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ABSTRACT

There are many factors that must be considered when designing a restraint system. The way the components function as a system and the design of the system's components are among these factors. While there are several tests required by the US Federal Motor Vehicle Safety Standards, not all factors are addressed.

This paper will address the resistance of a seat belt buckle to accidental or inadvertent release. The test procedure deals with the design of the buckle only and does not consider other important factors such as placement or shielding. There have been numerous reports where occupants are found unrestrained following a crash even though evidence, such as witness statements, use and custom or clear physical findings, indicates the occupant was belted. It is believed by many that some of these cases are the result of inadvertent buckle release. Such a release occurred during a test program conducted and was the result of contact to the buckle release button by the arm of the test dummy. Similar results have been reported by other researchers and test facilities. The test procedure included in this paper was developed to assess the ability of a buckle to remain engaged when subject to the application of a sphere to the release button as discussed in the European standards. It is hypothesized that the more difficult it is to actuate the buckle release mechanism with the sphere, the less likely it will inadvertently release in a crash. The ability of a buckle to remain latched unless deliberately released is a basic and fundamental requirement of good restraint system design.

The paper will present the test procedure as well as test results from a sample test program conducted by the authors.

INTRODUCTION

There are many factors to consider when designing a seat belt buckle, these include the buckle's mounted location, latch plate design, and buckle performance to name a few. While there are requirements that the restraint system buckle must meet in the Federal Motor Vehicle Safety Standards (FMVSS), there are additional tests that should be conducted to verify an acceptable design.

The ability of a buckle to remain latched unless deliberately released is a basic and fundamental requirement of good restraint system design. There have been numerous reported cases where an occupant is found unrestrained following a crash even though evidence, use and custom and witness statements, indicate the occupant was belted. In some of these cases there has been objective evidence and in some cases physical marks that independently supports belt use by the occupant. Yet in other cases there has been no objective findings to clearly indicate belt use by the occupant. More recently there have been instances where "black box" data has indicated belt use by an occupant early in the crash sequence where post-crash the belt is found unbuckled.

Generally a seat belt system becomes unbuckled in the course of a crash for one of two reasons, excluding false latches. The buckle was either inertially released, i.e. it could be opened due to contact on a non-release button surface, or inadvertently released, i.e. the buckle release mechanism is actuated during the crash. In either case a buckle that releases or opens during a crash violates the most basic concept of occupant protection. While both mechanisms pose a serious risk of injury or death to an occupant in a crash, only the inadvertent release will be discussed in this paper.

In addition to the reported cases of inadvertent release occurring in real world crashes, there are cases where it has occurred during controlled testing and published literature. Rechnitzer et al. reported that some buckles maybe vulnerable to opening through occupant contact during rollovers [1]. Also the authors of this paper have seen inadvertent release in numerous tests conducted by various vehicle manufacturers. Additionally, in a rollover test conducted by the authors of a vehicle with a prototype restraint system, the belt system was seen to release during the rollover. It had been verified prior to the test that the belt was buckled and remained buckled during the beginning phase of the rollover. However, it was found to be unbuckled after the test. Analysis of the in vehicle video of this test confirmed that the test manikins arm was moving towards the buckle just prior to the release. It was concluded the flailing arms of the dummy contacted the release button of the buckle, thus causing the release [2]. The buckle used on this prototype was taken from a production vehicle and integrated to the prototype seating system. This buckle had a non-enclosed release button as shown in Figure 1.

Figure 1. Buckle with Non-enclosed Button

It was this non-enclosed design and its placement which allowed the button to be depressed by the flailing arm/hand and release. The buckle was changed to the enclosed design on all latter prototypes as shown in Figure 2.

Figure 2. Buckle with Enclosed Button

While the non-enclosed buckle was well protected from inadvertent actuation by its location in proximity to the center console in its original application as shown in Figure 3, it was not protected on the system tested in the rollover tests as seen in Figure 4.

