RESTRAINT EFFECTIVENESS DURING ROLLOVER MOTION

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ABSTRACT

A large number of restrained occupants of vehicles in the United States suffer severe head and neck injuries during rollover accidents. Occupant protection in rollover impacts can be provided through the use of many components, one of which is the restraint system. The ability of various restraint systems to control occupant kinematics and keep occupant heads away from potential injurious loading conditions is important in providing protection to restrained occupants in rollover impacts. An experimental study was conducted to assess the ability of various restraints to control human volunteer vertical motions.

THE EXCURSION ALLOWED by different production restraint systems for different occupant sizes in different seat positions in a rollover environment has not been reported. The degree to which various size occupants are allowed to move towards upper interior contacts during a rollover while wearing production belt systems has not been available. An experimental study was conducted to assess the ability of various restraints to control occupant motions toward the roof structure.

A rollover test device allowing for rotation rates observed in rollover accidents was used to conduct tests of a variety of lap and shoulder belt systems. Lap and shoulder belts, seats, compartment geometry, and anchor point locations from various production vehicles sold in the United States were incorporated into the rollover fixture. Tests were then conducted using live subjects. The level of the roof structure was identified but the roof was not in place. The excursion allowed by the various restraint systems was determined. Given the production headroom provided, the excursion observed can allow the head of an occupant to be on the roof of a vehicle in a rollover accident for many occupants. In addition, some tests were conducted to identify the effects of incorporating geometry associated with only a manual lap belt attached to the seat independent of the use of a torso belt, as well as the effects of a pre-tensioned 3 point belt attached to the seat. The results of the study show that the amount of head motion allowed toward the roof varies between various restraint designs and occupant sizes. Moreover, the results make clear that opportunities for improvement are available.

TEST DESCRIPTIONS

A simple fixture was used for testing vertical excursion associated with rotational accelerations and gravity. It allows for the attachment of a vehicle seat and restraint system (among other elements) in an adjustable manner, providing for ease in positioning the seat and anchor points. The fixture can be rotated at varying rates with typical rates of 100-300 degrees per second.

Seats and anchor point locations were used which were representative of selected vehicles. Since the tests were conducted at different times, protocols varied somewhat between groups of tests.

GROUP 1 PROTOCOL typically involved consideration of an occupant who was in an accident. The seat position and occupant sizes involved were used in these studies. In addition, in some tests the retractor was locked with belt positions fixed to reflect belt spool out positions observed in the accident for comparison.

Within Group 1, belt modifications were made to identify opportunities available for improvement by using belts with alternative anchor points and pre-tensioned webbing. Measurements of occupant excursion were made with a rapid rotation through at least 180 degrees. The fixture was stopped by operator resistance and the excursion was determined manually by direct comparison with pre test measurements relative to a reference bar. Between the tests the occupants would reset themselves by removing the belt, raising themselves out of the seat, and then reattaching the belt. The occupant was allowed to put the belt on normally; if the belt was not in a proper location it was corrected. Typically, three tests were conducted consecutively in a given configuration. In addition, in most configurations one test would be conducted in which at least one complete roll was completed with the excursions being recorded on video tape from a camera mounted on the fixture. The occupant's head is protected from impact with the simulated roof rails and other elements by a crash helmet.

GROUP 2 PROTOCOL used a small female, a medium male, and a large male occupant using stock belt systems and the seat from the corresponding vehicle. The occupants were positioned in front, middle and rear seat track locations respectively. The conditions used for these tests is shown in Table 1.

Table 1. Group 2 Test Conditions

CONDITION	SEAT POSITION	SEX	HEIGHT	WEIGHT	SEATED HEIGHT
A	FULL FORWARD	F	147 cm	53 kg	79 cm
B	MID	M	174 cm	75 kg	88 cm
C	FULL REAR	M	190 cm	107 kg	99 cm

Three different restraint systems were used representing a single manufacturer's products for different vehicle types and designs. For each test the excursion was recorded using two on-board video cameras while a third on-board camera recorded retractor/belt information. For each configuration, three tests were done in which there was at least 180 degrees of rotation with the retractors pre-locked. In addition, three tests were done in which there was 360 degrees of rotation without locking the retractors. After each test, the belt was released and then reattached. The Group 2 tests had rotation rates of about 100 degrees per second. Excursion measurements were recorded at 180 degrees of rotation before deceleration of the fixture occurred in this group of tests. Additionally, three tests in each configuration were done with only a manual lap belt as a comparison. The revised anchor points were selected consistent with SAE Vehicle Occupant Restraint Systems and Components Manual but moved with the seat cushion. In the Group 2 tests the occupant wore a helmet with a reference for video interpretation.

TEST RESULTS

THE TEST RESULTS for Group 1 tests are shown in Table 2 below.

Table 2
Group 1 Test Results

Restraint Type	Vehicle Type	Seat Position	Occupant Size (cm/kg/sex)			Excursion (cm)
Web Grab/pass-through latch plate	2 Door Car	Mid	170	64	F	14
Dual Spool/Single Pendulum	Pickup	Rear	185	95	M	25
Passive Door Mounted	2 Door Car	Mid	178	86	M	21
Dual Spool/Dual Pendulum	Utility	Mid Rear	173	71	M	19
Web Grab pass-through latch plate	Pickup	Mid	159	65	F	13

GROUP 2 results are shown in Table 3. The differences between the 180 degree and 360 degree tests generally appear small. However, rotation rate was only about 100 degrees per second.

