

Effects of Safety Belt Pretensioning on ATD Motion in Rigid Fixture Rollover Testing

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ABSTRACT

General Motors conducted a series of subsystem rigid fixture sled rollover tests to evaluate the effects of various safety belt pyrotechnic pretensioners on Anthropomorphic Test Device (ATD) head motion. Twelve tests were conducted using a rigid fixture comprised of a modified compact sport utility vehicle (SUV) body encased in a rigid exoskeleton. The testing simulated the pre-trip/trip, free flight and first roof to ground impact phases of a field representative curb trip initiation rollover crash test with a roof to ground impact angle of approximately 180 degrees. Various combinations of safety belt lap anchor, buckle and retractor pretensioners were tested and film analysis was used to measure trailing side ATD head motion relative to the vehicle. Additionally, a new analysis technique of measuring the reduction of lap webbing length during the crash event was developed for evaluating the ability of a restraint system to reduce ATD head motion during the rollover tests. The results indicated that with deployment times prior to occupant belt loading, certain pretensioner combinations were able to reduce the lateral and vertical motion of the trailing side ATD head when compared to non-pretensioner baseline tests.

INTRODUCTION

The effectiveness of safety belts in reducing serious injuries and fatalities in motor vehicle collisions is well known. Over the years numerous features have been added to safety belts to further address the comfort, convenience of use, occupant kinematics and energy management. Safety belt pretensioners are one of the technologies used in many restraint systems during the last decade. This technology is used within the safety belt system to help tighten the webbing in the system for

earlier restraint of the occupant during the onset of moderate to severe crashes. The evaluation of the performance of safety belt systems with pretensioners has occurred primarily in standardized frontal planar tests. To date, few studies have been published that evaluate safety belts with pretensioners in rollover events due to the difficulty of conducting a repeatable field relevant rollover test.

Real world vehicle rollovers are chaotic events, varying in type and severity. The National Highway Traffic Safety Administration (NHTSA) has devised a method to categorize rollover types by the method of rollover initiation and severity by the number of vehicle $\frac{1}{4}$ turns. As described by O'Brien-Mitchell, et. al. [1], the field data indicates that the trip-over is the most frequent rollover initiation type and that 84% of the rollovers in the field are one full roll (four $\frac{1}{4}$ turns) or less.

In 2010 General Motors reported on a subsystem level rollover test method that provided a repeatable simulation of a rollover curb trip initiation crash test up to the first roof-to-ground impact [2]. The same twelve tests were also utilized to evaluate the effects of safety belt pretensioning on trailing side ATD head motion during rollover crash simulations. The tests involved combinations of up to three pretensioners and two deployment times and were used to assess the effect of pretensioners on ATD kinematics during the pre-trip/trip, free flight and first roof to ground impact phase of the rollover curb-trip initiation test event. The results of this study are reported in this paper.

BACKGROUND

Prior studies have evaluated the effectiveness of pretensioners on limiting occupant motion during a rollover test. Most of these studies have focused on a single pretensioner in tests representing various subsets of the pretrip/trip, free flight and/or impact phases of a vehicle rollover.

Some early research to evaluate pretensioner performance in full scale dolly rollover testing was reported by Hare, et. al. [3]. This paper reported the results of eight modified Federal Motor Vehicle Safety Standard (FMVSS) 208 dolly rollover tests using midsize SUVs containing belted driver and passenger ATDs. The FMVSS 208 dolly rollover test method was modified to simulate a pre-trip phase. The safety belts utilized were three point continuous loop safety belts with and without retractor pretensioners. Pretensioners were deployed in three of the eight tests. Deployment of the pretensioners was performed remotely based on roll rate and angle from an initial test since rollover sensors had not been developed for the vehicles tested. The deployment of the pretensioner occurred at 383 milliseconds after time zero (dolly contact with the snubber).

Hare, et al opined that even if sensor technology was available to appropriately activate the pretensioners in a rollover crash, based on the partial data collected, the maximum occupant injury values did not indicate any improved protection for the tests with pretensioners activated as compared to those without pretensioners. While this study did evaluate restraint performance during the pre-trip/trip, free flight and impact phases of a rollover event, it did not evaluate various pretensioner types, multiple pretensioner combinations, and different deployment times nor were ATD vertical and lateral excursions quantified or reported.