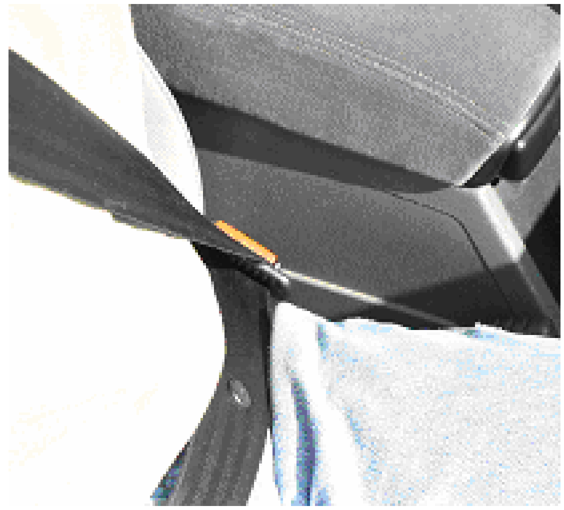

Figure 3. Non-enclosed Button in Original Application

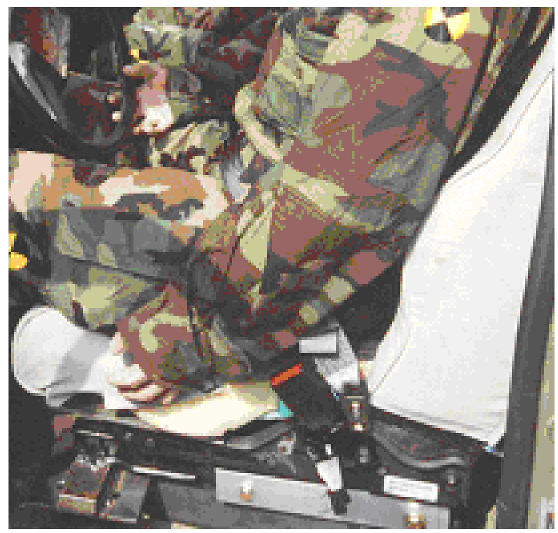

Figure 4. Non-enclosed Button in Prototype Application

As was demonstrated in the rollover testing, it is very important to protect the buckle from inadvertent release. As shown above, this can be done by installing or positioning the buckle itself to reduce the potential for contact during a crash or by designing the buckle to have a button that is difficult to inadvertently depress to such an extent to cause a release. This can also be done through design of the latch plate to guard the release button from inadvertent contact.

TEST PROCEDURE DEVELOPMENT

The need to install a buckle in an unprotected location, as was shown in Figure 4, innovate a buckle design that is resistant to being inadvertently depressed enough to cause a release. This led to the development of an objective, scientific and repeatable method to evaluate a buckle release button's resistance to being inadvertently depressed enough to cause a release.

Investigation showed that there were no requirements or tests to measure a buckle's ability to resist inadvertent release in the US Federal Motor Vehicle Safety Standards. The European standards do contain a section implying a test that investigates the ability of a buckle to be depressed with a sphere. This is a requirement in ECE Regulation 16 (Paragraph 2.26 in 11 August 2000 version). ECE Regulation 16, paragraph 2.26 states that an enclosed buckle shall have a "… buckle-release button such that it must not be possible to release the buckle using a sphere having a diameter of 40 mm." Additionally, it has been reported that at least two major automobile manufacturers have made statements indicating that they would not use a buckle that releases during a 40 mm sphere test in their vehicles.

The ECE Regulation 16 requirement does not contain written test procedures to verify compliance with paragraph 2.26. In addition, no written test procedures were found in European regulations, United Nations regulations, Society of Automotive Engineer (SAE) recommended practices or U.S. Federal Motor Vehicle Safety Standards (FMVSS). Due to the lack of an available test procedure, the procedures contained herein were developed. The scientific basis for these procedures include U.S. FMVSS test procedures, SAE Recommended Practices J140 and J141, and ASTM E860-97. These procedures were then peer reviewed by a panel of engineers and scientists to ensure that they followed sound scientific methods.

The procedures were developed based on the test set up specified in FMVSS 209 to test the overall strength of a seat belt system (paragraph S5.3). The actual tension used in this new test procedure is the same as tensions that are used by FMVSS 209 (paragraph S4.3(j)). The buckle latch plate (tongue) inversion test portion of these procedures is also based on FMVSS 209 (paragraph S5.3(b)(6)). The buckle release portion of the test procedure then utilized the specified diameter sphere, 40 mm, to demonstrate its compliance to the ECE Regulation 16. Additionally, testing was performed with a 30 mm diameter sphere, a more stringent requirement to which reportedly the belt systems of some automobile and restraint system manufacturers are using as a design goal. It is expected that the if this smaller sphere can not actuate the release mechanism of the buckle the more unlikely it is that an inadvertent strike by a hand, elbow or other object will result in a release.

