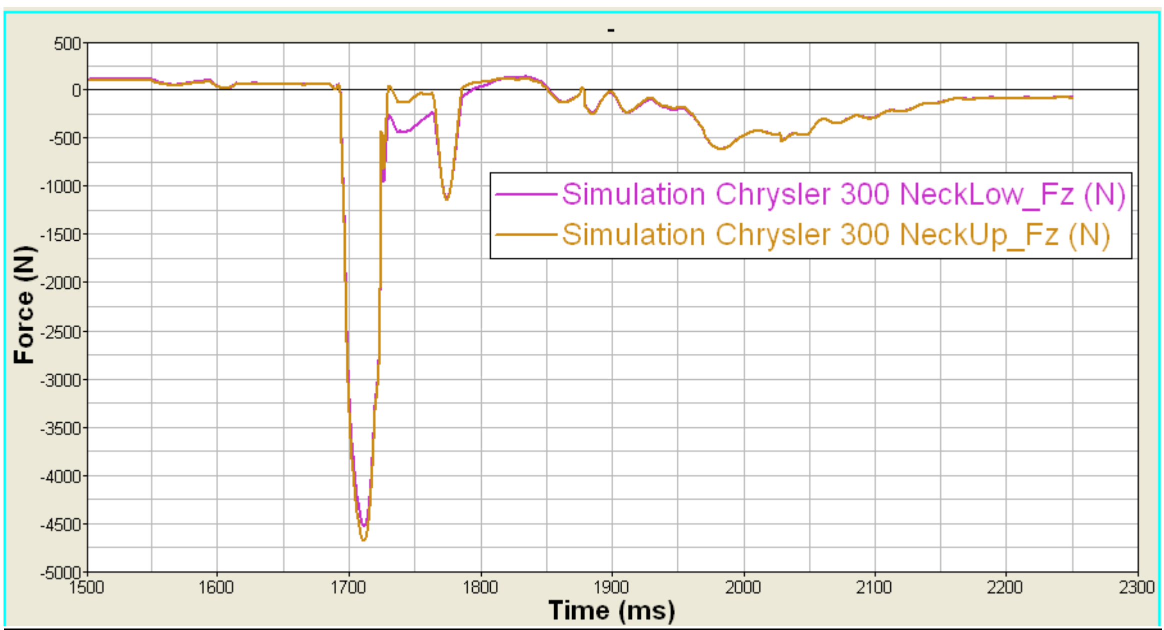


Figure 5 -Hybrid III Simulation Compression Force

The modeled Neck Injury Criterion (NIJ) was also compared to the physical test. Figure 6 shows the NIJ vs. Time graphic at the time of roof intrusion during the first roll. The highest Nij value corresponds to the Neck Compression Flexion in the lower neck reaching a value of 1. 5. This value is also lower to the physical test by 15%, approximately.

