

Improved Seat Belt Restraint Geometry for Frontal, Frontal Oblique and Rollover Incidents

John Patalak and Thomas Gideon
NASCAR

John W. Melvin
Tandelta

Mike Rains
TK Holdings Inc

ABSTRACT

Throughout the first decade of the twenty first century, large improvements in occupant safety have been made in NASCAR®'s (National Association for Stock Car Auto Racing, Inc) race series. Enhancements to the occupant restraint system include the development and implementation of head and neck restraints, minimum performance requirements for belts and seats and the introduction of energy absorbing foam are a few highlights, among others. This paper discusses nineteen sled tests used to analyze hypothesized improvements to restraint system mounting geometry. The testing matrix included three sled acceleration profiles, three impact orientations, two Anthropomorphic Test Device (ATD) sizes as well as the restraint system design variables.

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BACKGROUND

In 2007 NASCAR required a minimum six point seat belt restraint, which consisted of two shoulder belts, two lap belts and two anti-submarine belts. The purpose of this requirement was to improve pelvic restraint during frontal and frontal oblique impacts thereby reducing occupant chest loading. Specifically, the six point restraint system replaced the single negative G belt, commonly referred to as the fifth point, with two anti-submarine belts, also commonly referred to as sub or crotch belts. The two anti-submarine belts have been recommended to be fitted tightly to the inner thighs and mounted at a rearward angle of 20°, mounted with two separate anchors four to six inches apart [1]. The incorporation of the six point restraint system greatly reduced the occurrence of serious chest injuries during frontal and frontal oblique impacts from 2007 through 2013 in NASCAR.

Appendix F shows the multi-point seat belt configurations common to motorsports. Within these configurations are many options including latch-link or cam-lock locking mechanisms, pull up or pull down adjusters, formula or hybrid style anti-submarine belts, two inch and three inch webbing and many types of termination hardware.

During a frontal on-track incident in 2013 a NASCAR driver experienced a manubrial-sternal dislocation requiring sternal reduction and rigid sternal fixation. The driver was also diagnosed

with a possible concussion. No other serious injuries were reported. The driver was an otherwise healthy 26 year old male weighing 182 pounds (82.7 kg) and 70 inches (1.78 m) tall. The driver was seated in a composite seat and utilized a six point restraint system with a HANS head and neck restraint device. This type of driver restraint system and its effectiveness has been detailed in previous publications [2,3,4,5,6]. The driver returned to regular racing activity 13 weeks after the on-track incident. Each NASCAR National Series race vehicle is equipped with an onboard IDR (Incident Data Recorder) [7]. Figure one shows the IDR acceleration time profile and the calculated change in velocity for this incident. The three incident vehicle acceleration axes are shown on Figure ones primary vertical axis. The forward (X ΔV) and side (Y ΔV) velocities, or change in velocity (the integrated acceleration) and the resultant forward and side velocity are shown on the secondary vertical axis in Figure one.

Figure two shows the calculated X-Y plane PDOF (Principle Direction of Force) for the first 160 milliseconds of the impact, which had a linear trend line angle of 2.9° to the right of forward, indicating an almost pure frontal impact.

