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 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 (50th) male dummy [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. The RRT has demonstrated to be repeatable; however, there are some concerns about the real world relevancy of the RRT dynamics in the absence of a lateral component. The RRT does not have a mechanical component for lateral motion that is typical in some real world rollover events.

This research attempts to determine if reducing occupant excursion during a rollover event is possible by utilizing the RRT. Results presented at the 20th ESV conference demonstrated that excursion characteristics can be affected with the implementation of advanced restraints in the 50th percentile male dummy [Sword, 2007]. This paper presents expanded research with the 50th percentile male dummy and also includes the 5th percentile (5th) female and 95th percentile (95th) male dummies.

When compared to a baseline 3-point restraint, advanced restraints utilizing pretensioning and other technology reduced excursion of all the dummies in both the Y and Z directions, where the Y direction is lateral motion and the Z direction is vertical motion. The current production technologies, pyrotechnic and motorized retractors, were able to reduce Y and Z excursion in RRT tests, by up to 66% and 60%, respectively. The advanced restraints, inflatable belts and 4-pt belts, reduced excursion in the Y and Z directions up to 80% and 86%, respectively.

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. The NHTSA has a program focused on reducing occupant ejections through side windows. For non-ejected occupants, rollovers still pose a serious threat of injury; particularly head injuries from hitting the interior surfaces of the vehicle. Federal Motor Vehicle Safety Standard, No. 216, Roof crush resistance (FMVSS No. 216), addresses this issue by requiring minimum roof strength allowing for survival space in the cabin. Safety belt slack and stretch have been thought to allow occupants to ‘dive’ toward the roof structure in rollover crashes.

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 [Rains, 1998]. Occupant excursions toward the roof were measured for common 3-point belts and other advanced restraints systems. The NHTSA has revived this program with the intent to examine the latest restraint technology. Many of these devices have been developed for the more common frontal and side crashes. The goal of this research is to determine if these same devices could be employed to improve restraint of belted occupants in rollovers.

The RRT was presented at the 20th ESV Conference along with an initial data series [Sword, 2007]. This device provides a repeatable dynamic environment suitable for comparing various restraint configurations. 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.

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

The RRT [Sword, 2007], was developed to simulate a rollover where 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 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.

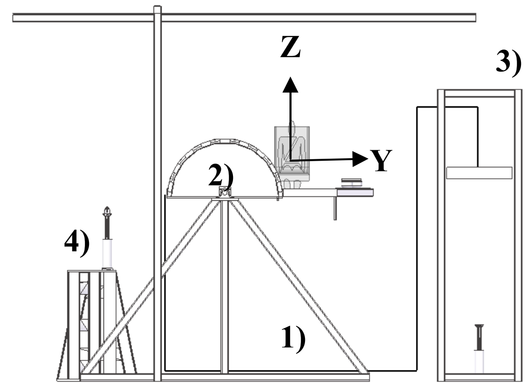

Figure 1. Rollover Restraint Tester (RRT).

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. 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 Hybrid III dummies 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.

Test Matrix

The test matrix for the restraint evaluation is included as Table 1. It includes the configuration description, code and the test series for the 50th percentile, 5th percentile female, and 95th percentile male adult dummies and fire angle testing. Also included is the 50th percentile male dummy repeated test series for head excursion explained earlier. Configuration C is the baseline treatment for test comparison. It is a standard 3-pt. non-integrated seat without pretensioning. The code letter is used throughout the results section to simplify the graphics.

Table 1.
Test Matrix for 50th, 5th, 95th Hybrid III Dummies, Fire Angle Testing and 50th Percentile Male Dummy Repeats.

		Test Series				
Configuration Description	*Code*	*50th*	*5th*	*95th*	*Fire Angle*	*50th Repeat*
Integrated Seat	A	X	X	X		X
Integrated SWAP	B	X	X	X		X
* 3-pt. Non-Integrated (3PN)	C	X	X	X		X
3-pt. Non-Integrated (3PN)	D	X	X	X		X
(3PN) Retractor Pretensioner	E	X	X			X
(3PN) Buckle Pretensioner	F	X	X			X
(3PN) Retractor w/Buckle Pretensioner	G	X	X	X	X	X
(3PN) Motorized Retractor	H	X	X			X
(3PN) Motorized Retractor w/Buckle Pretensioner	I	X	X	X	X	X
4pt system w/Pretensioner (50th ONLY)	J	X				
Inflatable Belt w/Lap Pretensioner	K	X	X	X		
Inflatable Belt without Pretensioner	L	X	X			
4pt system w/Pretensioner (Redesign)	M	X	X	X		

- *Baseline Configuration for comparison*

Evaluated Restraint Technology

A variety of restraints were selected for testing. They ranged 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: Integrated Seat, Integrated SWAP Seat, Non-Integrated Three Point Seat, Retractor Pretensioner, Buckle Pretensioner, Motorized Retractor, 4-Point Belt, and Inflatable Belt.