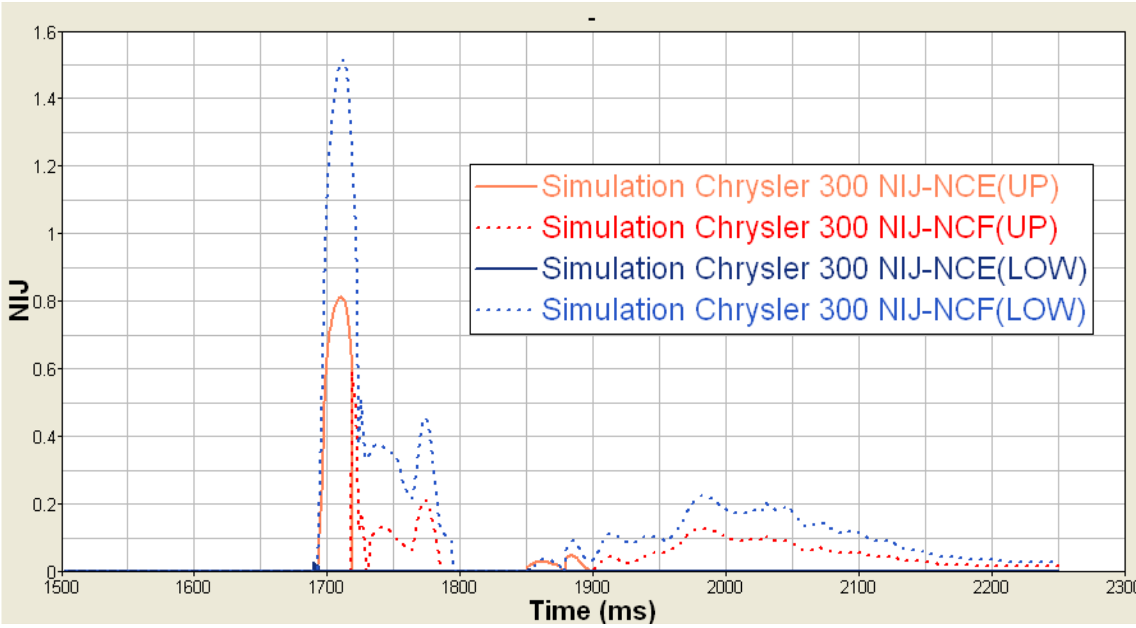
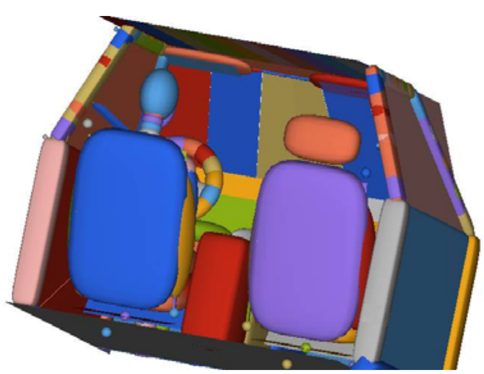


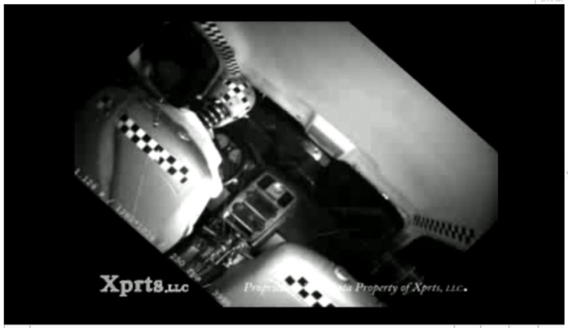
Figure 6 - Hybrid III Simulation NIJ

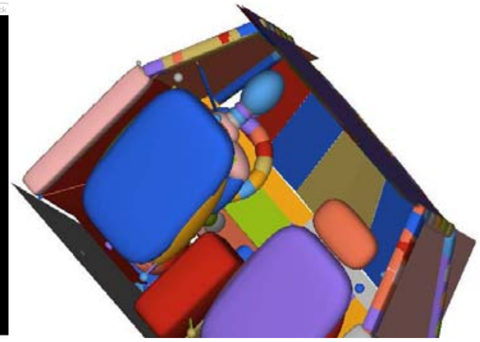
We also compared the kinematics of the tests to evaluate the performance of the simulation. Using visual approximations, the TNO's Hybrid III model moved similarly to the Hybrid III physical model under the same rollover configuration. Figures 7 and 8 show the kinematics comparison between the physical test and the simulation from two different views: back view and side view.

In the third and fourth frame of figure 7 we can see how the simulation shows less lateral movement of the neck. In the fifth frame of figure 7 the head of the dummy is still away of the window sill when the roof intrusion starts. But in the next frames the head is near the window sill, as in the physical test.



Chrysler 300 (2006) JRS Dynamic Rollover Crash Test





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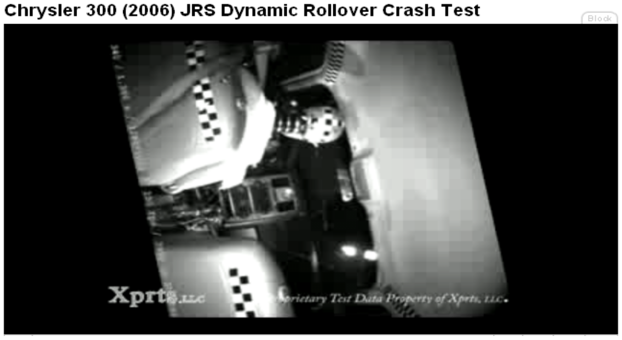