Test Procedure

The test procedure detailed below was developed to conduct tests using a 40 and 30 mm diameter sphere. Appropriate steps need to be deleted if only one size sphere is to be used. Likewise, steps could be added if more spheres in addition to the aforementioned sizes are to be used.

Test Specimen Preparation:

1. The test specimens should be buckles with mating latch plates and webbing.
2. This set up assumes a standard continuous loop lap and shoulder belt assembly with a single retractor mounted to the shoulder belt portion. For a system other than this, appropriate deviations will be required but should be clearly called out on the test data sheets.
3. The set up is designed to be similar to the test set-up of Federal Motor Vehicle Safety Standard (FMVSS) 209 for the seat belt assembly performance [3]. Figure 5 from FMVSS 209 shows the test setup and is shown in Figure 5, two photographs of the actual test setup are shown in Figures 6 and 7.
4. Assemble the Bench Top Testing Fixture (BTTF) as shown in Figures 5, 6 and 7 and secure the BTTF to a suitable test stand or workstation that is level.
5. Mark all test specimens to be tested with a permanent marker with an identifying mark that is consistent with the one appearing on the data sheet that identifies each specimen. Remove any plastic sleeve(s) from buckle stalk to reveal the buckle stalk webbing [4].
6. Cycle each new or used buckle by inserting the latch plate and then depressing the release button by hand to ensure that the buckle is operating properly. Repeat this until a total of 20 cycles are completed [5].

