NHTSA RESEARCH ON IMPROVED RESTRAINTS IN ROLLOVERS

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ABSTRACT

As part of a comprehensive plan to reduce the risk of death and serious injury in rollover crashes the National Highway Traffic Safety Administration (NHTSA) has reinitiated a program to characterize restraint system response in rollovers. A rollover restraint tester (RRT) is utilized to produce a 180 degree roll followed by a simulated roof-to-ground impact. Recognizing the unpredictability of the real world rollover phenomenon, this test provides a repeatable and consistent dynamic environment for suitable lab evaluation. Similar NHTSA research during the mid-1990s demonstrated an excursion reduction of up to 75% when an inflatable belt was compared to the standard three-point belt with a 50th percentile male [Rains, 1998].

Technologies being considered include integrated seat systems, pyrotechnic and electric resetable pretensioners, four-point belt systems, and inflatable belts. High speed video data are collected and analyzed to examine occupant head excursion throughout the tests and are presented for discussion. Though repeatable, concern about the real world relevancy of the RRT dynamics have been focused toward the absence of a mechanical component for lateral motion. This component is not inbuilt to the test fixture.

This research attempts to determine if reasonably reduced excursion is possible in the simulated rollover. This research has been constrained to examining restraint systems focused to the seat. Future research to include a partial vehicle cab structure is planned to allow evaluation of devices that utilize it for a reaction surface; such as rollover air bags.

Restraint advancements have primarily been focused on frontal and side crash performance. It is believed that many of these advancements can also aid in reducing occupant excursion during a rollover crash. Improving restraint effectiveness in rollovers may further enhance protection for belted, non-ejected occupants in rollovers.

INTRODUCTION

Rollover crashes are a major problem in the U.S. Digges [2002] reported that rollovers constitute about 2.2% of crashes but represent 33% of the total injury cost. Much of this cost is attributed to ejections, especially of unbelted occupants. NHTSA has a research program focused on reducing occupant ejections through side windows and the U.S. Congress has mandated that a new standard be published by October 2009. For non-ejected occupants, rollovers still pose a serious threat of injury; particularly head injuries from hitting the interior of the vehicle. FMVSS No. 216 approaches this issue by requiring roof crush resistance and survivability space in the cabin. Safety belt slack and stretch have been thought to allow occupants to 'dive' toward the roof structure in the rollover crash.

In the mid-1990s, the agency initiated a research program to explore the effectiveness of various restraints in rollovers. A rollover restraint tester (RRT) was developed to simulate rollover conditions. It provided a controlled roll for a seated occupant and was followed by a simulated roof-to-ground impact. Occupant excursions toward the roof were measured for common 3-point belts and other advanced restraints systems. NHTSA has revived this program with the intent to examine the latest restraint technology for the seat belt. Many of these devices have been developed for the more common frontal and side crashes. The goal is to determine if these same devices could be employed to improve restraint of belted occupants in rollovers.

The RRT provides a repeatable dynamic environment suitable for comparison testing of various restraint configurations. It has been criticized for lacking a built in lateral component. No single device can replicate the dynamics of all rollovers because every rollover crash is very different and unique. This device allows for consistent repeatability of a specific dynamic environment. In addition to the physical testing, NHTSA has initiated a cooperative project to use computer simulation to validate the RRT testing with real world accident data and FMVSS No. 208 dolly testing. The simulation will allow for expanded capabilities for evaluating technologies in many different ways.

With anticipated FMVSS No. 216 improvements and previous work highlighting the potential effectiveness of advanced restraints, this research program provides an opportunity to evaluate current and future available state-of-the-art countermeasures for occupant protection during a rollover.

TESTING

Test Device

A device, similar to the original RRT [Rains, 1998], has been developed. The rollover simulated is one in which the vehicle becomes airborne at the initiation of the roll and then impacts the roof structure after rotating approximately 180 degrees.

Figure 1 is a schematic of the new rollover restraint test device. The coordinate system is set to the dummy for excursion analysis. The device has four (4) main features consisting of

1) A support framework,
2) A counter-balanced test platform with rotating axle,
3) A free weight drop tower assembly, and
4) A shock tower.

The test platform, with vehicle seat, dummy and restraint device(s) attached, is mounted to the supporting framework. The free weight drop tower provides energy to rotate the test platform at a desired angular acceleration and peak roll rate. The peak roll rate can be adjusted by changing the weight of the drop tower mass. To simulate the roof impact, the rotating platform impacts an adjustable shock-absorbing tower after approximately 180 degrees of rotation. Rollers are attached to the shock absorbers to accommodate the Nylon impact blocks custom mounted to the table. Figure 2 shows the impact region of the table to the shock tower.