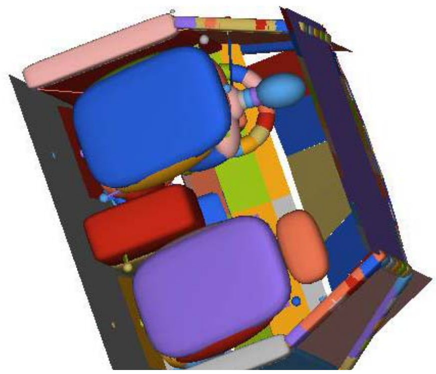

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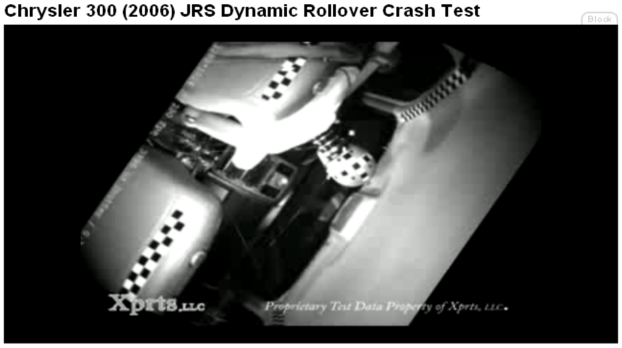

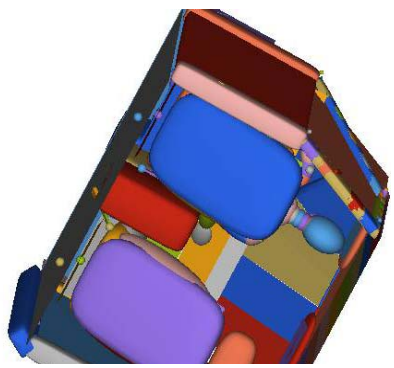

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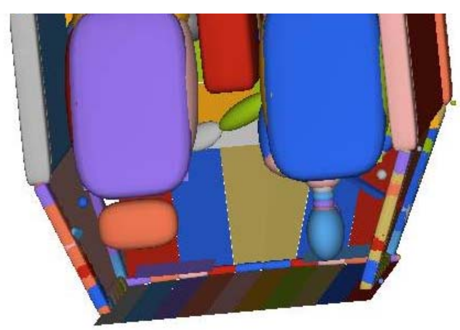