In 2005 Summers et al [4] and in 2007 and 2009 Sword et. al. [5, 6] reported on a series of subsystem level tests using the NHTSA Rollover Restraints Tester (RRT). The tests included evaluation of trailing side ATD head excursion. A 180 degree roll with impact was simulated which represented the free flight and impact phases of a rollover event. The RRT did not simulate the pretrip/trip phase of a vehicle rollover. The restraint configurations tested included buckle pretensioners, lap anchor pretensioners, retractor pretensioners individually, and a combination of buckle and retractor pretensioners. Various deployment times were utilized in the tests. The research reported that for the tested conditions the pretensioners in all configurations reduced head excursion in the lateral and vertical directions compared with a non-pretensioned baseline configuration. It was also concluded that pretensioner deployment time was critical and should be further studied.

In 2007 McCoy et al reported the results of 15 tests of a midsize SUV encased in a rigid exoskeleton fixture described as Rollover Component Test System (ROCS) [7]. The tests were

designed to simulate a 24 mph driver side leading curb trip and included the pretrip/trip, free flight and impact phases of a rollover event. The tests included 5th, 50th, and 95th percentile ATDs in both the driver and right front passenger seating positions. Lateral and vertical head displacements were measured. Safety belt configurations included load limiting retractors, motorized retractors, and buckle pretensioners activated at various times. Multiple pretensioner combinations were not considered. It was reported that the ability of the buckle pretensioners to reduce vertical excursion was limited primarily to the free flight phase of the rollover. The authors also noted that for the pretensioner to affect vertical excursion during the free flight phase, the pretensioner needed to be activated prior to the vehicle "roll initiation phase". Despite the reduction in vertical excursion achieved with the buckle pretensioner, the safety belt configurations tested were not able to prevent any of the 50th and 95th percentile trailing side ATDs from contacting the upper interior of the vehicle during the ground contact phase. The authors reported that only one test resulted in no ATD head contact (5th percentile leading side) with the upper interior.

In 2010 McCoy reported the results of additional ROCS testing [8]. Sixteen tests used a midsize SUV rigid exoskeleton fixture, and six tests used a mid size car rigid exoskeleton fixture. The tests were intended to simulate a 24 mph driver side leading curb trip. 50th percentile ATDs were placed in the driver and right front passenger seating positions. Safety belt configurations tested included lap anchor pretensioners, and buckle pretensioners, but no combinations of the two. ATD neck loads were measured but excursion was not reported. It was reported that activation of pretensioners alone did not prevent the ATDs from contacting the roof, and had limited effect on neck loading in general. However, activation of side curtain bags along with pretensioners early in the event appeared to influence leading side ATD excursion and neck loads, but not for the trailing side ATD.

The prior work discussed above did not address multiple pretensioner combinations during the three phases of a rollover event. This study builds upon the prior research by evaluating a combination of different pretensioner types deployed using production representative deployment times with a test procedure that simulates the pre-trip/trip, free flight and initial impact phases of a laboratory version of a particular curb-tripped rollover.

TEST DESCRIPTION

Twelve tests were conducted to evaluate the performance of different pretensioner combinations in limiting ATD head motion in a given rollover crash simulation. The test methodology was based on testing that utilized a deceleration sled designed to simulate a vehicle curb trip rollover event as described by O'Brien-Mitchell et. al. [1]. This test method allows the vehicle to undergo the pretrip/trip, free flight

rotation, and first roof-to-ground impact phases of a tripped vehicle rollover event (Figure 1). The rigid fixture was tethered and consequently the rollover event was limited to only two quarter turns.

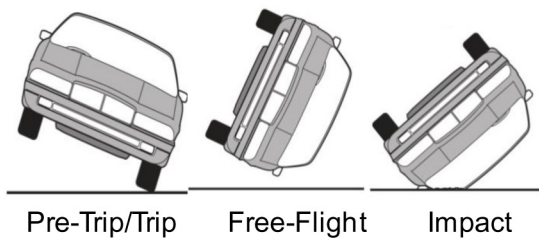


Figure 1. Three Phases of a Tripped Rollover Event

The test series reported on in this paper utilized the test deceleration sled methodology. However, instead of testing a complete vehicle, one compact SUV body with a steel exoskeleton fabricated around the vehicle body was used for all tests. The rigid fixture allowed for repeated roof-to-ground impacts without sustaining significant deformation. There were no drive train or suspension components attached to the body. Two pneumatic bladders, located near where the leading-side wheels would have been, allowed for lateral and vertical movement of the rigid vehicle fixture during the lateral deceleration.