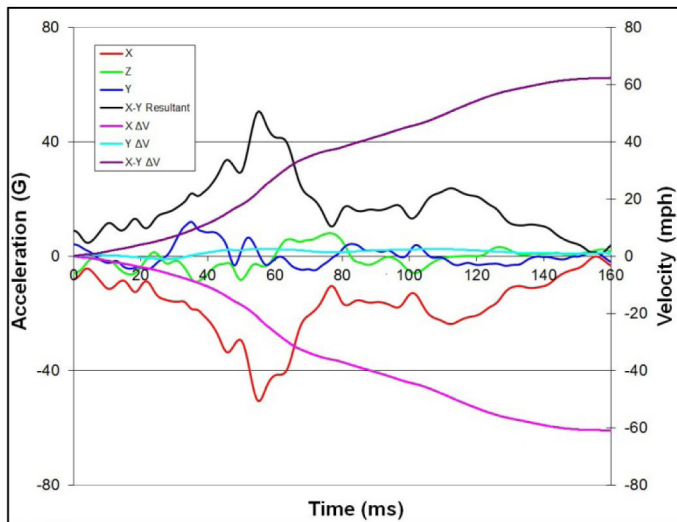


Figure 1. IDR acceleration data for incident vehicle

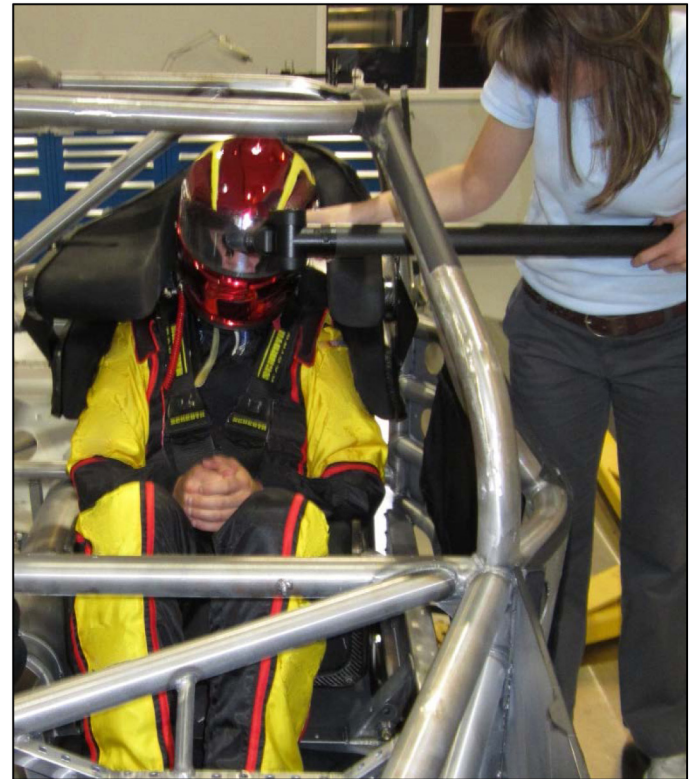


Figure 3. Driver fit check (image altered to maintain driver anonymity)

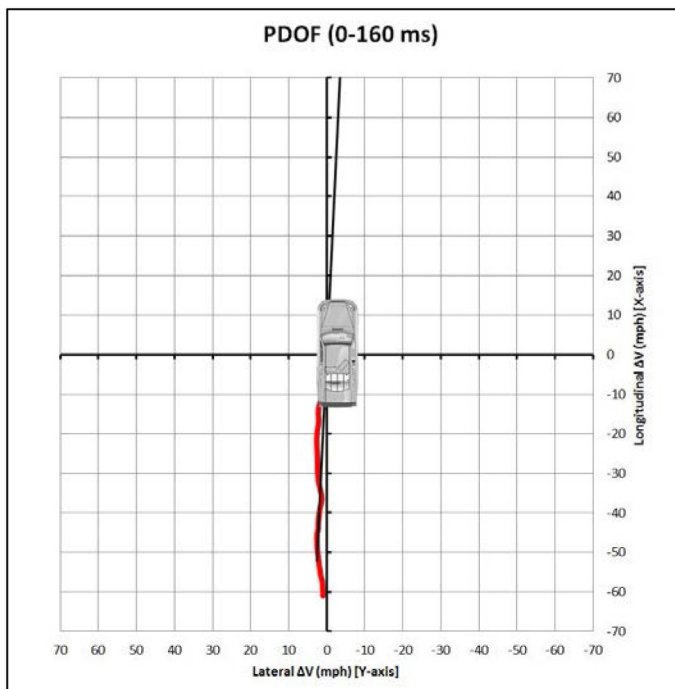


Figure 2. PDOF for incident vehicle

Post incident inspection of the vehicle and the restraint systems found all restraint system components to be in acceptable and expected condition with no deficiencies or possible injury causation issues noted. A fit check was conducted with the driver in an undamaged vehicle with the incident seat and restraints. The driver, seat and restraint system were then digitized as shown in [Figure three](#).