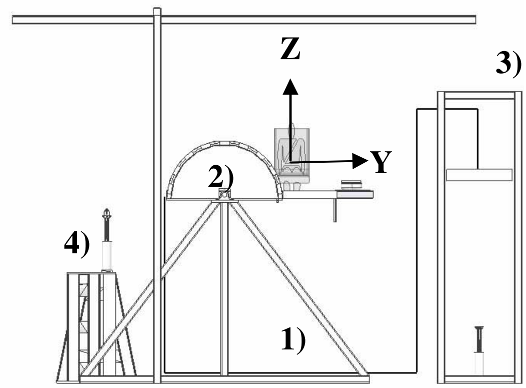

Figure 1. Rollover Restraint Tester (RRT)

Figure 2. Impact area of RRT

Instrumentation

The RRT was instrumented to help characterize the dynamics of the testing. An encoder was used to monitor the roll rate. Two (2) 50,000 lb. load cells were mounted to the roll table at the point of impact to record the impact force. Figure 2 shows how the load cells were mounted between the impact blocks and roll table. A string potentiometer was utilized to measure the shock absorber deflection. A 2,000 g rated accelerometer, mounted to the platform directly underneath the center line of the seat, was used to collect the acceleration at impact.

The 50th percentile male Hybrid III dummy used for testing contained full head, neck and chest instrumentation, and these channels were collected during testing. Seat belt load cells were used for both the lap and shoulder portion of the belts. Video data were collected with a combination of on-board real time cameras (33 fps) and off-board high speed cameras (500 fps).

Evaluated Restraint Technology

A variety of restraints were selected for testing. They range from current consumer available technologies to prototype devices. Cooperation with automotive suppliers and original equipment manufacturers (OEM) allowed for much of the technology to be assessed. The following devices were selected for evaluation. They have been tested individually and in conjunction with others, depending on feasibility of implementation.

Integrated Seat – The integrated seat has the seat belt hardware incorporated into the seat. Many SUV and other light trucks utilize these seats. These seats are generally reinforced to accommodate the increased loads experienced in a crash event. Figure 3 shows the integrated seat used for the evaluation.

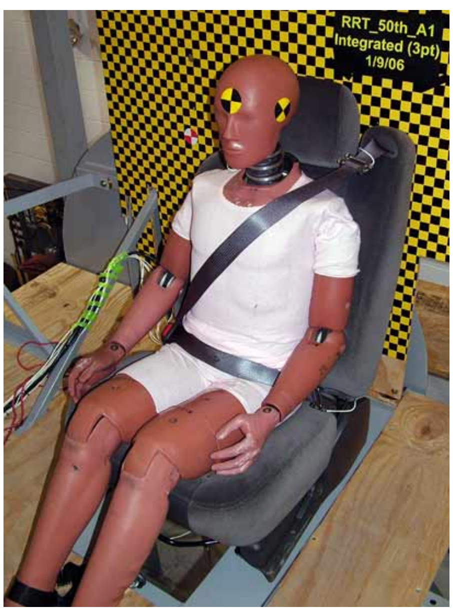

Figure 3. Integrated Seat

Integrated SWAP Seat – The integrated SWAP seat refers to a supplier technology where the restraint, integrated with the seat, comes from the inboard side of the car and buckles on the outboard side.

Non-Integrated Three-Point Seat – This is a standard fleet representative three-point restraint attaching to a B-pillar frame element of the vehicle. A representative B-pillar was fabricated for testing. It was utilized for all non-integrated configurations of various technologies. Figure 4 shows the standard non-integrated seat used for evaluation. This seat was used for all non-integrated seat three-point testing configurations.

Retractor Pretensioner – The retractor pretensioner is a device that uses a pyrotechnic discharge to remove the slack from a seat belt when triggered by a sensor. The action for the removal of slack occurs in the retractor portion of the system. This is currently used in various production vehicles and was purchased as a replacement part. Once the system is ignited, it must be replaced with a new system and is not reusable; similar to an air bag.

Buckle Pretensioner – This is also a pyrotechnic device incorporated in the buckle and is fired to remove the slack near the pelvic region. This is currently used in various production vehicles and was purchased as a replacement part. Like other pyrotechnic devices, it is only usable one time and must be replaced.