TEST SETUP

The rigid fixture was placed against a two inch high curb on the sled (Figure 2) with the right (passenger) side leading in the direction of travel. The sled was gradually accelerated to a constant lateral velocity before the trip was induced by a braking system. In response to the sled deceleration the rigid fixture began to rotate and continued to translate laterally until it contacted an impact platform. Parameter runs were conducted in order to adjust the fixture motion to result in a fixture to ground impact at a fixture roll angle of approximately 180 degrees. This angle of impact was chosen because it was expected to result in the greatest unobstructed motion of the ATD head and therefore, provide the greatest opportunity to evaluate ATD head excursion. A roll angle of 180 degrees is also consistent with the impact roll angle used in several previous studies [4, 5, 6, 7, 8]. To achieve this, six inch vertical extensions were added to elevate the fixture, and it was determined to use a nominal sled test speed of 35.4 km/h. An impact platform was fabricated utilizing a structural steel frame with a plywood face that was positioned horizontally over tires placed on the floor. The objective of the impact platform was to reduce the acceleration of the rigid fixture at ground impact. After the rigid fixture impacted the platform, the fixture motion was arrested by tethers attached at front and rear locations on the leading side of the fixture limiting the event to two quarter turns. All twelve tests utilized these same input variables. Three off-board cameras were used to record

the motion of the rigid vehicle fixture from the front, side and rear. The test methodology provided repeatable fixture motion through the first roof-to-ground impact, as demonstrated in the roll rate time histories plotted in Figure 3. For additional details on the repeatability of these twelve tests, see the report by Cassatta et. al. "Subsystem Rollover Tests for the Evaluation of ATD Kinematics and Restraints" [2]. In all twelve tests the rigid fixture achieved a roll rate of approximately 250 degrees/sec and contacted the impact platform at about 800 ms into the test.



Figure 2. Rigid Fixture on Sled

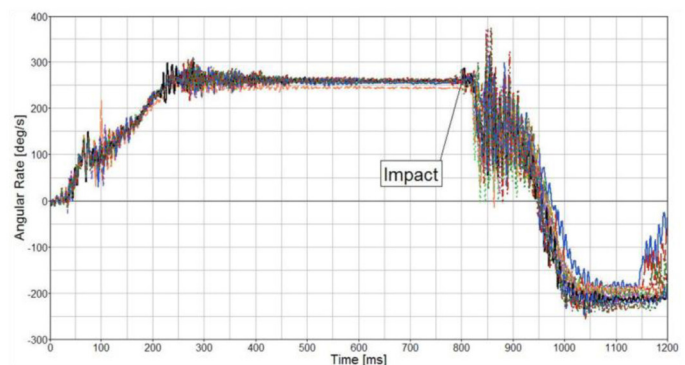


Figure 3. Rigid Fixture Sled Tests: Roll Rate vs. Time

The test series was conducted with a Hybrid III 50th percentile ATD that conformed to FMVSS 208 Part 572. The ATD was belted in the driver seat (representing a trailing side occupant). The compact SUV body within the fixture was modified by removing the headliner, reconfiguring the driver side roof rail and reinforcing the roof above the ATD. These modifications were made to improve the repeatability of potential ATD head to roof contacts and to provide for better video coverage of the ATD head.

One modified production seat assembly was used for all twelve tests. The use of the same seat for all tests contributed to some test to test variation of the ATD initial head target position in the rigid fixture. This variation was due to seat cushion shape changes from repeated usage and is consistent with the typical