Integrated Seat – The integrated seat has the seat belt hardware incorporated into the seat. Many sport utility vehicles (SUVs) and other light trucks utilize these seats. These seats are generally reinforced to accommodate the increased loads experienced in a crash event. Figure 2 shows the integrated seat used for the evaluation.

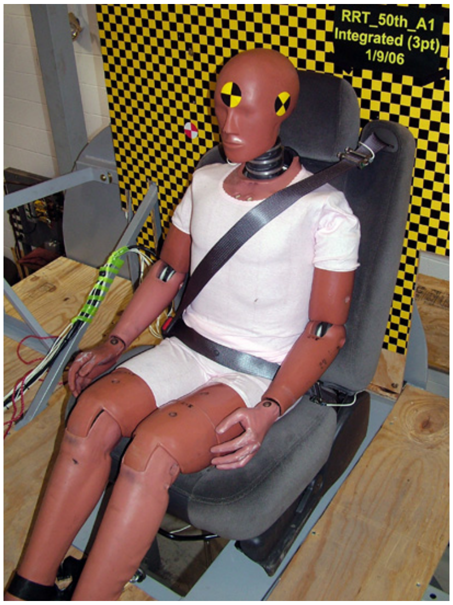

Figure 2. Integrated Seat.

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 3 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. A force around 1500 Newtons is experienced at the shoulder belt when the retractor is fired. 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. A force around 500 Newtons is observed at the lap belt when the buckle is fired. Like other pyrotechnic devices, it is only usable one time and must be replaced.

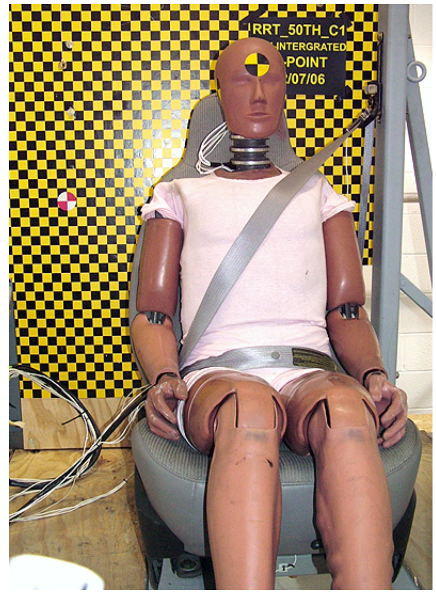

Figure 3. Standard 3-point Non-Integrated Seat.

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 (~140 N). 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 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. The motorized retractor requires a control box and algorithm to be programmed for specific implementation of the device.

Four-Point Seat Belt –The four-point (4pt) seat belt design used in this study is a device that utilizes belts across both shoulders and buckles at the center of the lap. Figure 4 illustrates the 4-pt device utilized for testing.

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 in both frontal and side crash protection. Two (2) different configurations were utilized with the 4pt system (J and M).

Initial testing with the 50th percentile male dummy led to a conversation with the supplier regarding the belt routing of the device itself. The attachment points of the 4-point belt were relocated and tested as Configuration M.

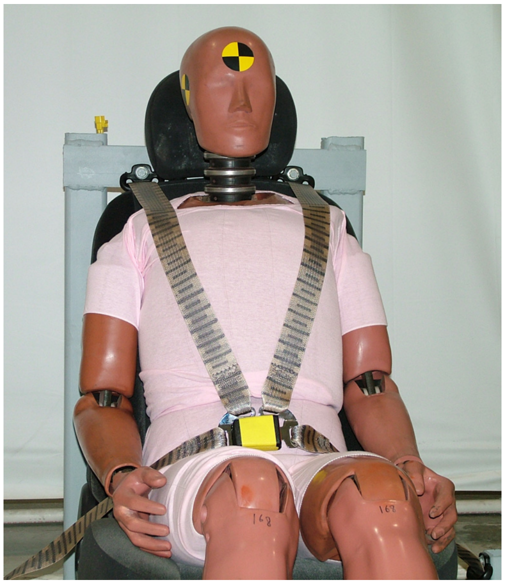

Figure 4. 4-Point Seat Belt with the 50th Percentile Male Dummy.

Inflatable Belt – The inflatable belt, similar to the inflatable tubular torso restraint (ITTR) tested in the mid 90s [Rains, 1998], is a three-point device. 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 belt configuration. Two configurations (K, L) were tested. One (K) included a lower/lap anchor retractor pretensioner in addition to the inflatable device. Figure 5 is an image of the inflated belt along the torso section of the belt system. This particular device utilizes a pyrotechnic inflator integrated in the buckle of the belt system. For the shoulder belt portion of the belt to inflate, the buckle must be latched. This enables the buckle mounted inflator to inflate the air belt.

