FACTORS IN ROLLOVER NECK INJURY POTENTIAL

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ABSTRACT

The effect of roof crush on occupant injury in rollovers has been the subject of a considerable number of technical publications. One very simple way to determine whether occupant injuries result from roof crush is to conduct pairs of inverted drop tests with instrumented test dummies and to compare the results between stock deformable roofs and structurally modified roofs. This was done in 1990 in a study conducted by General Motors. [1] This study compared the axial neck load, in restrained instrumented Hybrid III test dummies in drop tests with stock production vehicles, against those with roll cages. The authors concluded that roof crush was not causal to injury. Much of the literature has addressed this study and the general consensus is that there are many fatal flaws in the GM study. We have endeavored to expand the knowledge base and conduct additional drop tests to explore this idea further. Our tests have shown a clear and direct link between roof crush and injury.

INTRODUCTION

In inverted drop tests, a vehicle is suspended upside down and dropped onto the ground to produce roof damage, which can be compared with real world rollover accidents. These drop tests produce repeatable roof impacts which can be used to compare the results of one test to another. Inverted drop tests have long been used by the automotive industry and researchers to test roof integrity. Several automobile manufacturers routinely conduct inverted drop tests as part of their regular vehicle testing matrix. Inverted drop tests are currently being considered by the National Highway Traffic Safety Administration (NHTSA) as an alternative roof strength test to FMVSS #216.

Based on the methodology used by General Motors, the authors have conducted, and previously published, inverted drop tests on a pair of domestic small sedans. [2,3] A stock vehicle was dropped from a height of about 46 cm with a roll angle of 16 degrees and a pitch angle of 7 degrees. The axial neck loads generated in a Hybrid III Anthropomorphic Test Dummy (ATD) in the unmodified vehicle were about 9,730 N with 16 cm of roof crush. Another vehicle with structural roof modifications was dropped in an identical manner using the same protocol. The axial neck loads generated in the HYBRID III were about 1,283 N with about 9 cm of roof crush. While there is still some disagreement in the literature about injury levels for specific axial neck loads, the 1,283 N value would be considered by virtually all investigators to be non-injurious and the 9,730 N value would likewise be considered to have a high probability of neck injury. These results clearly show a direct link between roof crush and injury. The string potentiometer indicated that roof crush preceded neck loading in both cases.

Also previously published are the results of inverted drop tests conducted on a pair of full size domestic vans. (4) These tests were conducted without ATD's and the drop height was 43 cm. The roof crush generated in the stock vehicle was 32 cm while the roof crush generated in the modified vehicle was 12 cm (a reduction in roof crush of 63%).

METHODOLOGY

An inverted drop test (Test 1) was previously performed by another facility on a full size domestic van with a roll-caged vehicle. The roll cage was installed about 15 cm below the roof level over the occupant. A restrained Hybrid III test dummy was placed in the front seat compartment and lowered so that the head was with 3 cm of the roof while the vehicle was inverted. In effect, this was the same as testing an un-modified vehicle with a restraint system that was ineffective or spooled-out. The Hybrid III recorded a peak axial force of 9159 N.

The authors obtained an equivalent full size domestic van and structurally modified it. The modifications included a B-pillar area roll bar and structural foam filling. The inner B-post and B-pillar sheet metal was removed and a 5cm diameter tube was inserted inside the cavity. This tube extended up both B-posts, through both B-pillars and across the inside of the roof panel. After installation, the interior trim was reattached and the roll bar was effectively concealed. Both side headers, both A-pillars and the front header were filled with rigid polyurethane foam. Previous studies by the authors have shown that structural foam can significantly increase the strength of roof structural elements. [5,6] The interior was then outfitted with a string potentiometer to measure dummy excursion towards the roof. In addition, tri-axial accelerometers were installed at floor pan in several locations.

A HYBRID III was positioned in the front seating compartment. The production restraints were applied in a fashion consistent with normal occupant use without any pre-tensioning. The vehicle was then inverted via a vehicle rotational mechanism, which allowed the occupant to move towards the roof to the degree allowed by the restraint system. The vehicle was then oriented similar to the previously described inverted drop test, Test 1. The vehicle was dropped onto the top of the A-pillar from a height of 61 cm with a roll angle of 10 degrees and a pitch angle of 5 degrees.