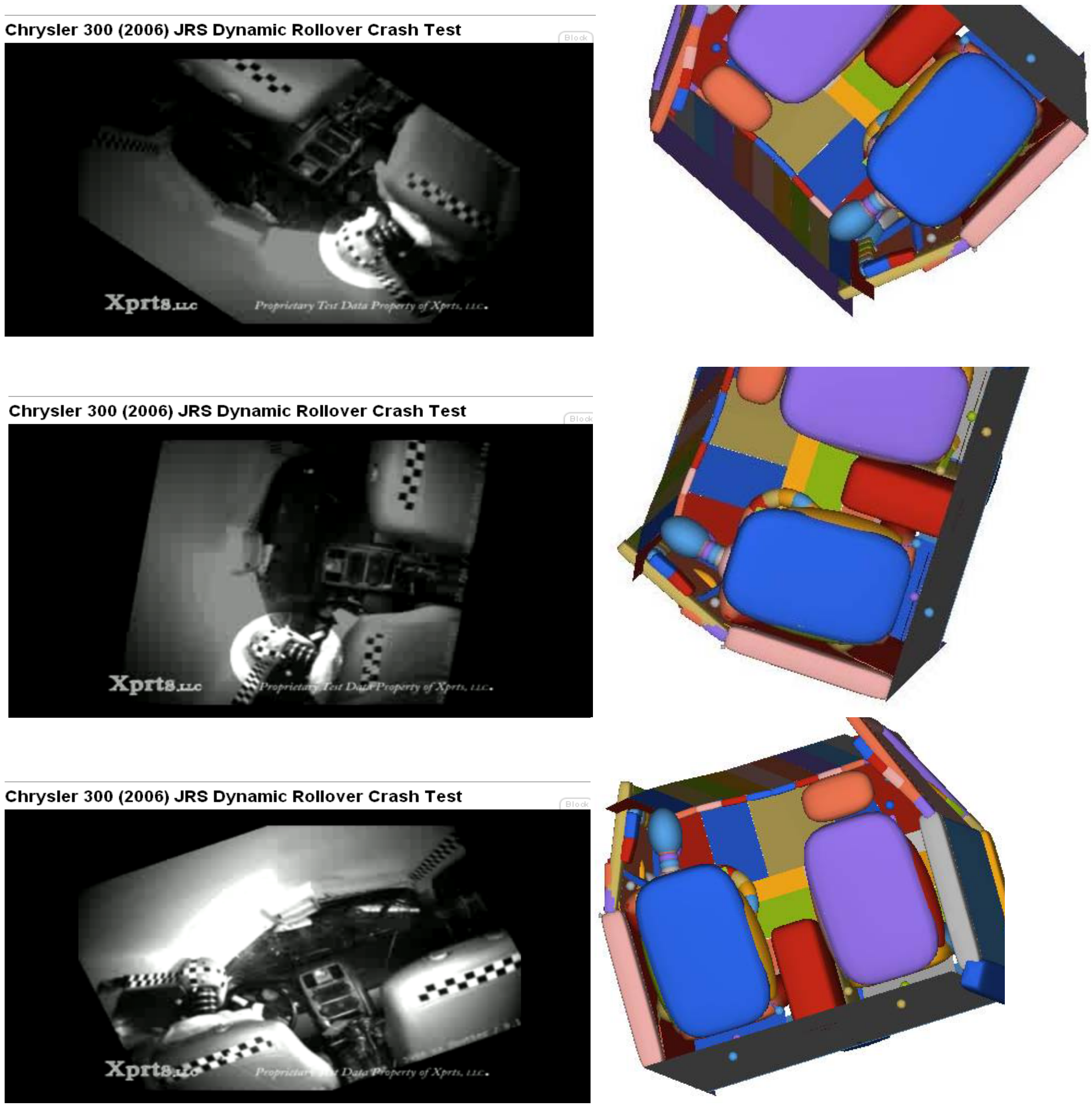

Figure 7 - Back View Comparison Chrysler 300 JRS test and MADYMO Simulation

Figure 8 shows the side view of the rollover at the moment of roof intrusion. In the first frame although not visible from the angle, the head of TNO's Hybrid III is still away from the window sill - unlike the physical test. Frames 2-4 show that the head position is closer to the test position. In these frames the neck compression is visible when the roof intrusion is present. In the fourth frame we can also see that the head of the MADYMO dummy tilts sideways, which does not happen in the physical test. To match the dummy kinematics the dummy was stabilized so that it does not move towards the door in the initial rolling acceleration. This helps the MADYMO model to match the motion of the physical one more closely.