A three dimensional CAD model of the restraints, available restraint mounting locations, seat cross sections and driver cross sections were developed from the fit check as shown in [Figures four](#) and [five](#).

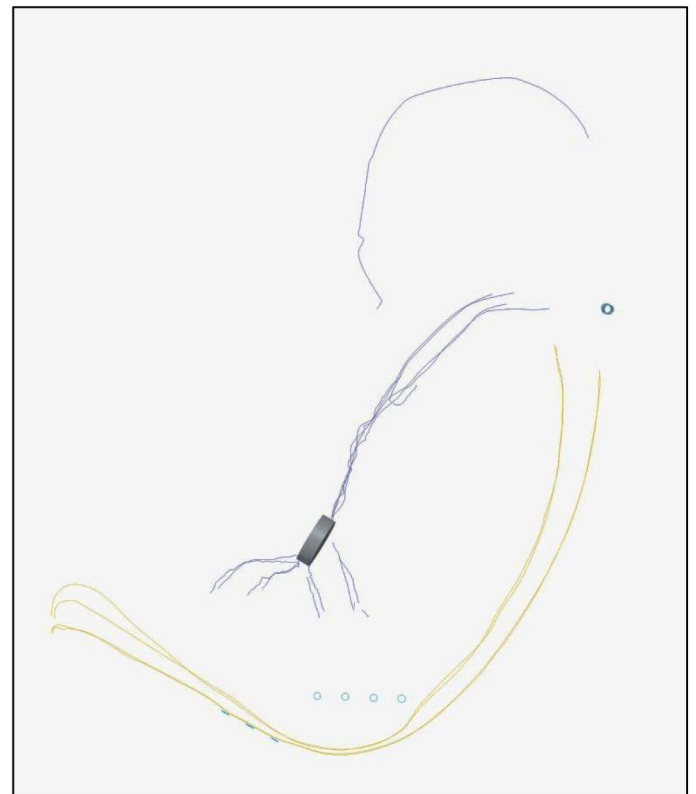


Figure 4. Screen capture of the 3D CAD model

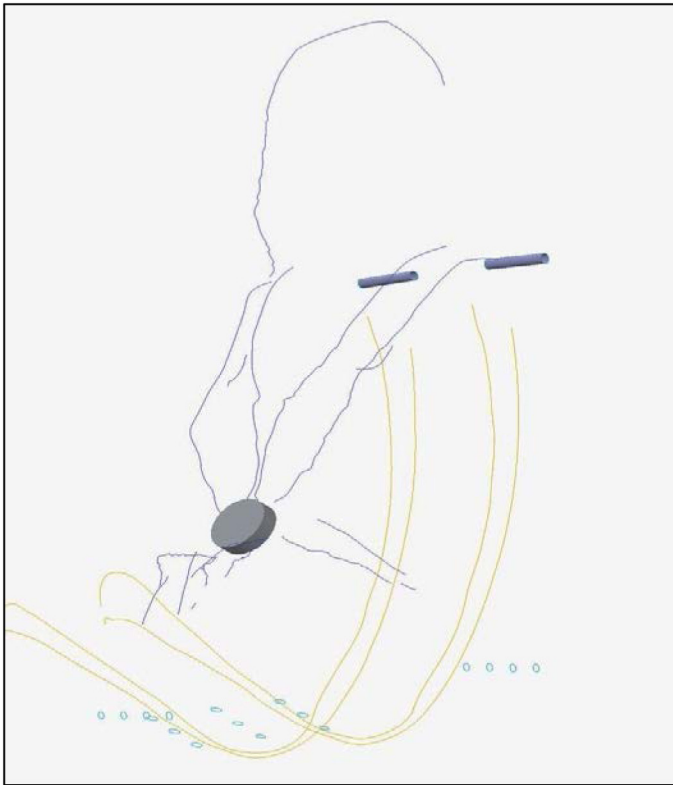


Figure 5. Screen capture of the 3D CAD model



Figure 7. Sled buck with integrated shoulder belt mounts



Figure 6. Sled buck with stanchion mounted shoulder belts

The three dimensional CAD model allowed measurements of the restraint system and available mounting locations to be analyzed and duplicated into a sled test buck. The sled test buck was designed and fabricated to replicate the subject vehicle restraint mounting locations and seat cross section. Additional mounting locations for the anti-submarine belts and shoulder belts were designed into the sled buck for the hypothesized improvement analysis. The sled buck utilized no side supports and was only used for frontal and vertical sled tests. The original sled buck which did not incorporate the shoulder belt mounts into the seat is shown in [Figure six](#) (note the