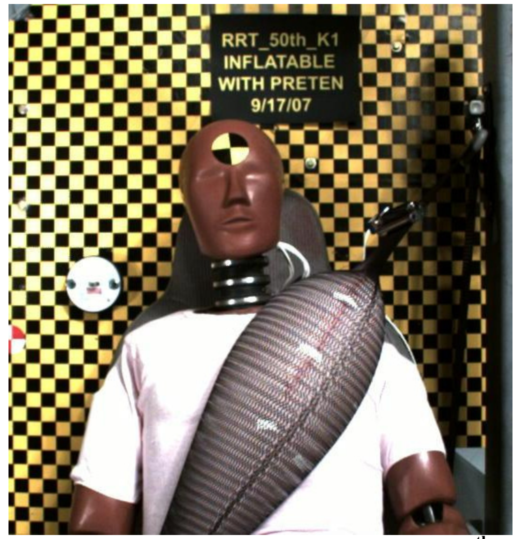

Figure 5. Inflatable Seat Belt on the 50th Percentile Male Dummy.

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). Working with an automotive supplier, a computer simulation was used to determine when during the rollover event the sensor would deploy the pretensioners. This translated to an angle of about 45 degrees of rotation with the RRT device. This angle was used for firing all pyrotechnic pretensioners, including the inflatable belt, used in testing.

For the motorized restraint configurations, the assumption of use prior to the onset of the roll was made 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.

Fire Angle Comparison

As stated, all pyrotechnic pretensioners were fired at an angle of 45 degrees for the testing program. A small subset of tests was conducted to examine the influence of firing the pyrotechnics earlier (30 degrees) and later (60 degrees) of roll. Two current production configurations, G and I, were selected for their performance from the 50th percentile male dummy testing.

50th Percentile Male Dummy Repeated Test Series

Previously reported excursion data of the 50th percentile male dummy was generated using a combination of onboard real time and off board high speed video cameras. [Sword, 2007] Upgrades to image capture and analysis after this series raised questions to the original excursion analysis. New on board high speed cameras and upgraded image analysis software increased the accuracy of the data collection. It was determined to repeat all original testing to ensure accurate comparisons of data between various dummies. These tests are Configuration A-I, and all of the presented excursion data for the 50th percentile male dummy tests come from the repeated series.

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 aim was to have an angular speed of the table at impact of ~320 degrees/second. The average impact roll rate for each tested configuration, with the standard deviation for the 3 repeated tests, is provided in Figure 6. Average roll rate stayed within six percent (6%) of the target.

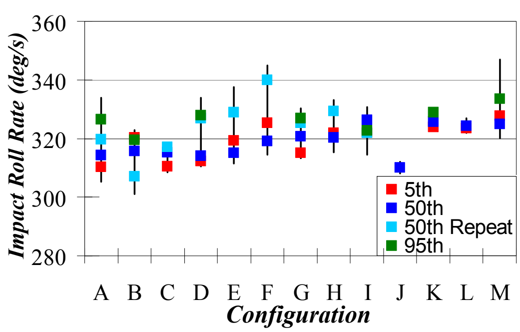

Figure 6. Average Impact Roll Rate w/Std Deviation (320 deg/s target).

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 theoretical 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 role for Z-direction motion (out of the seat toward the roof) past 90 degrees of rotation, until impact.

After impact, the dummy immediately changed from an outboard and up (i.e. off the seat) motion to a dramatic inboard and amplified up motion. The centripetal accelerations were eliminated when the table stopped, leaving momentum and gravity to act on the dummy.

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 the analysis for the RRT shows less significance X-direction motion compared to the Y and Z directions. The presented data will focus only on Y and Z-direction motions. For simplicity and comparative purposes, the plots shown and discussed are Configurations A, C, G, I, and K. These configurations represent five unique test parameters.

Y-Direction Excursion

Figures 7 and 8 plot the average Y-direction head excursion of six selected configurations, A, C, G, I, K and M for the 5th percentile female and 50th percentile male dummy Hybrid III dummies. As previously mentioned, configuration C is used as the baseline because it represents a standard 3-pt belt system without the use of pretensioners. This test was analyzed as a baseline to compare to the other test configurations. 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.

The impact happens at time zero. The portion of the curve before time zero is the pre-impact excursion, while the portion of the curve after time zero is the post-impact excursion. Within a configuration, dummy head excursions were relatively consistent.

When comparing the 5th percentile female and the 50th percentile male dummy's plots, similar trends can be noticed for Y-direction excursion. All configurations compared to the baseline, C, show reduced pre-impact Y excursion.

Post impact average maximum Y-direction dummy head excursions are quite variable between the configurations. Post impact Y-direction evaluation of excursion with the RRT is difficult because dummy motion is very dramatic from the immediate stopping of platform rotation. Real world crashes similar to the RRT are less prevalent and most generally continue to roll beyond 180 degrees and do not immediately stop.