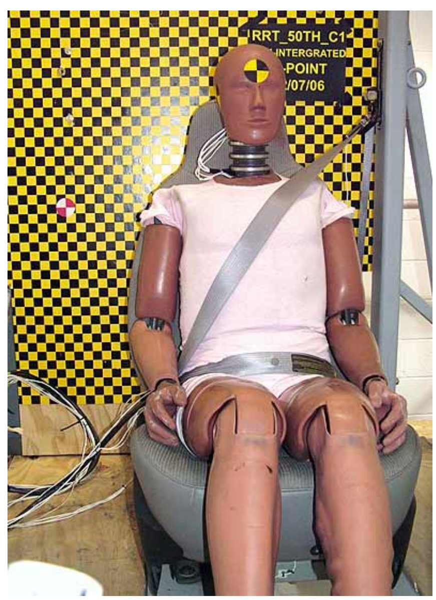

Figure 4. Standard 3-point Non-Integrated Seat

Motorized Retractor – The motorized retractor, sometimes called electric pre-pretensioner, is a reusable device designed to remove slack from the seat belt system. The force rating is generally much lower than the pyrotechnic devices. The reusability of the device allows implementation much earlier when the possibility of a crash is sensed, but the crash is not yet imminent. An example could be one where a car with Enhanced Stability Control (ESC) was activated from an erratic vehicle dynamic; the motorized retractor could be triggered to remove occupant belt slack even if ESC prevented a crash.

Four-Point Seat Belt – The four-point seat belt is a device that has belts coming across both shoulders and buckles at the center of the lap. Two pyrotechnic pretensioners are utilized on each side of the restraint's lower retractors. This is a prototype device being evaluated by suppliers and OEMs for improved restraint performance.

Inflatable Belt – The inflatable belt, similar to the inflatable tubular torso restraint (ITTR) tested in the mid 90s, is a three-point device [Rains, 1998]. It has an inflatable section in the shoulder portion of the belt designed for both pretensioning and cushioning. Previous testing demonstrated reduced dummy excursion when the inflatable belt was compared to a standard three-point system. This prototype restraint is being considered by automotive suppliers and OEMs.

Test Matrix

The test matrix for the restraint evaluation is included as Table 1. The 50^{th} percentile male Hybrid III dummy was used for this series of tests. Configuration code C is baseline treatment for test comparison. It is a standard 3-pt. non-integrated seat without pretensioning. The D-ring position is set in the lowest position.

Pretensioner Deployment

Pyrotechnic and motorized pretensioners were tested for the series. To maintain consistency regarding their use, a switch was mounted to activate at a prescribed angle of table roll. As the table rotated, the dummy began moving out of position, mainly in the Y-direction (lateral). A simulation with an automotive supplier determined a hypothetical dummy motion before a rollover sensor would detect that a rollover was inevitable and would trigger the pyrotechnic devices. For the RRT device this motion amount occurred at about 45 degrees of rotation. This angle was used for firing all pyrotechnic pretensioners used in testing.

Table 1.
Test Matrix for 50^{th} Hybrid III Male

Configuration Description	*D-Ring Position*	*Code*	*REPS*
Integrated Seat	N/A	A	3
Integrated SWAP DURA	N/A	B	3
* 3-pt. Non-Integrated (3PN)	Lower	C	3
3-pt. Non-Integrated	Upper	D	3
(3PN) Retractor Pretensioner	Lower	E	3
(3PN) Buckle Pretensioner	Lower	F	3
(3PN) Retractor w/Buckle Pretensioner	Lower	G	3
(3PN) Motorized Retractor	Lower	H	3
(3PN) Motorized Retractor w/Buckle Pretensioner	Lower	I	3
4pt system w/Pretension	N/A	J	3

** Baseline Configuration for comparison*

For the motorized restraint configurations, the assumption was that they would be used prior to the onset of the roll because of their reusability in the fleet. For instance, if a motion sensor detected irregular vehicle kinematics, it would engage the motorized pretensioner to remove slack early. From this assumption, motorized pretensioners were activated just prior to the initiation of roll.

Static Test

A static test was conducted for each configuration prior to testing to evaluate the natural system slack. The dummy was first seated to testing position with the restraint configuration. A hydraulically driven gearbox, mounted to the rotating table, was then used to slowly roll the table 180 degrees. The rotated table would just barely touch the rollers mounted on the shock absorbers. Static measurements of the X (longitudinal), Y and Z (vertical) direction for the inverted dummy were recorded. The table was rotated back to the start position and the dummy was reseated for the dynamic test.

Dynamic Test

A test to simulate a 180 degree roll followed by a roof impact was administered. Dynamic testing utilized a free-falling mass to drive the rotation of the table. A cable system connected the free falling mass to the half circle drive feature of the test platform. The mass, housed in the drop tower, was stopped by a series of shock absorbers. Platform kinematics were adjusted by changing the mass weight. The target impact angular rate was 315 degrees/second. Earlier reported testing was conducted around 260 degrees/second [Rains, 1998]. Improved structural design of the latest RRT allowed for increased rates.