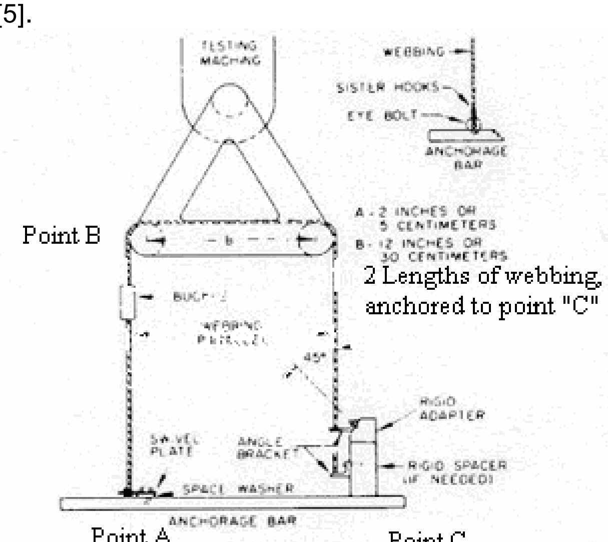

FIGURE 5

Figure 5. FMVSS 209 Figure 5 with Annotations

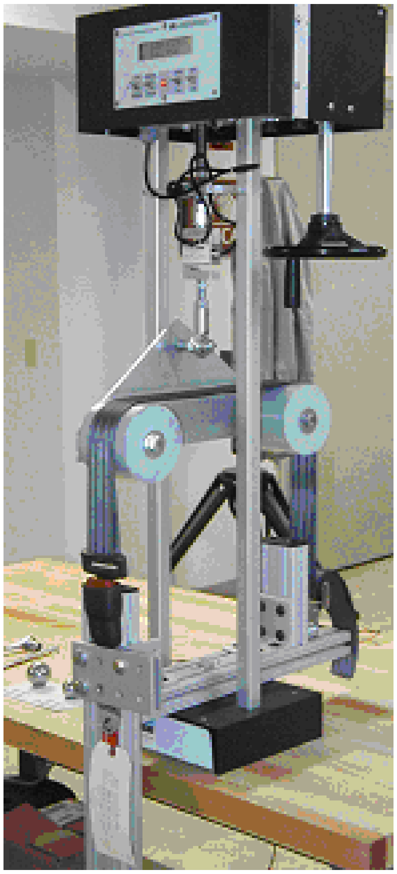

Figure 6. Test Setup

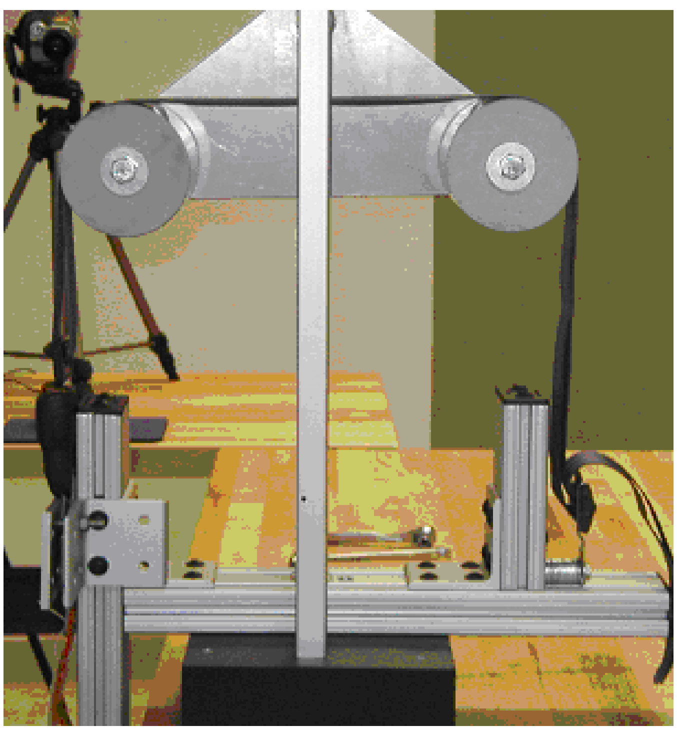

Figure 7. Test Setup

Camera/video coverage:

All testing should be documented with both still photographs and video coverage. It is desired that the video coverage include:

- one view of the test machine to include the tension gage reading
- one close up view of the buckle/latch plate assembly
- one overall view of the buckle/latch plate assembly

Test Procedures:

1. The buckle anchor shall be securely mounted to point A on the BTTF (see Figure 5). The buckle shall be mounted so that the rear or body side of the buckle is supported over at least ½ of its height but not over the top edge of the buckle housing. In addition, the buckle housing surface opposite the latch plate must be in direct contact with the mounting hardware so as to prevent vertical motion of the buckle during the test. This is mainly a concern for buckles using a "soft" or flexible stalk, i.e. a webbing or cable stalk where the buckle motion could cause large variations in the load on the webbing during the test.
2. The latch plate shall have the webbing routed through it as designed and oriented in the buckle as it would be in a vehicle for an occupant at the intended position, this is defined as the "normal" position. The latch plate shall then be inserted into the buckle.
3. Approximately 80 inches of webbing or the maximum available, which ever is less, shall be removed from the retractor. The webbing may be cut from the retractor or the retractor positioned so it does not interfere with the test. Equal portions of this webbing shall be routed over the rollers and the 2 free ends shall be secured to point "C" on the BTTF at a point approximately 32 inches from the latch plate (see Figure 5). The webbing may be secured through permanent attachment or using some type of clamping device, such as a tilt lock latch plate that locks directly to the webbing, thus not allowing the webbing to slip through.
4. Record seat belt system being tested on the test data sheet.
5. Place title board identifying the test specimen in position.
6. Start video cameras.
7. Photograph set up.
8. Apply 55 (± 5) pounds of tension to point D (referring to Figure 5) on the BTTF to take up all slack in the belt system. This is the tension specified in FMVSS 209 to remove belt system routing slack when testing a belt assembly [6].
9. Decrease the tension to 1.5 (± 0.5) pounds of tension in the belt system. This is within the range allowable for retractor force as specified in the FMVSS [7].