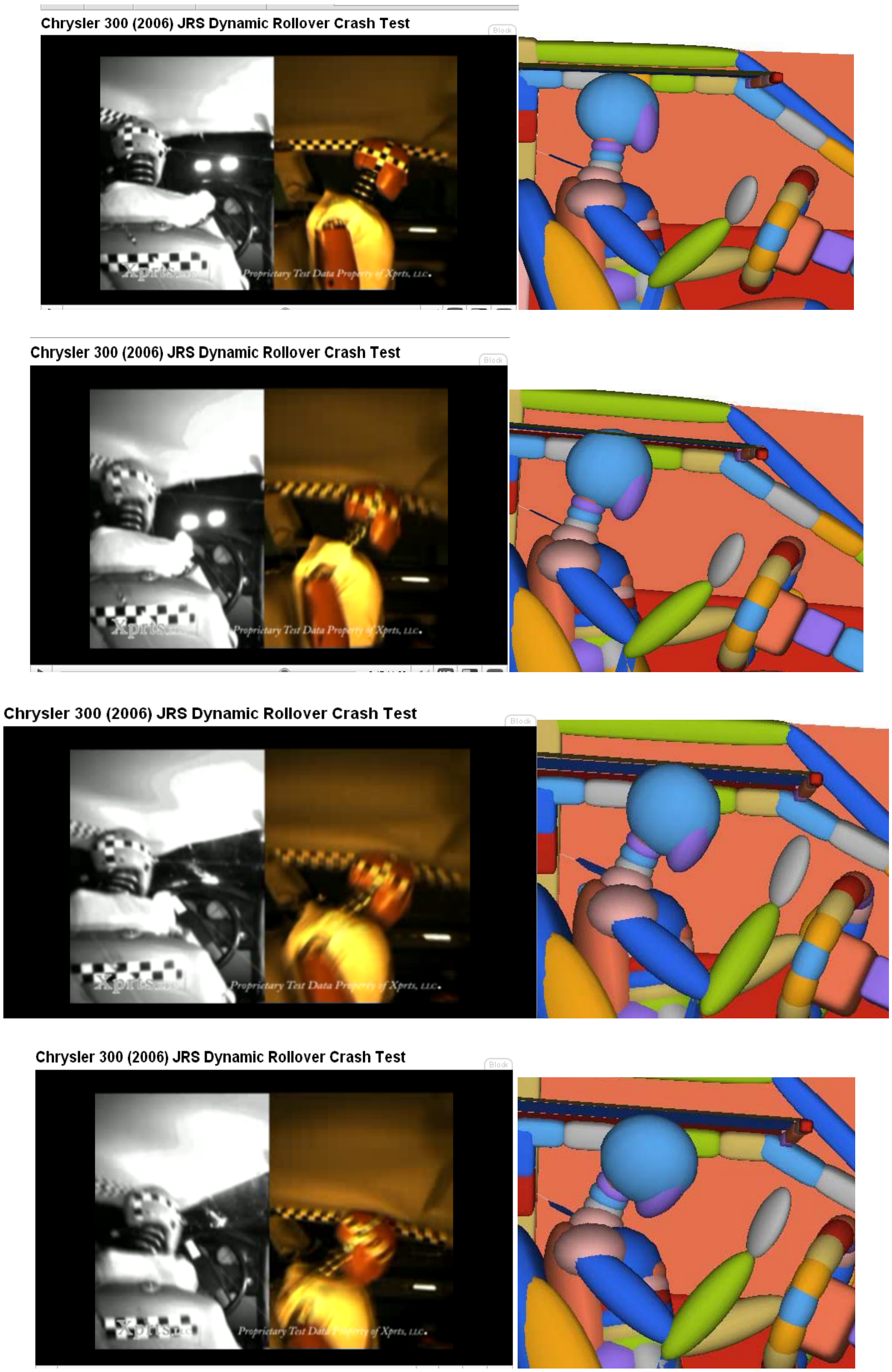

Figure 8 - Side View Comparison Chrysler 300 JRS test and MADYMO Simulation

The differences in the kinematics can be attributed to multiple reasons. (1) The rolling pulse of the physical test was not available, so the initial acceleration up to the 190 degrees per second was approximated. (2)The amount of slack and/or pretension of the seatbelt was also approximated and varied to see the differences in the kinematics. The amount of pretension/slack of the seatbelt does affect the kinematics of the dummy significantly. If too much slack is present, the dummy has a lot more lateral movement. With too much pretension it has too little lateral movement. However, in both ranges of pretension the head of the dummy did not reach the window sill in a timely fashion. (3) Another factor that could affect the results of the simulation is the geometry of the vehicle. The MADYMO vehicle model was a generic vehicle and was not matched to the Chrysler 300 model. (4) Also the geometry of the roof intrusion is not captured completely with this model. The roof intrusion is simulated by planes that move relative to the vehicle. The window sill is represented by ellipsoids. (5) The positioning of the dummy was done visually with the available video but no measurements were available to position the dummy precisely as the physical test.