Roof impact simulation was achieved through the adjustable shock absorbers. The damping adjustment changes the impact force deflection characteristics. A harder impact resulted in less shock deflection. For all testing reported, only one setting was utilized. The selected setting allowed for some deflection of the table and limited rebound after impact. A very “hard” setting would result in dramatic rebounding and bouncing of the table.

Two event marks were utilized for data collection. The first was when the locking clasp was triggered to initiate the test. The second and main event mark for testing was the impact of the nylon blocks with the roller bearings. Data were collected throughout the entire event. All presented comparison data curves utilize the impact mark for setting a zero time for comparison purposes.

Resting dummy measurements along with pictures were taken post testing. Video data collected at the head area were analyzed with video imaging software for excursion. Real-time (33 fps) cameras mounted on-board were used to measure pre-impact excursion. High speed cameras (500 fps) were setup off-board and collected excursion data post impact. After video analysis, the two views were married to develop excursions curve in the X, Y and Z directions for the entire event.

RESULTS

RRT Device Kinematics

Each test is characterized by an acceleration of roll rate until impact. The acceleration is initially slow and increases with time up until impact with the shock tower. The distinct motion profile for the rotating platform is provided as Figure 5 where time zero is the data mark when the table mechanically begins to roll.

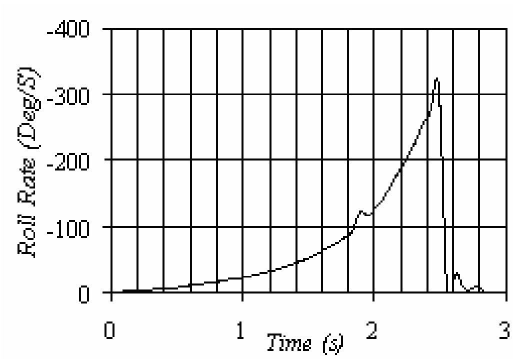

Figure 5. Rotating Platform Angular Speed Profile for Representative Testing of RRT with Target Impact Speed of 315 degrees/second.

The motion is very sensitive to the major weight changes on the table created by certain configuration changes. Changes of the moment about the rotating axle affect the start of the initial roll. The motion profile can be adjusted through changing the drop weight total mass. Sandbags were used to adjust this mass. The aim was to have an angular speed of the table at impact of 315 degrees/second. Average impact roll rate for each tested configuration, with the standard deviation for the 3 repeated tests, is provided in Figure 6. The rates did not deviate beyond 3% of the target rate. An explanation for the configurations is provided in Table 1.

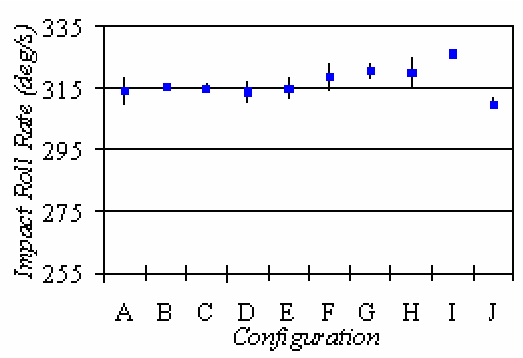

Figure 6. Average Impact Roll Rate w/Std Deviation (50th male test series)

RRT Impact Force

The impact was characterized through a combination of the table-mounted load cells and an accelerometer mounted directly under the seat. Table 2 summarizes these data for all the tested configurations.

Table 2.
Average Impact Force and Accelerometer Data for RRT
50th Hybrid III Male

Restraint Config.	***Avg. Impact Force Max (N)***	***Avg. Impact Accel. Max (g)***
A	95,784	51.9
B	95,370	53.6
C	102,456	46.4
D	102,696	47.3
E	102,277	43.8
F	103,300	45.6
G	104,172	45.5
H	101,402	45.1
I	101,964	45.1
J	93,747	47.4
**Avg.*	*100,820*	*46.7*
**Std Dev*	*3,575*	*3.0*

**Calculated from all tests*

Average impact force and acceleration between the three repetitions on any specific configuration never exceeded ±2% and generally was below ±1% of the average. Differences between configurations generally were noticed after significant table weight changes occurred between configurations. An example is between the integrated seats (A, B) and the non-integrated seats (C-I). In these cases, the seat fixture required changes that resulted in platform weight changes for testing. Non-integrated testing utilized similar seating with restraints utilized in different combinations. 4-point testing (J) also required a seating fixture change leading to differences in RRT impact forces.