10. Measure, within the view of one of the video cameras, the diameter of the 40 mm sphere.
11. Using the 40 mm sphere and starting at approximately the center of the buckle housing, maneuver the sphere until it contacts the buckle release button.
12. Attempt to release the buckle with the sphere by maneuvering the sphere across the button with reasonable finger pressure so that the sphere contacts the latchplate. Care must be taken not to contact the buckle release button with anything other than the sphere.
13. Continue to try and release the buckle by moving the sphere across the buckle towards the front of the buckle, and continue to work the sphere back and forth from the edge of the buckle housing to the latch plate. Continue until the sphere moves off the front edge of the buckle.
14. Move the sphere back onto the buckle and work the sphere over the button side of the buckle until it moves off the rear edge of the buckle.
15. Work the sphere over the button 2 addition times in the manner described in steps 10 to 14. Note that during steps 11-14 the latch plate my move slightly due to natural play in the latch plate and this may cause a slight rise in the belt tension (approx 1-2 pounds).
16. If the latch plate is still in the buckle, state "no release", measure the sphere under video, increase the tension on the webbing system to 55 (± 5) pounds. This is to verify if the latch plate has released but not separated from the buckle. Again, this is the same tension used in FMVSS 209 to remove belt system slack and far exceeded the tension specified to verify that the buckle is not in a "false latch" condition. State for the video if there was a release or not.
17. Record the test results (release or no release) on a data chart similar to the one shown in the Appendix. If the release occurred when the tension in the system was raised, this should be noted on the data sheet with an asterisk or some type of identifying note.
18. If the buckle did not release when the tension was raised, decrease the tension to 1.5 (± 0.5) pounds of tension in the belt system and proceed to step 19. If it did release, re-engage the latch plate into the buckle and repeat steps 8 through 18. Ensure that the buckle is tested a total five (5) times.
19. If the buckle has not released, repeat steps 11 through 18 until a total of five tests have been performed.
20. If the buckle did not release in any of the five tests with the 40 mm sphere, release the tension, release the latch plate and reinsert it. Repeat steps 7 through 19 with the 30 mm sphere until a total of five tests have been performed. If the buckle did release with the 40 mm sphere, proceed to step 22.
21. After the completion of all of the above tests, remove the tension from the belt system and unfasten the buckle.
22. For all of the above tests, the latch plate has been oriented to have the webbing routed through as designed and oriented as it would be in a vehicle for an occupant at the intended position, i.e. "normal" position. If it is possible for the latch plate to be installed into the buckle in a reversed or inverted, i.e. 180º, from the prior or normal orientation, then install the latch plate in a reversed or inverted position and continue. This is done to verify that the ability of a buckle to remain latched is not compromised by a foreseeable misuse, i.e. engaging the latch plate in an inverted position. FMVSS 209 has a similar procedure when verifying the strength of the restraint system hardware [8].
23. Repeat steps 2 through 21 with the inverted latch plate installation.
24. Remove all tension from the system and remove the test specimen.
25. Return fixture to its initial set up.

Test Results:

As part of the development of this test procedure, a test program on 15 buckles from mid-1990's as well as 2000 and 2001 minivans and sedans was conducted. Of these 15 buckles tested, only 3 of them released with the 40 mm sphere. One additional buckle, for a total of 4, released with the 30 mm sphere. All 15 of the buckles performed the same with the latchplate installed in the normal and inverted positions when tested with the 40 mm sphere. In one case a buckle that released with the 30 mm sphere in the "normal" position could not be released in the inverted position. It is thought that some latchplate designs may use a flange on the latchplate to shield the release button. This prevents the sphere from contacting the release button and causing a release of the restraint. It is possible that if such a flange was included, it may only be present on one side of the latchplate thereby resulting in varied test results depending on the orientation of the latchplate. A summary of the tests results is contained in Table 1. A sample table used to record all test data is included in the Appendix.

	Buckle/Vehicle Description					Normal Latch Plate Orientation		Inverted Latch Plate Orientation	
Test Asset #	Year	Seating Position	Make	Model	Status New/Used	Number of Releases with 40 mm Sphere	Number of Releases with 30 mm Sphere	Number of Releases with 40 mm Sphere	Number of Releases with 30 mm Sphere
1	1994	LF	Oldsmobile	Silhouette	New	0	0	0	0
2	1995	LF	Ford	Windstar	New	0	0	0	0
3	1994	LF	Dodge	Caravan	New	5	5	5	5
4	2001	LF	Oldsmobile	Silhouette	New	0	0	0	0
5	2001	LF	Ford	Windstar	New	0	0	0	0
6	2001	LF	Dodge	Caravan	New	0	0	0	0
7	1994	LF	Pontiac	Grand Prix	New	0	0	0	0
8	1994	LF	Ford	Taurus	New	0	0	0	0
9	1994	LF	Dodge	Intrepid	New	5	5	5	5
10	2001	LF	Pontiac	Grand Prix	New	0	0	0	0
11	2001	LF	Ford	Taurus	New	0	0	0	0
12	2001	LF	Dodge	Intrepid	New	5	5	5	5
13	2000	LF	Toyota	Camry	Used	0	0	0	0
14	2000	LF	Honda	Accord	Used	0	5	0	0
15	2000	Dodge	Durango	LF	New	0	0	0	0