aluminum stanchion to which the shoulder belts were mounted). An updated sled buck with incorporated shoulder belt mounting is shown in [Figure seven](#). While this structure change was inconsequential for the 0° frontal tests, integrating all restraint anchorages onto the seat buck allowed for repositioning of the same seat buck for use in the vertical tests.

TESTING

The sled tests were conducted at the Takata sled test laboratory in Auburn Hills, Michigan. Setup parameters for all sled tests are shown in [Appendix A](#). The Takata sled is supplied by Instron Structural Testing Systems. It utilizes a servo valve to control hydraulic flow to achieve the desired acceleration pulse. This system also has pitching (vertical axes) capabilities which were not used for these tests. The sled has 562 kips (2.5 MN) of thrust and can achieve a peak acceleration of 90 G's with an 1,100 lb (500 kg) payload. The maximum system horizontal stroke is 67 inches (1.7 m) and the maximum horizontal system velocity is 50 mph (80 kph). Acceleration pulse matching accuracy is better than 2.0 G RMS at greater than 80 Hz. [Figure nine](#) illustrates how accurately the target pulse was achieved.

Sled acceleration and ATD data was acquired at 20 kHz and processed according to SAE J211 standards. The ATD was calibrated prior to each test series. The ATD limbs were tethered appropriately to avoid over travel and ATD joint damage during rebound. Care was taken to avoid snubbing ATD limbs prematurely.

In addition to ATD and sled data, seat belt restraint loads were recorded at each individual mounting location. For the shoulder belts, load cells from Humanetics Innovative Solutions, Incorporated were used, detailed in [Appendix B](#). For the lap belts, anti-submarine belts and negative G belt custom instrumented anchorages were developed, calibrated and used. A standard seat

belt anchorage mounting tab was fitted with appropriate strain gages. This Strain Gage Load Cell Anchor instrumentation is shown in [Figure eight](#) (U.S. patent pending).

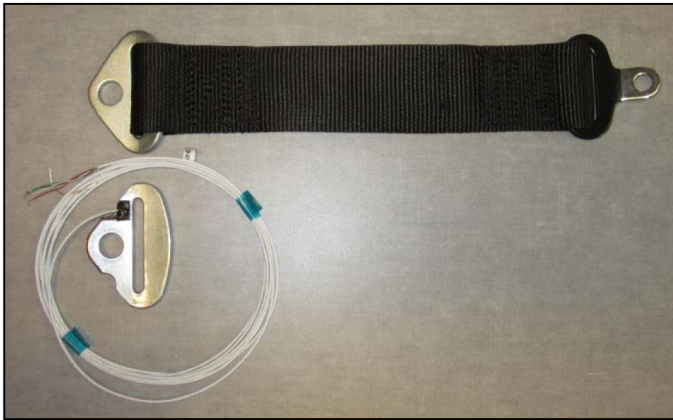


Figure 8. Strain gage load cell anchor instrumentation

Frontal Sled Tests

Thirteen 0° frontal sled tests were conducted as part of this analysis. Ten were conducted in a steel seat buck and three were conducted in an actual composite seat. Pretest photos for two of these frontal tests are shown in [Figures six](#) and [seven](#). The ability of the Takata servo sled to match the subject vehicle acceleration pulse allowed for near exact replication of the subject vehicle x-axis acceleration pulse. The return of the sled acceleration to zero around 130 milliseconds was due to the limited stroke of the sled. The subject vehicle x-axis acceleration pulse with the overlaid sled acceleration pulse is shown in [Figure nine](#).

