

Evaluating Self-Unlocking Doors in Rollover Accidents using a Shock Testing Machine

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ABSTRACT

Automotive manufacturers often rely upon features such as automatic locking to enhance the security and crashworthiness of doors in rollover accidents. This can be verified in warnings conveyed to vehicle owners through some owner's manuals. At the present time, there are no requirements on the dynamic performance of door locking systems within the Federal Motor Vehicle Safety Standards (FMVSS), although some static inertia requirements exist for latch systems.

Field accident investigation and laboratory testing has revealed that some locked doors can self-unlock in rollover accidents when a vehicle sustains a roof impact. Using standard laboratory shock testing machinery, the acceleration boundaries required to trigger self-unlocking have been mapped for some sample doors. Impact pulses of surprisingly low levels of acceleration, when combined with sufficient duration have been found to trigger this response.

Furthermore, two entirely different failure mechanisms have been identified and documented thus far. One failure mode results directly from inertial triggering of the locking system; this mode is anticipated by FMVSS. The second failure mode is the unexpected consequence of the vibratory response of the lock system linkage. This failure mode has not yet been recognized in the safety literature.

This paper presents the findings of a field accident investigation where self-unlocking was believed to have

occurred as well as test data from doors exhibiting the two different self-unlocking mechanisms.

INTRODUCTION

Figures 1-3 show a 1998 auto-lock equipped van that was involved in a single vehicle loss-of-control accident reportedly caused by a wind gust. The driver over-corrected and ultimately lost control, which led to an off road rollover. During the rollover, the driver's door came open without destruction of the latch and was ripped from its hinges when the attaching bolts broke. The driver, who was ejected, suffered fatal injuries. It was disputed, among experts examining the restraint system, whether or not the driver's belts were in use.



Figure 1. Hinge bolts sheared after door opened.

The failure of the door latch was attributed partially to vertical loads it sustained before opening, which enlarged the fishmouth opening and reduced the detent engagement with the fork bolt by about 40% (see ref. 1), and by activation of the outside handle system. The latch was triggered when crushing of the door outer skin pushed the handle and its attached rod into the door.



Figure 2. Door suffered relatively little damage in spite of being torn from hinges.

The latch failure mechanism was reproduced and confirmed with a series of dynamic impacts to an exemplar door skin directly above the handle; but, the outside handle linkage should have been disabled due to the auto-locking feature. Thus, this failure mode should not have been possible. This was the background that motivated development of the test procedures reported on in this paper.



Figure 3. Latch was functional but with a slight expansion of the fishmouth. Ruler indicates ripples in end panel from vertical loads.

Evidence that manufacturers depend upon automatic locking to prevent outside linkage activation can be seen in many owners' manuals that warn about the benefits of locked doors in preventing ejection. Figure 4 contains an example of such a warning.

Door Locks

⚠ CAUTION:

Unlocked doors can be dangerous.

Passengers -- especially children -- can easily open the doors and fall out. When a door is locked, the inside handle won't open it.

Outsiders can easily enter through an unlocked door when you slow down or stop your vehicle.

This may not be so obvious: You increase the chance of being thrown out of the vehicle in a crash if the doors aren't locked. Wear safety belts properly, lock your doors, and you will be far better off whenever you drive your vehicle.

Figure 4. Owner's manual warning alludes to outside handle linkage failure.

TEST PROGRAM

A series of hypotheses were developed in an effort to understand how the outside linkage could remain operational if the vehicle was auto-lock equipped. Ultimately, a functional check of the control module responsible for engaging the auto-locks (the Remote Antitheft Module or "RAP" module) found it to be working and programmed to auto-lock the doors.

This eliminated the most obvious explanations (broken module, auto-locking deprogrammed etc.). It was decided at this point to test the hypothesis that the door could be unlocked inertially by impacts encountered in a rollover.

This hypothesis was evaluated by first dropping doors and later full scale vehicles from heights of approximately 28 to 34 cm on a hard surface. It was learned that drops from as low as 20 cm could reliably unlock the van door.

While this finding was surprising and offered a potential resolution of the dilemma in this specific investigation, it did not establish the engineering parameters of the failure nor did it isolate the details of the unlocking failure mechanism.