Table 1 Test Results

CONCLUSION

This testing demonstrated the repeatability of the methodology described in this paper. For the buckles tested, the results were the same for all 5 repetitions of the test on a specific buckle. The setup and procedure were such that the belt tension did not vary significantly during the test. It appears that the procedures provide a reliable, consistent and repeatable method to determine the ability of a buckle to remain closed when tested with a sphere as discussed in ECE Regulation 16.

Additionally the testing showed that some buckle designs are more resistant than others to being opened with a sphere. These more resistant buckles generally incorporated a flush mounted button or a scalloped button that had to be depressed below the level of the housing to actuate the latch release mechanism. While this testing does not demonstrate that buckles which remain latched during this test cannot be inadvertently released in a crash, it is generally thought that the more resistant a buckle is to being released by a sphere, the more unlikely it is to be inadvertently released in a crash. Obviously the likelihood of inadvertent release decreases as the size of the object required to cause the release decreases and the travel distance of the buckle release mechanism increases.

Given the importance of keeping a buckle latched during a crash, a buckle should be designed to resist inadvertent actuation. This procedure provides a scientific and repeatable method developed based on standard and accepted test procedures, to verify the ability of a buckle to remain latched during a crash. Incorporation of a test procedure, such as this one, into the Federal Standards or as a Recommended Practice would help increase the probability that future buckle designs provide a defined level of resistance to inadvertent actuation in a crash.

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5. Federal Motor Vehicle Safety Standard Number 209, Seat Belt Assemblies, S5.2(g), 49 CFR S571.209
6. Federal Motor Vehicle Safety Standard Number 209, Seat Belt Assemblies, S5.3(a)(2), 49 CFR S571.209
7. Federal Motor Vehicle Safety Standard Number 209, Seat Belt Assemblies, S4.3(j), 49 CFR S571.209

8. Federal Motor Vehicle Safety Standard Number 209, Seat Belt Assemblies, S5.3(b)(6), 49 CFR S571.209

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APPENDIX

	Buckle/Vehicle Description					"Normal" Latch Plate Orientation									
Test Asset #	Year	Make	Model	Seating Position	Status New/Used	40 mm Sphere Trial 1 Release (Yes/No)	40 mm Sphere Trial 2 Release (Yes/No)	40 mm Sphere Trial 3 Release (Yes/No)	40 mm Sphere Trial 4 Release (Yes/No)	40 mm Sphere Trial 5 Release (Yes/No)	30 mm Sphere Trial 1 Release (Yes/No)	30 mm Sphere Trial 2 Release (Yes/No)	30 mm Sphere Trial 3 Release (Yes/No)	30 mm Sphere Trial 4 Release (Yes/No)	30 mm Sphere Trial 5 Release (Yes/No)

Buckle Release Testing Data Chart

	Buckle/Vehicle Description					"Inverted" Latch Plate Orientation									
Test Asset #	Year	Make	Model	Seating Position	Status New/Used	40 mm Sphere Trial 1 Release (Yes/No)	40 mm Sphere Trial 2 Release (Yes/No)	40 mm Sphere Trial 3 Release (Yes/No)	40 mm Sphere Trial 4 Release (Yes/No)	40 mm Sphere Trial 5 Release (Yes/No)	30 mm Sphere Trial 1 Release (Yes/No)	30 mm Sphere Trial 2 Release (Yes/No)	30 mm Sphere Trial 3 Release (Yes/No)	30 mm Sphere Trial 4 Release (Yes/No)	30 mm Sphere Trial 5 Release (Yes/No)

Buckle Release Testing Data Chart