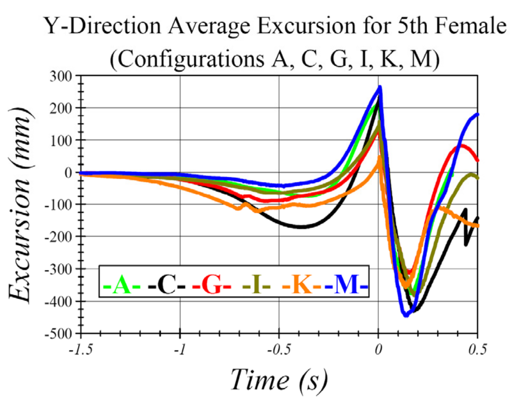

Figure 7. Average 5th Female Dummy Ydirection movement for Configurations A, C, G, I, K and M.

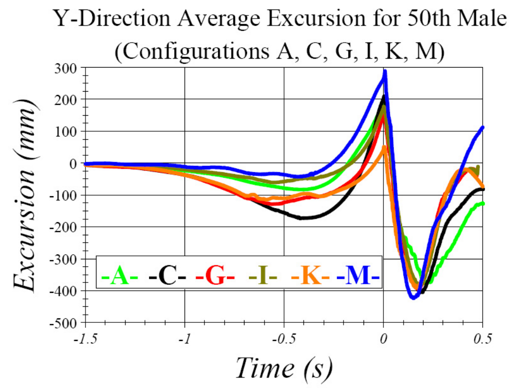

Figure 8. Average 50th Percentile Male Dummy Y-direction movement for Configurations A, C, G, I, K and M.

Table 2 summarizes the percent reductions of the pre-impact dummy Y-direction head excursion for the highlighted configurations, A, G, I, K and M when compared to the baseline (C) of no pretensioning. Integrated seats (A), Motorized Retractor (I) and 4-point belts (M) reduced Y_in head excursion beyond 50% when compared to the baseline. For Y_out excursion, inflatable belts (K) gave reductions as high as 89%.

When compared to the baseline seat, pretensioning was effective in reducing the overall dummy Y-direction head excursion. Motorized pretensioners were able to reduce early Y_in excursion because of their earlier activation. The high pretensioning power of the pyrotechnic devices appeared to provide reduced dummy head Y-direction excursion in both the inboard and outboard phases.

Table 2.
Average Percent Reduction of Y_in and Y_out Head Excursion for 50th, 5th, 95th Hybrid III for Configurations A, G, I, K and M when compared to Baseline Configuration C.

	Y_in			Y_out		
	5th	*50th*	*95th**	*5th*	*50th*	*95th**
A	56%	52%	36%	2%	6%	17%
G	47%	26%	1%	37%	27%	16%
I	62%	65%	59%	35%	15%	(11%)
K	29%	34%	18%	89%	81%	23%
M	74%	74%	46%	(17%)	(45%)	(27%)

* Baseline for 95th is Configuration D (upper D-ring)