Dummy Kinematics

Dummy kinematics were influenced by a combination of platform rotational and gravitational forces. At the onset of the test, the dummy was seated in an upright position. Gravity was the primary initial dummy force for the slow starting action of the rotating platform. As the platform began to rotate, the dummy's course was changed and gravitational forces tended to move the dummy inboard (negative Y-direction).

The angular speed of the platform increased with the centripetal or normal acceleration, creating the appearance of an outward or centrifugal force on the dummy. This outward force pushed the dummy outboard and up (toward the roof) of the vehicle (positive Y-direction, positive Z) during the pre-impact roll event. The dummy tended to start moving back in the positive Y-direction at about 90 degrees of platform rotation. Gravitational forces continued to play a roll for Z-direction (out of the seat toward the roof) past 90 degrees of rotation, until impact.

After impact the dummy immediately changed from outboard and up motion to a dramatic inboard (opposite) Y-direction movement and an amplified Z-direction (positive, toward roof direction) movement. The stopped table eliminated centripetal accelerations leaving momentum and gravity until the dummy came to a hanging rest.

Dummy Head Excursion

Video data of the dummy's head were collected for excursion analysis. X-direction (fore and aft) data have been omitted. The kinematics of the RRT do not have an X-direction motion component, and analysis shows less significance in motion compared to the Y and Z directions. It is recognized that real world rollovers do have varying magnitudes of X-direction motion that can be significant. However, the presented data will focus only on Y and Z direction motions.

Y-Direction Excursion

Figures 7-10 illustrate the results of specific configurations tested. Not all tested configurations are shown for brevity. These figures offer insight into the testing that was conducted. The figures include results for the Integrated Seat (A), Non-integrated Seat (C), the combination pyrotechnic retractor with buckle pretensioner (G) and the electronic motorized retractor with pyrotechnic buckle pretensioner (I). From these figures, the general Y-direction dummy kinematics are observed. These configurations demonstrate how effective each countermeasure was in altering the dummy head excursion values. They also demonstrate the consistency of dummy head excursion between repetitions within a configuration set.

Time zero is the impact moment, and beyond is the post-impact excursion. The portion of the curve before time zero is the pre-impact excursion while the platform is rotating. Within a configuration, dummy head excursion was relatively consistent. Here the dummy tendencies in the test are noticed. The initial pre-impact Y-direction inboard movement is depicted by a negative value. The subsequent pre-impact outboard movement is noticed from the increasing value of Y before time zero.

The impact stops rotation of the platform. After time zero, the dummy head Y-excursion shifts. This inboard movement peaks and the dummy rebounds to a resting position.

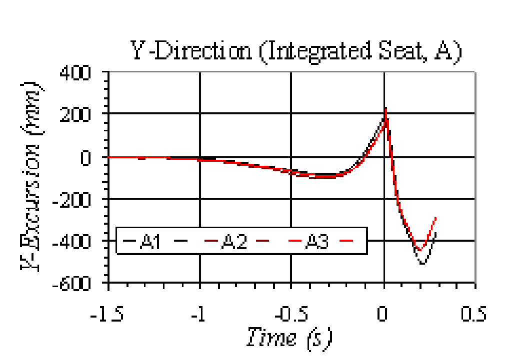

Figure 7. Configuration A Y-direction excursion of 50th male.

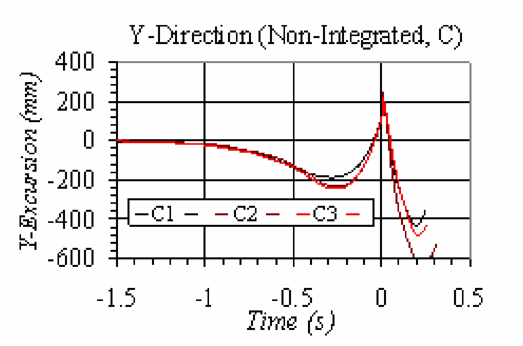

Figure 8. Configuration C Y-direction excursion of 50th male.

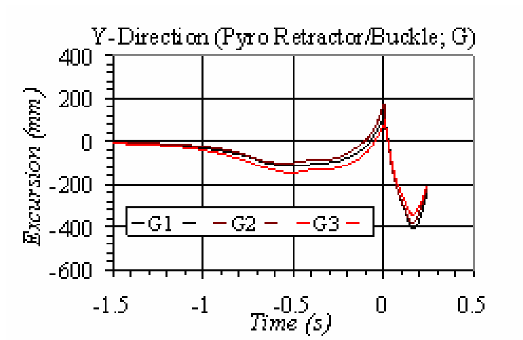

Figure 9. Configuration G Y-direction excursion of 50th male.