Table 3
Group 2 Test Results

180 degree tests		Condition A	B	C
Passive door mounted	4Door A	19	18	23
Dual Spool/Dual Pendulum	Sport/Utility	12	16	17
Single Retractor/lockbar latch	4Door B	11	17	20
360 degree tests				
Passive Door Mounted	4 Door A	20	21	26
Dual Spool/Dual Pendulum	Sport/Utility	21	17	23
Single Retractor/lockbar latch	4 Door B	9	11	22

Manual lap belt - The use of only the manual lap belt produced the results shown in Table 4. The manual lap belt was simply put on comfortably without special tightening. Without the torso belt there was substantial erection of the torso.

Table 4
Excursion (cm) with Manual Lap Belt

Vehicle	180 degree tests Condition			360 degree tests Condition		
	A	B	C	A	B	C
Sport/Utility	5	5	15	5	6	14
4 Door A	8	7	15	9	7	20
4 Door B	5	9	16	7	7	18

PRE-TENSIONED BELTS - For the pre-tensioned webbing tests the anchor points were moved to represent a more vertical orientation, approximately 70 degrees, with attachment on the seat frame for both the lap and shoulder portions. Belts were tightened to a load of approximately 23 Newtons. It was observed that the tightening of the belt makes use of the seat to provide additional occupant space by pulling the occupant further into the seat cushion. The excursion shown in Table 5 is relative to the initial head position prior to belt tightening.

Table 5
Pretension Mockup Tests

Height	Weight	Sex	Excursion
170 cm	64 kg	Female	2 cm
178 cm	89 kg	Male	3 cm

DISCUSSION

Rollovers, in general, are the most benign impacts in terms of the time frame and distance over which the vehicle is decelerated and the magnitude of the accelerations sustained by the vehicle. Appropriate occupant packaging, restraint, glazing, padding, and seat, door, and roof design are required to ensure that severe head and neck injuries are prevented in foreseeable rollover impacts. The belt performance is an important element in determining the requirements placed on other parts of the occupant protection system in rollover impacts.

The excursion observed in the stock production systems in these tests ranged from 13 to 26 cm. For many occupants such motion is sufficient for head contact, and associated neck loads and flexion, with upper interior structures in many current vehicle designs. Real world rollovers occur over a range of roll angles and orientations; therefore other belted occupant excursions may occur under other conditions and circumstances.

For effective occupant protection in rollovers the motion allowed by the belt system must be taken into account. Consideration should be given to the excursion allowed by the restraint system over the range of occupant sizes and seat positions. With the belts attached to the seat, the considerations can then be focused on the range of occupant sizes.

During testing with the three point pre-tensioned webbing, it was found that controlling the shoulder with the torso belt was important in reducing head excursion. This is consistent with the lap belt only test in which much of the head excursion observed was due to the erection of the torso; it was particularly noticeable in the large male case. Thus strategies for incorporating control of the upper torso motion appear to be an important tool available in providing occupant protection in rollovers.

The use of the space contained within the occupant seat cushion offers opportunities for increasing the occupant survival space by pulling the occupant into the seat, or through other mechanisms to utilize the seat in the occupant protection system approach.

Most investigators would agree that serious head and neck injury in rollover accidents could be avoided by ensuring that no injurious contacts occur with the upper interior structure. Rains and Kanianthra (1995) showed from the 1988-1992 NASS files, that for restrained occupants average residual headroom (the difference between headroom over an occupant before and after a rollover as a result of roof crush) was 6 cm more for uninjured as compared to injured restrained occupants. In a separate, but related study, Friedman (1996) found that there was a substantial difference in average residual headroom between restrained occupants with serious head and neck injuries and those with less serious head/neck injuries or no head/neck injuries.

The implication from these studies is that reducing restraint excursion may play an important role in reducing the occurrence of head and neck injury in rollovers. The potential role of roof strength in the prevention of serious head and neck injury in rollovers has been confounded and obscured in field evaluations of current vehicles by restraint systems which are ineffective in controlling excursion. But the residual headroom concept incorporates the effect of roof crush in rollover injuries, and the aforementioned studies imply that increasing roof strength to limit roof crush is another important mitigating factor in reducing injury. It seems likely then, that a combination of increased roof strength and reduced restraint excursion, among other alternative measures, will prove effective in mitigating rollover injury.

Effective occupant protection for restrained occupants in rollovers depends on providing and maintaining survival space to prevent for example, severe neck injuries, injuries associated with partial ejection, and head injuries. It appears that in many vehicles for many occupants there may not be a sufficient survival space in rollovers. The survival space can be provided through changes in compartment geometry and seat position, the use of improved seat and belt systems and increased roof strength.

REFERENCES

Friedman, K., Friedman D., "Improved Vehicle Design for the Prevention of Severe Head and Neck Injuries to Restrained Occupants in Rollover Accidents," 15th International Technical Conference on the Enhanced Safety of Vehicles (ESV), 96-S5-0-14.

Rains, C. R., Kanianthra, J.N., "Determination of the significance of roof crush to passenger vehicle occupants in rollover crashes," SAE 950655.