Human Facet Model

As mentioned earlier in this paper, the Human Facet Model needs to have a pre-simulation to position the model in a relaxed seated position, using restraints to keep the model upright. In short simulations these restraints are then removed leaving the Human Facet Model in a relaxed seated position. The rollover simulations are several seconds long and when these restraints are removed the Human Facet Model is not able to keep its upright position because of the lack of muscle tone as shown in Figure 9 and Figure 10. For the rollover simulations done for this analysis, these restraints were kept during the simulation to keep the Human Facet Model in an upright position (see figure 9 and 10). The characteristics of active muscle given by MADYMO were used in the rollover simulations.

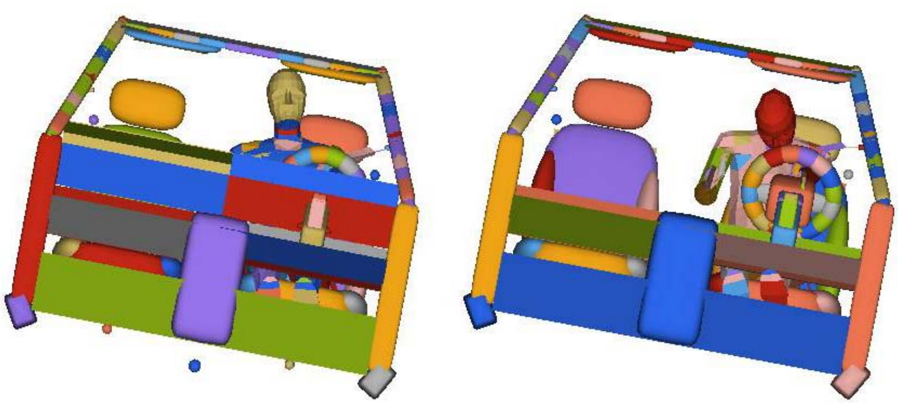

Figure 9 - Frontal View of Human Facet Model Rollover Simulation with active muscle restraints (left) and without active muscle restraints (right)

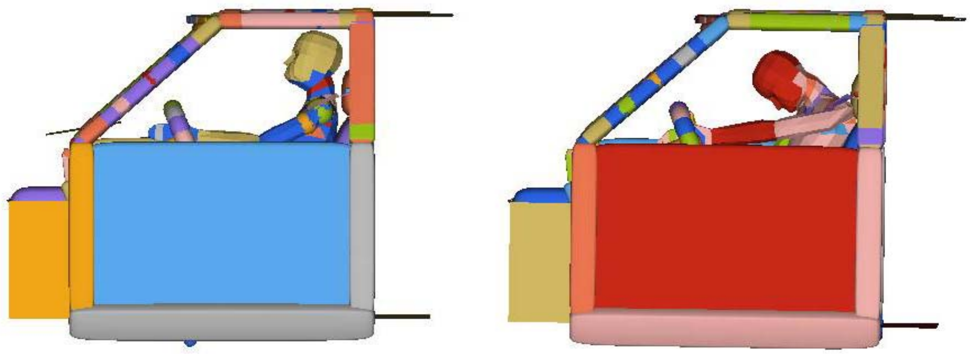

Figure 10 - Side View of Human Facet Model Rollover Simulation with active muscle restraints (left) and without active muscle restraints (right)

The Nij readings from the Human Facet Model in the simulations resulted in extremely low compression levels as shown in Figure 11. The Nij Compression Extension and Nij Compression Flexion are in the range of 0.005 and 0.09. In the kinematics caption shown in Figure 12, the neck of the Human Facet Model bends to the side at the moment of roof intrusion. The spine and the neck of the Human Facet Model may be too flexible for this type of simulation.