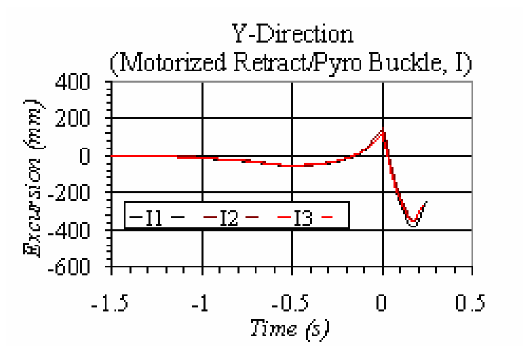

Figure 10. Configuration I Y-direction excursion of 50th male.

Figure 11 plots the average Y-direction dummy head excursion of the four configurations, A, C, G and I. As previously mentioned, configuration C is used as the baseline because it represents a standard 3-pt system with no use of pretensioners. The dummy Y-direction head excursion is reduced when each configuration is compared to the standard 3-pt. belt, C. Pre-impact Y_in (inboard) excursion is reduced from 223mm to 54mm (76%) when the motorized seat belt with buckle pretensioner (I) is compared to the baseline (C). Pre-impact Y_out (outboard) is reduced from 225mm to 131mm (42%) when the same configurations are compared.

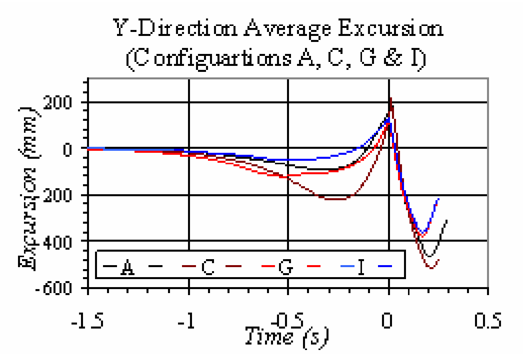

Figure 11. Average Y-direction movement for Configurations A, C, G and I.

Table 3 summarizes the average maximum dummy Y-direction head excursions for all tested restraints. These values are divided into pre and post impact categories. Pre-impact is subdivided for the inboard motion and outboard motion. Configurations with pretensioners were able to reduce dummy head Y-direction excursion.

Table 3.
Average Pre and Post Impact Dummy Y-Direction Head Excursion
50^{th} Hybrid III Male

Restraint	***PRE IMPACT Y_in***	***PRE IMPACT Y_out***	***POST Y***
A	-95	215	-466
B	-83	128	-387
C	-223	225	-518
D	-250	284	-445
E	-102	95	-392
F	-116	159	-458
G	-122	132	-354
H	-44	173	-391
I	-54	131	-362
J	-83	266	-514

A graphical summary of average maximum pre-impact excursion for all treatments is provided in Figure 12. The shaded background distinguishes between integrated (green), non-integrated (yellow) and the 4-pt (blue) configurations. In general, treatments resulting in a lower Y_in also had a reduced pre-impact Y_out when compared to the baseline (C) and the other non-pretensioned 3-pt. test (D). The integrated seats were effective in reducing excursion, with the SWAP configuration performing comparable to pretensioned treatments. It is important to consider that all pyrotechnic pretensioners were fired at a roll angle of 45 degrees (around 0.75 seconds before impact), and the motorized retractors were energized at the initiation of the roll. These devices were utilized in configurations E-J. Y_out of the 4-pt belt (J) was not reduced even though inboard motion was.

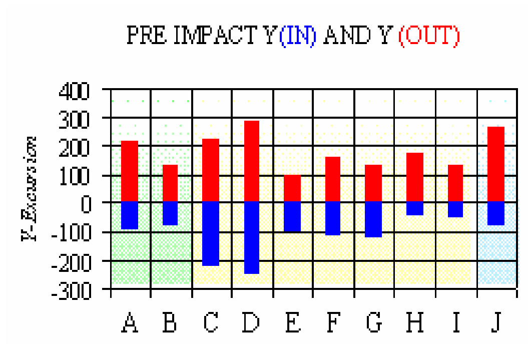

Figure 12. Pre-impact Y_in and Y_out Dummy Head

Post impact average maximum Y-direction dummy head excursions are quite variable between treatments, though pretensioning in 3-pt systems seemed to help reduce the excursion when compared to the baseline (C). The integrated SWAP (B) reduced post impact Y-excursion from 518mm to 387mm (25%) when compared to C. However, post impact evaluation of excursion by the RRT is difficult because dummy motion is very dramatic from the immediate stopping of platform rotation. Similar types of real world crashes are less prevalent and most generally continue to roll beyond 180 degrees and do not immediately stop.