RESULTS

When dropped, the vehicle roof in Test 2 crushed only about 3.3 cm vertically. The HYBRID III moved somewhat towards the roof and made light head-to-roof contact as shown by a transfer of colored chalk from the head to the roof. The resulting axial neck loads generated in the Hybrid III were about 1,207 N. Again, this is well below any published threshold for significant occupant injury. Clearly, this test shows that even from a drop height of 61 cm and with a speed of almost 8 mph, an occupant can be protected from injury with limited roof crush and adequate restraints. As compared to Test 1, reduced roof crush and improved restraint resulted in significantly reduced axial neck loads. The neck axial loads went from 9,159 N (high probability of serious injury) to 1,207 N (extremely low probability of serious injury). These tests confirm that a reduction of roof intrusion can significantly enhance occupant protection. A summary of results can be found in Table 1.

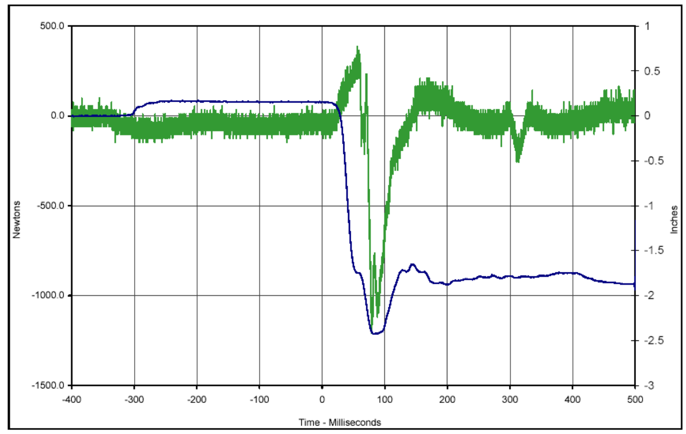
Table 1 – Test Measurements and Results

	Test 1	Test 2
Head to Roof Clearance	22.6 cm	22.6 cm
Head to Roof Clearance Inverted	2.5 cm	15.2 cm
Vertical Excursion-Static	20.1 cm	7.4 cm
Vertical Excursion - Dynamic	----	6.4 cm
Approx. Static Vertical Roof Crush	15.2 cm	3.3 cm
Peak Axial Neck Load	9159 N	1207 N

The primary differences between the two tests were static occupant excursion of 20.1 cm versus 7.4 cm and roof crush approximately 15.2 cm versus 3.3 cm. In Test 1, analysis of high-speed film and data indicates that the small amount of head to roof clearance and high degree of roof crush subsequently results in significant neck loads. In test 2, analysis of high-speed film and data contained in Figure 1 demonstrate that the roof crush clearly preceded the initial neck loading, the peak neck loading and the occupant vertical excursion. The peak neck load is minimized by the combination of increased head-to-roof clearance via restraint performance and reduced roof crush.

CONCLUSIONS:

- The degree of neck axial force and therefore injury potential is a function of the initial head-to-roof clearance, the restraint effectiveness and the degree of roof crush
- Structural reinforcements to the roof resulted in significantly reduced roof crush.
- Roof crush preceded initial and peak axial neck loading.
- Interior contacts occurred in inverted impact environments without significant injury measures.
- Axial compression loading of the Hybrid III during inverted impacts can be limited to below injury thresholds when adequate roof strength, effective occupant restraint and appropriate initial occupant survival space are present.



Curve Description	CURNO	Type	Units	Max	Time	Min	Time	SAE Class
Occupant Displacement			Inches	0.2	4.3	-2.4	83.0	180
Occupant Neck Force Z			Newtons	385.3	56.6	-1207.4	79.0	1000

Figure 1. Test 2 Data Plots

Previous work by the authors [7] describes that the HYBRID III neck is far from biofidelic in rollovers. It vastly over represents the likely injury potential due to its extremely stiff nature in low speed impacts. With this in mind, however, the HYBRID III can still be a useful tool insofar that if the designers can protect the highly sensitive HYBRID III neck from compression injury measures, they will likely protect occupants from the normally received flexion type injuries as well. Flexion injuries in humans require significantly more roof crush than the compression injury measures experienced by the HYBRID III.

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