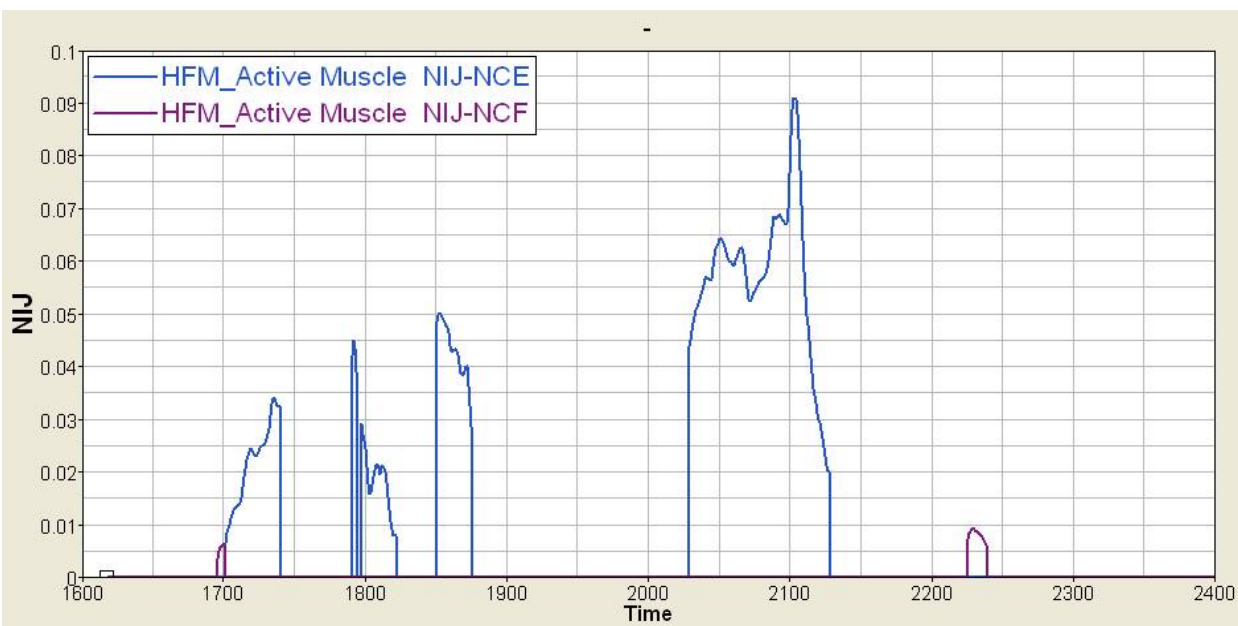

Figure 11 - NIJ Results from Human Facet Model Rollover Simulation

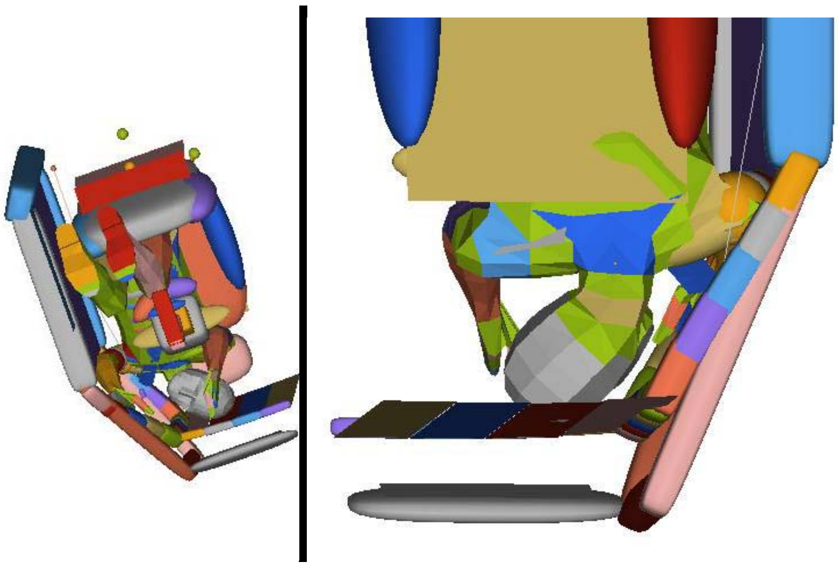

Figure 12 – Frontal (left) and Back (right) view of Human Facet Model with roof intrusion.

Several roll rates, contact characteristics and roof intrusions were tested to explore if these factors affected the kinematics and injury results, but the results were very similar in all different simulations. To explore if the positioning (active muscle) restraints affect the neck loading in the rollover/roof intrusion readings, the characteristics of the active muscle were varied. The results shown in Figure 13 indicate that the differences between MADYMO's active muscle characteristics and the modified active muscle characteristics were insignificant.