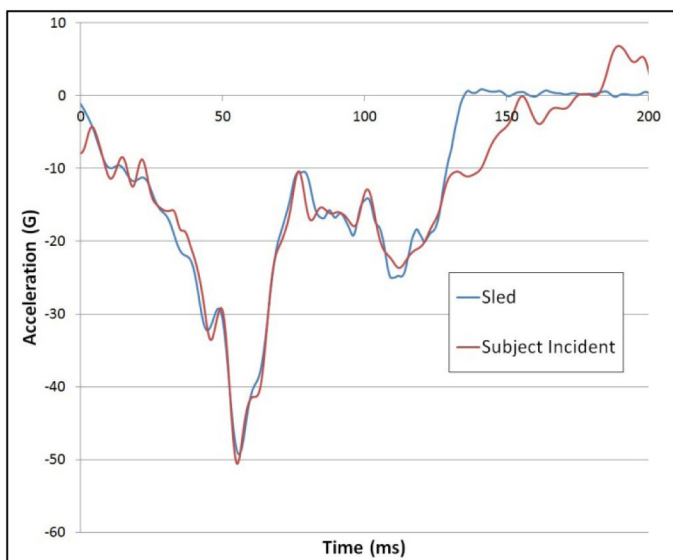


Figure 9. Subject vehicle and sled test acceleration profiles

A motorsports industry standard sled pulse was also used during the 0° frontal sled tests. This pulse is used during SFI (The SFI Foundation, Inc.) 38.1 Head and Neck Restraint Systems testing [8].

This acceleration pulse is also used by NASCAR to dynamically evaluate seats and other equipment. The SFI 38.1 pulse is shown in [Figure ten](#).

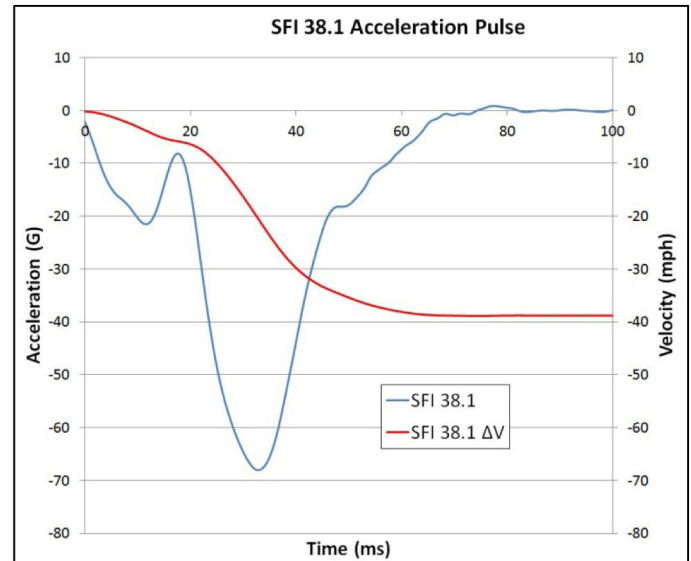


Figure 10. SFI 38.1 acceleration pulse

Both sled test pulses used during the 0° frontal sled tests are shown in [Figure eleven](#) along with their associated changes in velocity.