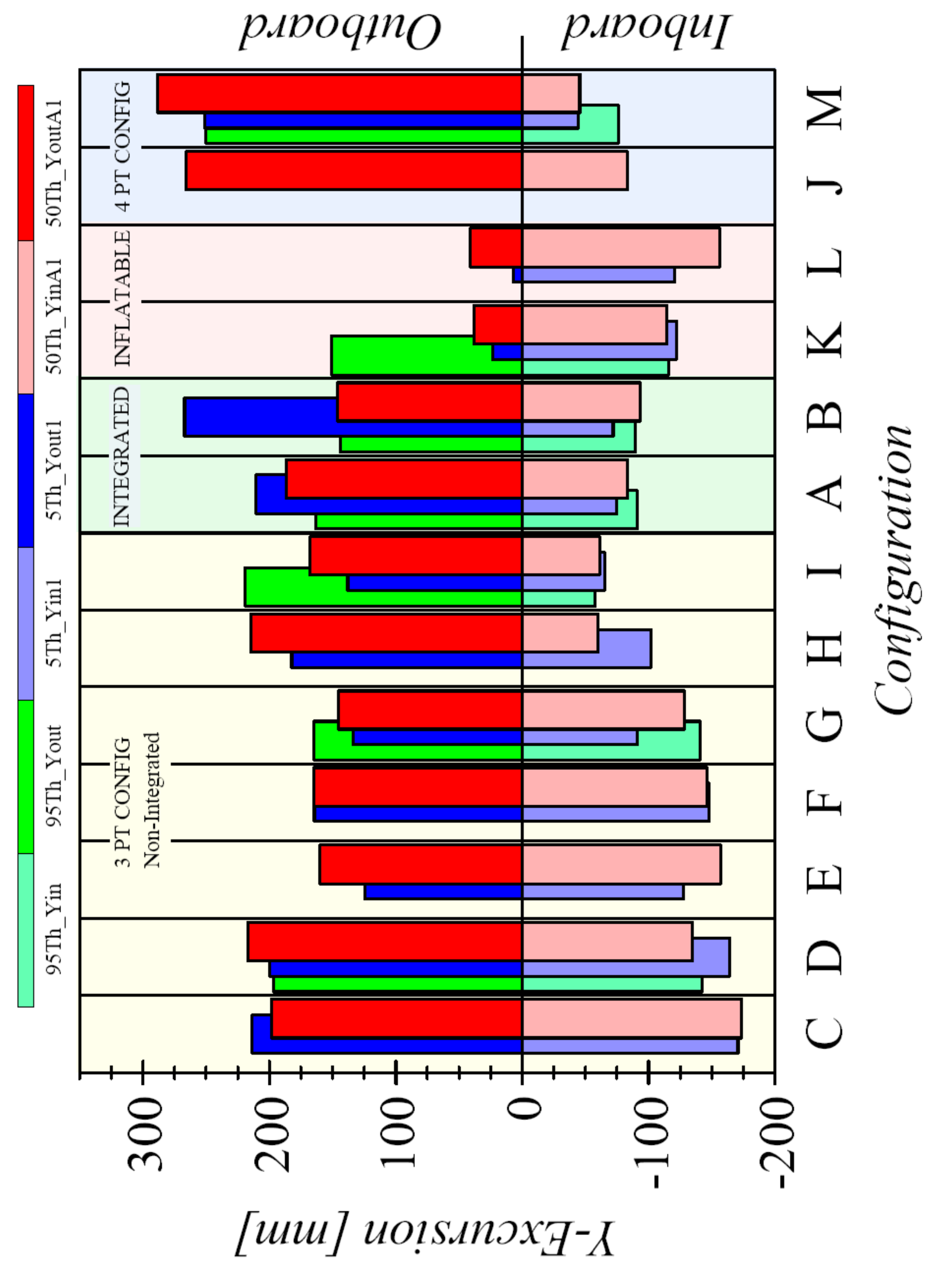

Figure 9. Average Pre-impact Y_inboard and Y_outboard direction Dummy Head Excursion for 5th (blue), 50th (red) and 95th (green) Hybrid III dummies

The Y_out excursion increased up to 45% with the 4-point belt system. The 4-point belt system was able to significantly reduce the initial Y_in motion of the dummy, but the shoulder belts came off of all the dummies during the outward motion in the pre-impact phase. With the shoulder belts coming off, the dummy was open to move in the Y-direction. The inflatable belt was able to stay on the dummies shoulders throughout the rollover and prevent the outboard motion.

A graphical summary of average maximum pre-impact excursion in both the Y_in and Y_out direction, for all treatments, is provided in Figure 9. The shaded background distinguishes between non-integrated (yellow) integrated (green), inflatable (rose) and the 4-pt (blue) configurations. In general countermeasures were able to reduce dummy Y-direction excursion. No one device, however, performed the best when considering both the Y_in and Y_out.

Z-Direction Excursion

The motion of moving up toward the roof is considered the Z-direction excursion for this testing. Figures 10 and 11 summarize the average Z-direction motion of configurations A, C, G, I, K and M for the 5th percentile female and 50th percentile male dummy respectively.

Similar to the Y-direction plots, time zero is the impact of the table. In general, 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. Gravitational forces continued to play a role for Z-direction motion from 90 degrees of RRT rotation until impact. 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 Z-direction motion occurs because the dummy is pivoting around the lap belt/pelvic region and the dramatic Y-direction inboard motion reduces the dummy Z-direction.

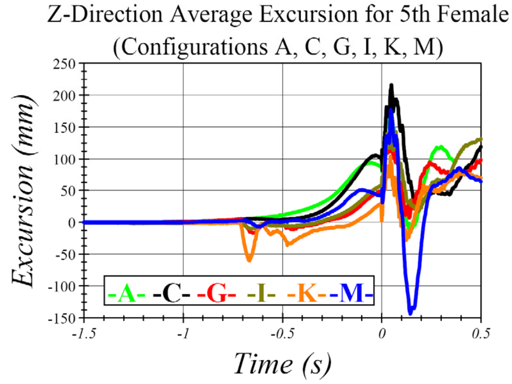

Figure 10. Average Z-direction movement for Configurations: A, C, G, I, K and M.

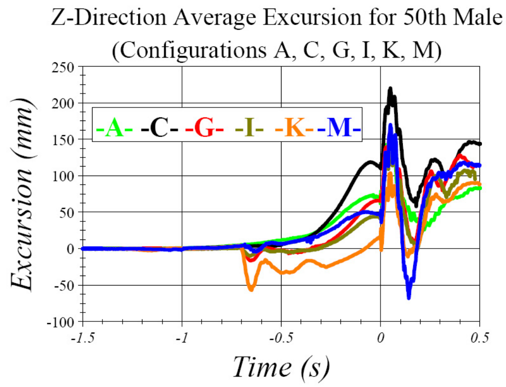

Figure 11. Average Z-direction movement for Configurations: A, C, G, I, K and M.