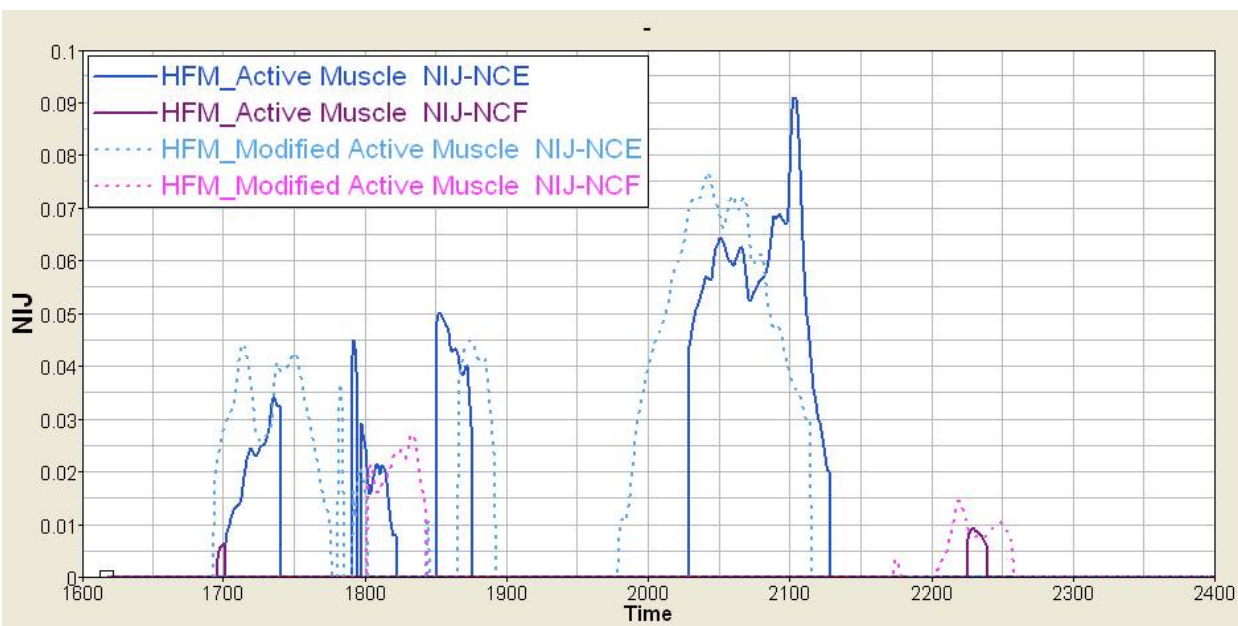

Figure 13 - NIJ Results from Human Facet Model Rollover Simulation with and without modified Active Muscle Characteristics

Conclusions

MADYMO's Hybrid III Model is a fairly good model to simulate rollover neck injuries. The simulation done in this paper was an approximate representation of the Chrysler 300 JRS test (Friedman 2009). The kinematics results show that the MADYMO model was sometimes late in reaching the same position of the real test. The injury parameter results came in within a15% of the real test. There were several unknown variables that could affect the kinematics and in consequence neck injury. To make a more accurate simulation rolling pulse, seat belt performance characteristics, vehicle geometry and a more detailed roof intrusion should be used.

The Human Facet Model predicts lower neck injury indicators than the Hybrid III Model for the cases simulated during this project. In order to determine which model more accurately predicts human injury risk, more studies need to be done to capture the neck/spine flexibility more accurately in addition to the unknown variables mentioned in the Hybrid III Model results.

References

Friedman, D., Grzebieta, R. "Vehicle Roof Geometry and its Effect on Rollover Roof Performance" ESV Enhanced Safety of Vehicle, Conference June 2009. Paper 09-0513

Friedman, D., Grzebieta, R. "A Proposed Rollover and Comprehensive Rating System" ESV Enhanced Safety of Vehicle, Conference June 2009. Paper 09-0515

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

TNO Automotive-MM. (2005). *MADYMO Model Manual. Version 6.3.*

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.

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

Echemendia, C., "PMHS Far-Side Sled Test Validation with MADYMO", Report to the National Crash Analysis Center, GW University, March 2009.

Dahdah, S. "Effects of Roll Rate and Tripping Velocity on Occupant Kinematics During Rollover" The George Washington University. May 2005