Z-Direction Excursion

The motion of moving up toward the roof is considered Z-direction excursion for this testing. Figures 13-16 summarize each test for the individual configurations illustrated. Similar to the Y-direction plots, time zero is the impact of the table. Typical Z-direction movement in the pre-impact phase is zero until the apparent centrifugal forces begin to force the dummy up out of the seat. At this point, the Z-excursion begins to increase through the pre-impact phase. At impact, the dummy experiences a pointed spike in the Z-direction. After this spike, the Z-direction begins to decrease and rebound to a resting position. Much of this post-impact spike Z-direction motion occurs because the dummy is pivoting around the lap belt and the dramatic Y-direction inboard motion reduces the dummy Z-direction. At stated earlier, rollover crashes that immediately stop after 180 degrees of roll are less common, making post impact data difficult to interpret.

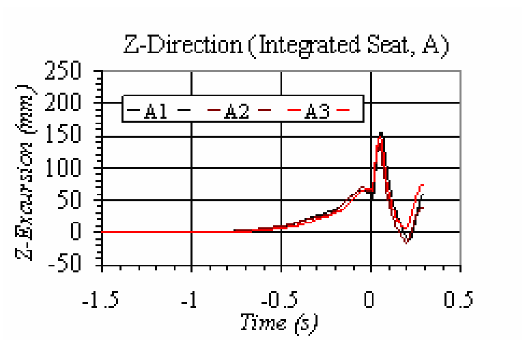

Figure 13. Configuration A Z-direction excursion of 50th male.

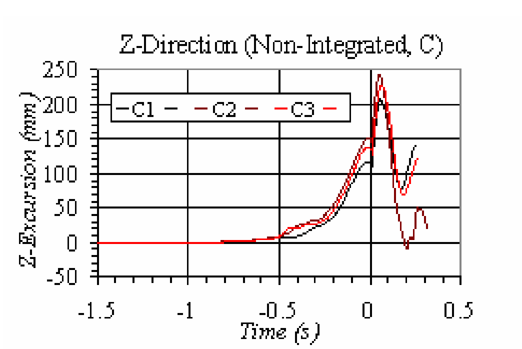

Figure 14. Configuration C Z-direction excursion of 50th male.

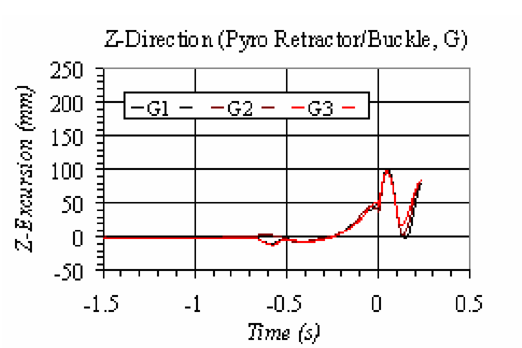

Figure 15. Configuration G Z-direction excursion of 50th male.

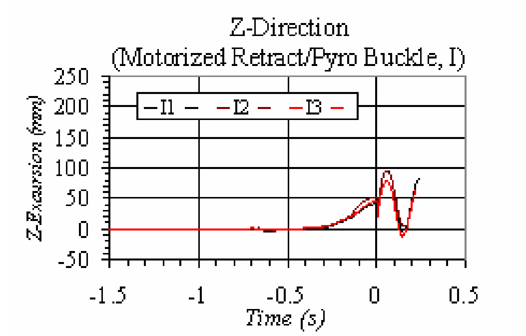

Figure 16. Configuration I Z-direction excursion of 50th male.

Similar to the Y-direction, pretensioners were able to alter the dummy head Z-direction motion between treatments. Figure 17 plots the average Z-direction motion of configurations A, C, G and I. With the baseline configuration as C, each treatment was able to reduce the Z-direction head excursion of the 50th male dummy.

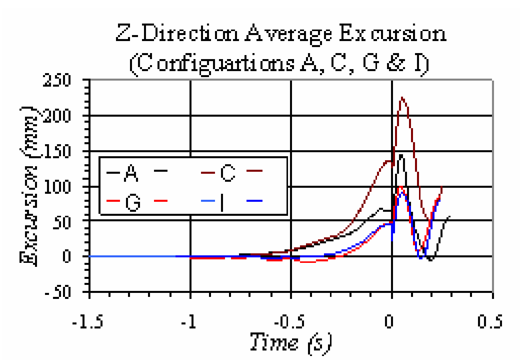

Figure 17. Average Z-direction movement for Configurations A, C, G and I.