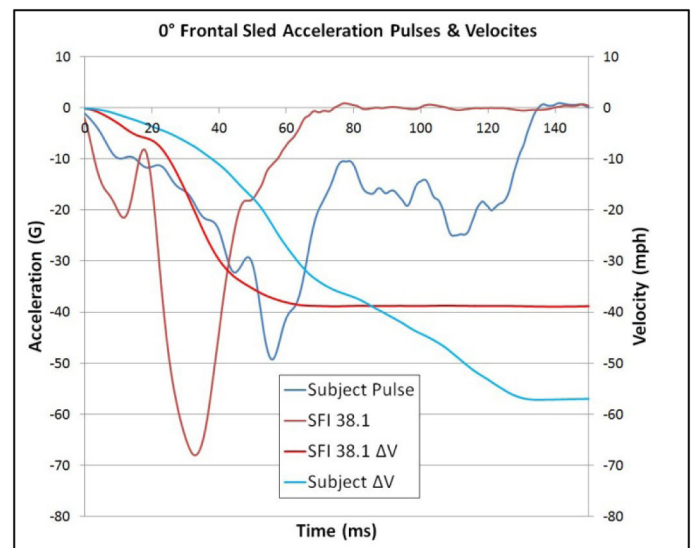


Figure 11. Frontal sled test pulses and associated velocity changes

Three different anti-submarine belt mounting locations were used during the testing. The subject vehicle anti-submarine belt mounting geometry served as the testing baseline for what was considered current practice in the field from 2007 through 2013. Some composite seat models also incorporated additional anti-submarine belt mounting locations. This existing rear anti-submarine belt mount was also tested. Additionally a new rearward and outboard anti-submarine belt mounting location was also tested. The dimensions of these mounting locations are shown in the X-Z plane in [Figure twelve](#) and the X-Y plane in [Figure thirteen](#).

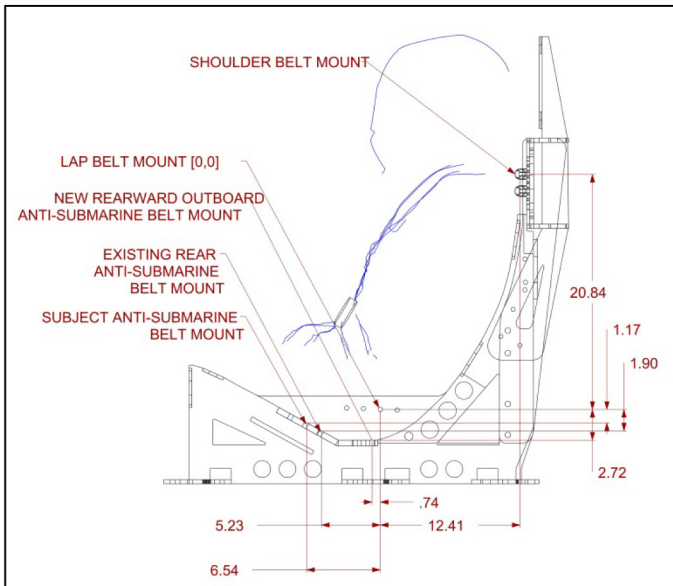


Figure 12. XZ Plane seat belt mounting locations (seat buck)

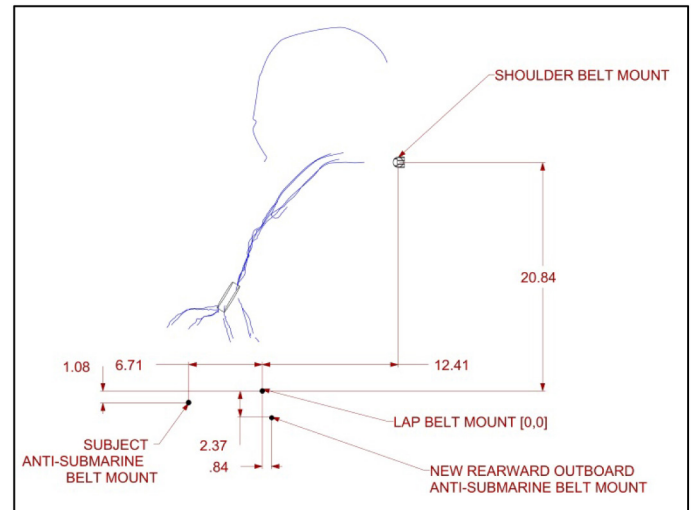


Figure 14. XZ Plane seat belt mounting locations (composite seat)

The 50th percentile American male ATD was used for two of these 30° right frontal oblique tests. The 95th percentile American male ATD was used for test #16, however the chest displacement transducer became dislodged during the test and therefore this test was excluded. Figure fifteen shows the 50th percentile ATD pre-test.