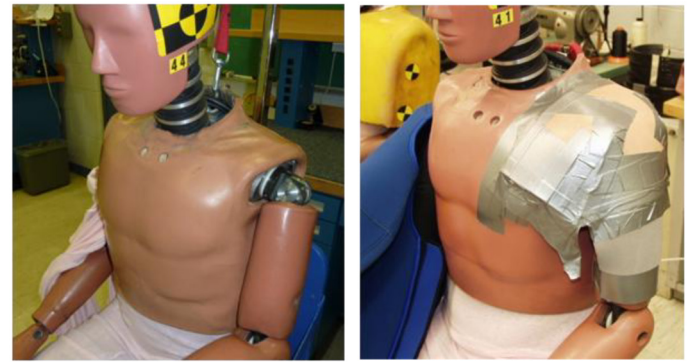
variation experienced with ATD positioning in vehicle crash testing. As called out in FMVSS 208, the seat was positioned in the middle fore/aft position and the seat height was fixed in the full down position in all tests. The seat back angle was fixed at 4.9 degrees rearward of vertical as measured at the head restraint post. The seat assembly was reinforced to facilitate its re-use and the safety belt anchorages were modified to accept the various safety belt buckles, buckle pretensioners and outboard lap anchor pretensioners. The head restraint was removed from the seat to allow for ATD head motion analysis using an onboard camera positioned behind the ATD.

The three-point continuous loop safety belt restraint system consisted mainly of a B-pillar mounted retractor, a B-pillar mounted adjustable guide loop, a free falling latch plate and an end release buckle. The buckle assembly and the outboard lap anchor were both attached to the seat structure. All of the tests used the same design retractor assembly which included the webbing, latch plate and guide loop. The retractor assembly and buckle assembly were replaced after each test. Some tests used outboard lap anchor pretensioners and/or buckle pretensioners. The retractors used in all tests were a production design used in a compact SUV and each incorporated a pyrotechnic pretensioning device as well as a load limiter. The prototype buckle and lap anchor pretensioners were also pyrotechnic. For all tests, the adjustable shoulder belt guide loop was positioned one notch below the full up position. Three onboard cameras provided views of the buckle/latch plate, retractor and a front view of the ATD.

Three modifications were made to the ATD to facilitate testing. First, the right forearm and hand of the ATD were removed and replaced with a ballast weight to obtain un-obscured visual access to the safety belt webbing near the latch plate during the testing. Secondly, during the parameter runs, the shoulder belt webbing moved off the ATD shoulder and became trapped in the top of the shoulder to arm joint. This affected the position of the webbing on the ATD and consequently influenced the subsequent lateral and vertical ATD motion. To make more realistic the webbing interaction on the ATD shoulder, the ATD left shoulder region was modified by securing a leather patch around it as shown in Figure 4. The patch inhibited the rotation of the upper arm but allowed safety belt webbing to transfer over the joint without embedding in the joint during the tests. Finally, the left hand of the ATD was tethered to the left thigh to mitigate the potential for arm flail that might cause the leather patch to separate from the shoulder during the testing.

Time history data was recorded for each of the following:

- Rigid fixture roll rate
- Acceleration under driver seat (x,y,z)
- Acceleration under right front passenger seat (x,y,z)
- Acceleration at SDM (x,y,z)



Unmodified

Modified

Figure 4. ATD Shoulder Modifications

- Acceleration at rollover sensor location (x,y,z)
- Acceleration of sled (x,y,z)
- Safety belt pretensioner deployment time(s) (if applicable)
- Safety belt webbing load at lap
- Safety belt webbing load at shoulder
- Safety belt webbing load at retractor
- Safety belt webbing displacement at retractor
- ATD head acceleration (x,y,z)
- ATD chest acceleration (x,y,z)
- ATD upper neck forces and moments
- ATD pelvis acceleration (x,y,z)
- ATD head to roof contact

For all of the instrumentation and cameras, time zero occurred when the sled contacted the braking system.

The pretensioner configuration for each test, along with the corresponding deployment time(s) are shown in Table 1. As stated earlier, all tests used retractors with built in pretensioners however, in some tests, they were not deployed. In a test where the retractor pretensioner was not deployed, “N/D” is listed in Table 1 and the test is considered to be a “no retractor pretensioner” test. When a lap anchor pretensioner or buckle pretensioner was not used in a given test, “--” is listed in Table 1. In tests without buckle pretensioners or lap anchor pretensioners, conventional end release buckle assemblies and lap anchors were used.

The pretensioner deployment times were generated by evaluating roll rate and acceleration data generated during the parameter runs of the rigid fixture sled series using a rollover sensing system calibration that was developed for a compact SUV. This sensor calibration had two deployment thresholds, one that was more predictive/sensitive and one that was less