Table 4 summarizes the average maximum dummy head Z-excursion pre and post impact for all tested configurations. This is graphically depicted as Figure 18. When compared to the baseline (C), the integrated seat configurations, A and B, had pre-impact Z-direction reductions of 49% and 54%, respectively. The post-impact were reduced 35% and 50%, respectively. No pretensioners were used in the integrated seat configurations.

The 3-pt pretensioner configurations, E-I, show a large reduction of dummy Z-direction head excursion. When compared to C, pre- and post-impact dummy head excursions for the motorized pretensioner and pyrotechnic configuration (I) were reduced 66% and 60%

respectively. In general, reduced pre-impact Z-head excursion led to reduced post impact Z motion. The 4-pt belt (J) had similar performance as the integrated seat configuration (A) in Z-direction excursion.

Table 4.
Average Pre and Post Impact Dummy Z-Direction Head Excursion
50th Hybrid III Male

Restraint	***PRE IMPACT Z***	***POST IMPACT Z***
A	69.0	147.5
B	61.7	113.3
C	135.4	226.0
D	140.1	226.9
E	47.3	89.9
F	61.7	128.9
G	49.9	98.7
H	60.8	117.2
I	45.7	89.8
J	62.7	162.6

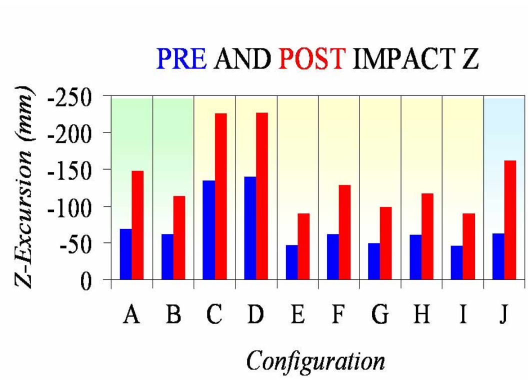

Figure 18. Average Z-direction movement for Configurations A, C, G and I.

SUMMARY

A test series focused on restraint technologies for rollover crashes was conducted with the NHTSA Rollover Restraint Tester (RRT). The 50th percentile male Hybrid III dummy was utilized. Restraints included fleet typical 3-point non-integrated seats, integrated seats, pyrotechnic retractor and buckle pretensioners, motorized pretensioners and a 4-point belt system. Pretensioners were tested in various combinations. Each configuration simulated a roof-to-ground impact at 180 degrees with an angular speed of 315 degrees/second and was repeated 3 times. Occupant excursions in the X, Y and Z direction were recorded utilizing a combination of real time and high speed cameras and analyzed with digitizing software. Configuration C is the baseline used for comparisons between treatments. All pyrotechnic devices were deployed at 45 degrees of table rotation. Motorized devices were activated at the initiation of roll. Observations from this round of testing include:

1. The RRT is a research device that provides a repeatable dynamic environment suitable for evaluating restraints in a rollover scenario.

2. Integrated seats, when compared to the baseline (C), reduced both Y (lateral) and Z (vertical) head excursions in the pre and post impact phase of the test. These reductions were up to 54%.

3. Pretensioners in all configurations effectively reduced maximum dummy head excursions in both the Y and Z-directions in pre and post-impact of the RRT.

4. Motorized retractor pretensioners (H, I) activated at the initiation of roll reduced pre-impact excursion in the Y-direction by up to 76% and Z-direction head excursion up to 66%.

5. The 4-pt belt (J), with 2 pyrotechnic retractors, reduced pre-impact Y_in motion by 63% and Z by 54%, however Y_out motion dummy head excursion increased 18% when compared to the baseline. The post impact Z excursion was reduced 28%, while the post impact Y excursion was essentially unchanged from the baseline configuration.

6. Initial results indicate that restraint technologies tailored for rollover crash events may reduce occupant excursion toward the roof.

CONTINUED WORK

Testing with the RRT is continuing. Other technologies that may have potential for restraint during a rollover crash are also being considered. One technology is the inflatable belt previously tested in the mid 1990s. Other considerations include adding a partial cab reaction surface to allow for testing of rollover air bags and similar devices being incorporated for rollover protection.

Other testing includes evaluation of the 5th female and 95th male dummies to investigate how occupant size affects rollover crash restraint. Physical limitations of the RRT play a factor in testing the heavier occupant (95th) and adding a cab structure.

New camera equipment has been purchased to improve visual data collection. They are high speed/high g rated cameras allowing all data to be collected on-board the RRT.

A rollover modeling program has also been initiated with goals of correlating dummy kinematics with the RRT to simulated real world rollovers. Physical results from the testing are aiding in developing a computer model. This will allow evaluation of technologies and situations that may be physically restricted by the RRT.

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