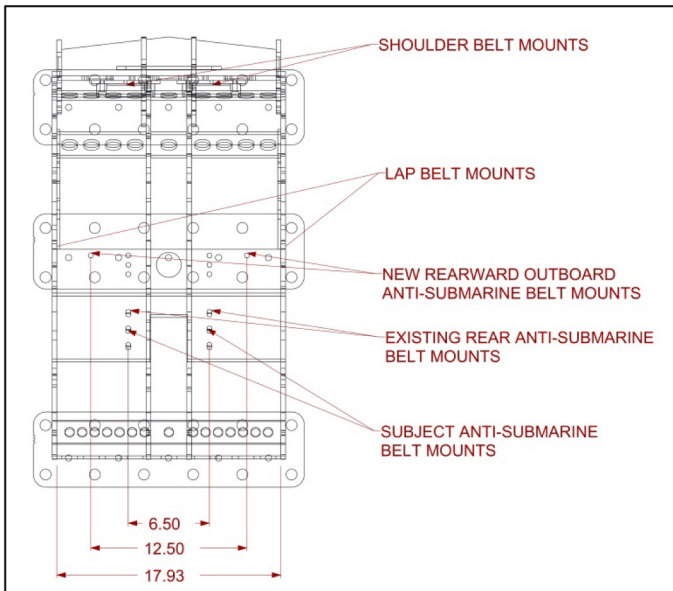


Figure 13. XY Plane seat belt mounting locations (seat buck)

30° Frontal Oblique Sled Tests

Three 30° right frontal oblique sled tests were conducted as part of this analysis. The SFI 38.1 acceleration profile was used for all three of these tests. Since these oblique tests had a lateral acceleration component, relative to the ATD, a full containment composite seat was used instead of the fabricated seat buck, which had no side supports. This test seat was similar to the actual subject vehicle seat and produced by the same manufacturer. The test composite seat was retrofitted with new rearward and outboard anti-submarine belt mounting locations. The existing anti-submarine belt locations were also used in this test series for a baseline comparison. The new rearward and outboard anti-submarine belt mounting anchors were located 6.0 inches (152.4 mm) to the left and right of the seat centerline. The X and Z locations are identified in Figure fourteen.



Figure 15. 50th percentile ATD 30° right frontal sled test, pre-test

Vertical Sled Tests

Three vertical sled tests were conducted as part of this analysis. The subject vehicle seat sled buck was again utilized for these vertical sled tests. A third acceleration pulse was used for the vertical testing. This pulse was recorded from an on-track incident and was an extremely severe roof impact. This particular incident was used as a worst case test and is a very unique and unusual, extremely severe roof impact, not typical of ordinary rollover incident accelerations.

The driver was able to self-extricate and was uninjured. The X-Z resultant acceleration of the actual incident as well as the sled pulse is shown in [Figure sixteen](#) with corresponding velocity changes.

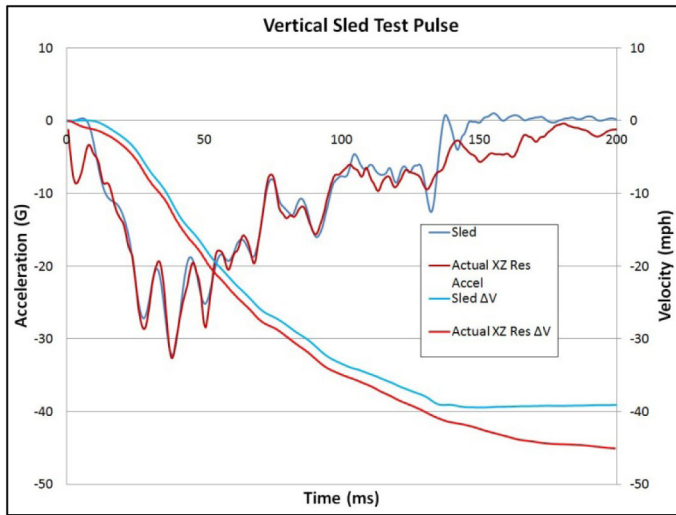


Figure 16. Vertical sled and actual incident acceleration pulses

In order to conduct the vertical tests in a repeatable manner a unique method of positioning the ATD was developed and used for all three tests. The seat buck was positioned at its normal attitude relative to the sled platform and the ATD was then positioned and the restraint system was tightened with the benefit of gravity. The entire seat buck assembly was then rotated 90° and locked to the sled platform for a vertical test alignment. [Figure seventeen](#) shows the ATD and seat in the pre-test position, prior to rotation.