Table 3 summarizes the percent reductions of Z-direction excursion for the highlighted configurations, A, G, I, K and M when compared to the baseline (C). All of these configurations resulted in reduced Z-direction head excursion for all the dummies in both the pre-impact and post-impact phase of the test. Integrated seats (without pretensioning) were able to reduce the Z-direction excursion by as high at 40% prior to impact. Pretensioning at all levels significantly reduced dummy Z head excursion.

Table 3.
Average Percent Reduction of Z_pre and Z_post Head Excursion for 50th, 5th, 95th Hybrid III for Configurations A, G, I, K and M when compared to Baseline C.

	Z_pre			Z_post		
	5th	*50th*	*95th**	*5th*	*50th*	*95th**
A	11%	38%	21%	17%	28%	15%
G	53%	44%	19%	34%	28%	6%
I	45%	63%	51%	28%	38%	25%
K	72%	86%	60%	52%	53%	27%
M	52%	56%	64%	18%	34%	28%

* Baseline for 95th is Configuration D (upper D-ring)

The inflatable belt was very effective in reducing both pre and post-impact Z excursion across all of the dummies. It reduced the 50th percentile male dummy pre-impact excursion by 86% and the post impact by 52%. The 4-point also performed well in the Z-direction, up to 64%. Although the shoulder belts slipped off of the dummy in the 4-point system, the two lower pyrotechnic retractors would pin down the pelvic region of the dummy, leading to the reduced Z excursion. Reductions for the 5th percentile female were less than larger dummies with the 4-point belt. This may be attributed to the belt fit since the geometry was generic and not tailored specifically for each dummy.

A graphical summary of average maximum pre- and post impact Z-direction excursions is presented in Figure 12. It summarizes all the results across the dummies tested. The countermeasures were very effective in reducing both the pre and post impact excursion when compared to the baseline.

Belt Forces

Seat belt load cells were employed to collect belt force loading. Generally one device was located on the shoulder section and one on the lap belt area of each configuration. One exception was with the 4-point belt testing. For these tests a total of four (4) seat belt load cells were utilized to collect forces on both shoulder belts and each lap belt section.

Average seat belt loads for the shoulder and lap belts for the 5th percentile female are presented in Figures 13 and 14. The selected 3-point configurations from the excursion data were examined to determine how loading of the belt was affected by seat belt configuration and the technology utilized. Similar results were noticed with the 50th and 95th percentile male dummies.

A distinct spike in loading for pyrotechnic devices fired at approximately -0.7 seconds (45 degrees) was observed. After the deployment, the belt forces dropped to a holding level before being loaded by the dummy at impact. Immediately after impact, belt forces would peak at roughly the same value to restrain the full dummy's weight.

For many configurations, the shoulder belt would slip off the dummy post impact leaving it loose. This explains the noisy belt loading values observed beyond 0.2 seconds. The inflatable belt forces (K) were the highest from the pretensioner deployment in both the lap and shoulder portion of the belts.

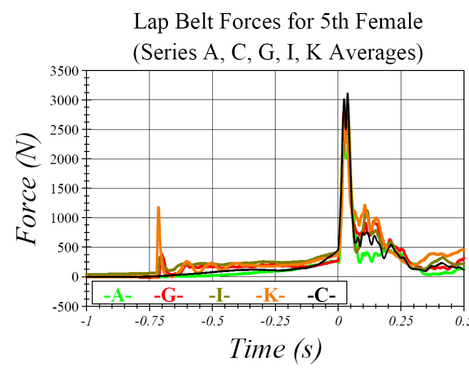

Figure 13. Average Lap Belt Forces for 5th Percentile Female Configurations A, C, G, I, and K.

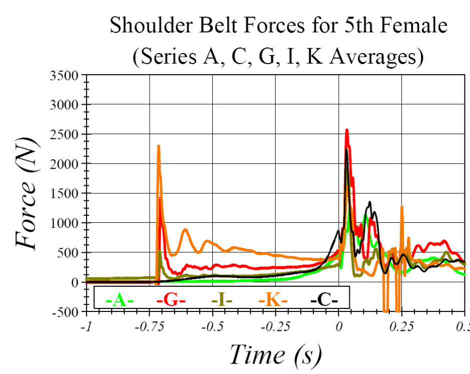

Figure 14. Average Shoulder Belt Forces for 5th Percentile Female Configurations A, C, G, I, and K.