Figure 17. 50th percentile ATD positioned for vertical test, pre-rotation

[Figure eighteen](#) shows the ATD and seat rotated 90° and locked down to the sled platform.

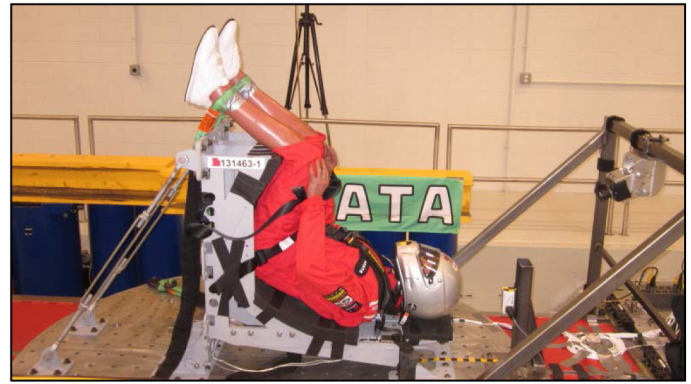


Figure 18. 50th percentile ATD positioned for vertical test

In addition to the ATD and sled data a displacement transducer was also used to measure the ATD excursion out of the seat. A hole was cut into the top of the helmet and a stud attached to the 1/2-20 threaded hole in the ATD head, normally used for lifting and positioning the ATD. The stud was then attached to the displacement transducer which was rigidly mounted to the sled platform. [Figures nineteen](#) and twenty show the displacement transducer setup, circled in pink.

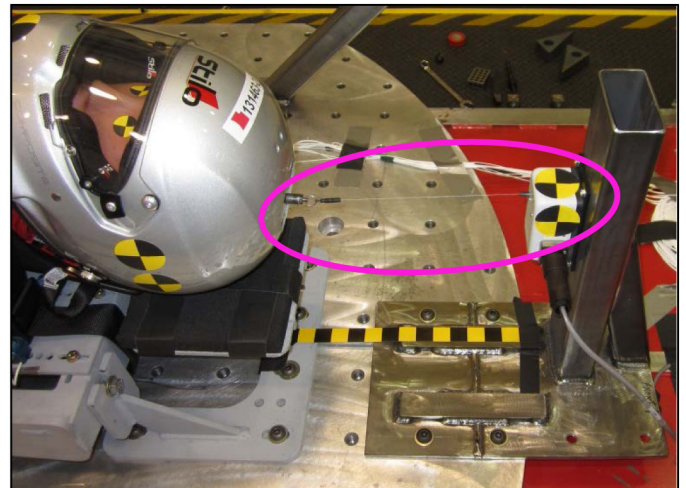


Figure 19. Vertical test ATD head displacement transducer

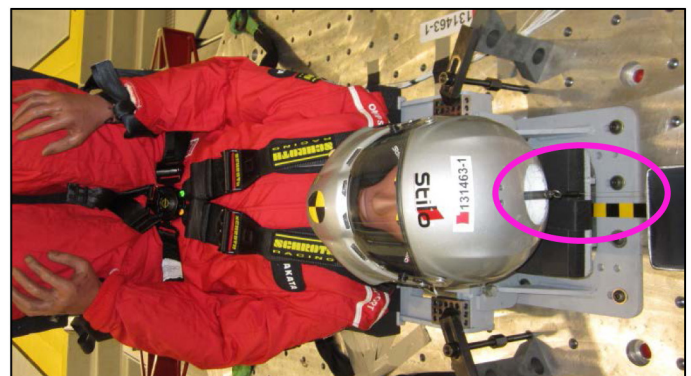


Figure 20. Vertical test ATD head displacement transducer