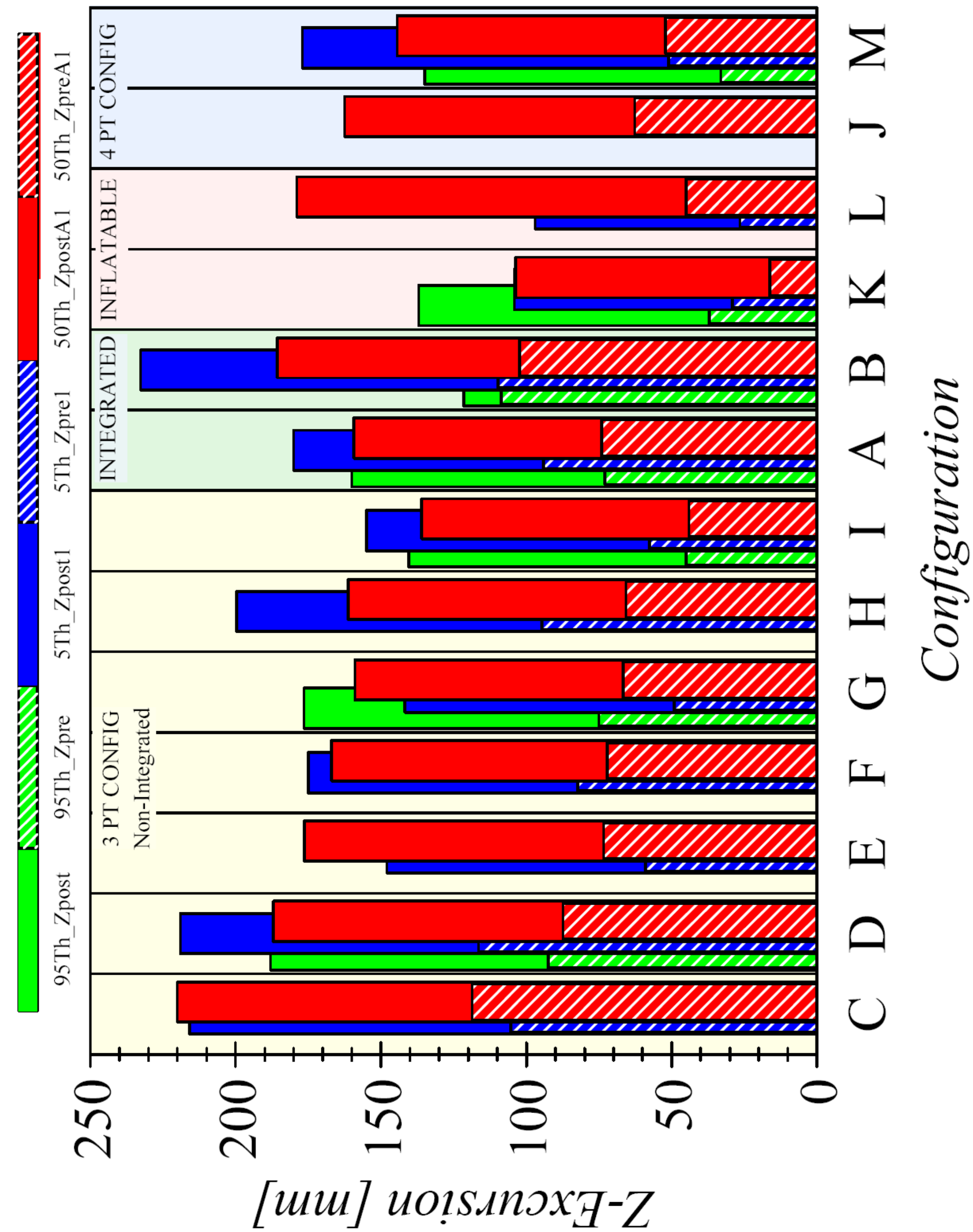

Figure 12. Average Pre (dashed)-and Post (solid) impact Z- Dummy Head Excursion for 5th (blue), 50th (red) and 95th (green) Hybrid III dummies

Fire Angle Comparison

A small study was conducted to look at the effect of the fire angle of the pyrotechnic pretensioners utilizing extra test hardware. The 50th percentile male dummy was used for this testing. Two configurations utilizing the most current production pretensioning were selected, G and I. The original testing was conducted at a fire angle of 45 degrees. The objective was to examine what would happen if the pyrotechnic devices were fired earlier or later in the pre impact phase. The two angles chosen were 30 degrees (earlier) and 60 degrees (later).

Figures 15 and 16 summarize the maximum average Y and Z excursions, respectively. Y_in excursion for the G configuration was reduced as the pyrotechnics were fired earlier. This configuration utilized both a retractor and buckle pyrotechnic device, and the result seems intuitive. For configuration I, utilizing the motorized retractor (activated at the initiation of roll) and a buckle pyrotechnic, the Y_in excursion was not significant between the different firing angles of the buckle.

Y_out excursions were less with the later fire angle (60 degrees) for the G configuration when compared to the earlier fire angles. It was observed that the initial inboard Y-direction motion can affect the final outboard position. During the pre-impact rollover, a dummy that moves far to the inside may not move far outboard by the time the test is completed. Overall lateral dummy movement (Y_in plus Y_out) is lower for the earlier (30 degree) fire angle for the G Configuration.

For the Z-direction, the pre-impact was reduced for the 30 degree fire angle compared to the 45 degree fire angle for the G configuration. There was no difference detected pre-impact between the 45 and 60 degree fire angles. The earlier fire angle (30) had the lowest post impact Z, suggesting that earlier fire time might lead to reduced excursion. Video of the testing shows that the shoulder belt slips off of the dummy's shoulder in the pre-impact phase for the 45 and 60 degree fire angles. The belts did stay on during the 30 degree fire angle tests pre-impact.

For configuration I, the pre-impact benefit was not noticed with earlier fire angles. This configuration utilizes motorized retractor early in the roll with the buckle pyrotechnic device fired at the prescribed angle. The 45 degree excursion was lower when compared to the other fire angles, but no clear trend was noticed.

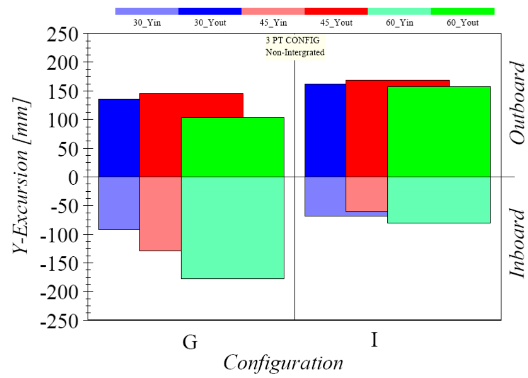

Figure 15. Average Pre-impact Y_inboard and Y_outboard direction Dummy Head Excursion at fire angle 30 degrees (blue), 45 degrees (red) and 60 degrees (green) for the Hybrid III 50th dummies.

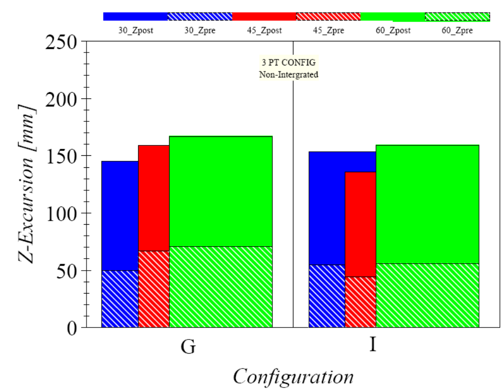

Figure 16. Average Pre (dashed) and Post (solid) Impact Z direction Dummy Head Excursion at fire angle 30 degrees (blue), 45 degrees (red) and 60 degrees (green) for the Hybrid III 50th dummies.

SUMMARY

A test series focused on restraint technologies for rollover crashes was conducted with the NHTSA RRT. The 5th female, 50th and 95th male percentile Hybrid III dummies were utilized. Several restraint systems were tested: 3-point non integrated belts, 3-point integrated belts, 3-point belts with various combinations of pretensioners, inflatable belts, and 4-point belt systems. Pretensioners were tested in various combinations with the 3-point and 4-point belts and several conditions at different fire angles. Each configuration simulated a roof-to-ground impact at 180 degrees with an angular speed of 320 degrees/second and was repeated 3 times.

Occupant excursions in the Y and Z direction were recorded with onboard high speed cameras and analyzed with digitizing software. Configuration C, no pretensioning, 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. 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 56% and 52% for the 5th percentile female and 50th percentile male dummies, respectively.

2. Pretensioners used with 3-point belts in all configurations reduced maximum dummy head excursions in both the Y and Z-directions in pre and post-impact of the RRT.

3. Motorized retractor pretensioners (H, I) activated at the initiation of roll reduced pre-impact excursion in the Y-direction by up to 65% and Z-direction head excursion up to 63%.

4. The inflatable belts (K,L) reduced Y_out excursion by up to 89% when compared to the baselines. Pre and Post impact Z-direction reductions were as high as 86% and 53%, respectively. These are similar reductions noticed by Rain, 1996.

5. The 4-pt belt (J,M), with 2 pyrotechnic retractors in both the shoulder and lap belt, reduced pre-impact Y_in motion by up to 74% and Z by up to 64%, however Y_out motion dummy head excursion increased as high as 45% when compared to the baseline. The upper shoulder belts slipped off all of the dummies near the end of the roll leading to increased Y_in motion. The two lower retractors were effective in holding down the pelvis of the dummy.

6. Belt loads increased in the pre-impact phase when pretensioners were activated when compared to the baseline without pretensioning. However, the observed maximum loading immediately after impact was similar across all configurations.

7. The effect of dummy size at a particular configuration demonstrated some variability; however the general trends of reduced excursion with implemented countermeasures appeared to follow across the dummy size.

8. Fire angles can affect the dummy excursion and should be considered for further evaluation with advanced restraint technologies.

9. These results suggest that restraint technologies tailored for rollover crash events may reduce occupant excursion toward the roof.

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