It became apparent that to answer these questions, repeated drops under a range of impact conditions would be necessary. It was also obvious that it would not be feasible to destroy an exemplar vehicle or door with every test. It was decided, therefore, that a non-contact test method that could control the impact parameters, similar to a hyge sled was needed.

TEST EQUIPMENT - Upon consideration of the possible alternatives, it was decided to attempt testing of a full scale door on an MRAD pneumatic shock test machine. The specific model used was a 0909(100)PA-MP machine, an industry standard for use in mechanical testing.

The MRAD produces a shock pulse by using compressed air to force a platform or carriage downward to impact the base of the machine, which is insulated by various types of elastomeric padding and shock absorbing materials. These materials help determine the shock pulse shape, which, is approximately a $\frac{1}{2}$ sine wave.

The MRAD offers the advantages of an indirect impact, reliable and accurate measurement of the impact pulse, and exceptional visibility of the test subject for high speed filming. The particular model used in this test program featured a 22.86 X 22.86 cm carriage platform that could be expanded to 91.44 X 91.44 cm by bolting a magnesium expansion head to the original carriage.

A lightweight but sturdy, adjustable frame was fabricated from aluminum alloy to adapt a full size vehicle door to the expansion head. The frame was designed to accept a range of doors and place the CG of the load approximately over the center of the machine. Figure 4 shows the relationship of the machine base, elastomeric padding, carriage, expansion head and test subject.

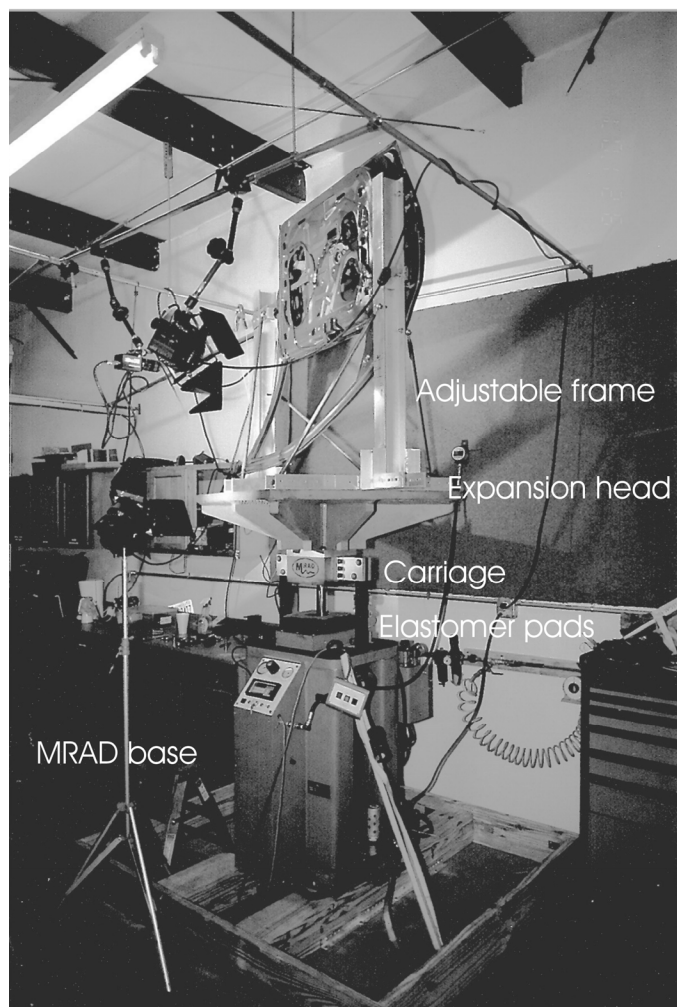


Figure 4. MRAD machine with expansion head attached to carriage, adjustable door fixture and inverted door mounted to expansion head.

In order to minimize the mass of the test subject and reduce the potential hazard of shattered tempered glass,

the glass was removed from door test subjects. Also, to provide exposure for high speed video, the door trim panel was removed.

Successful trials produced useful data with this configuration but attempts at viewing video of the movements of the lock levers and attached linkages was less productive. A large percentage of the locking linkage system and the latch was concealed inside the doors.

It was feared that cutting windows into the door sheet metal would compromise its rigidity and perhaps introduce structural flexing effects at the low end of accelerations being examined, so, alternative solutions were evaluated.

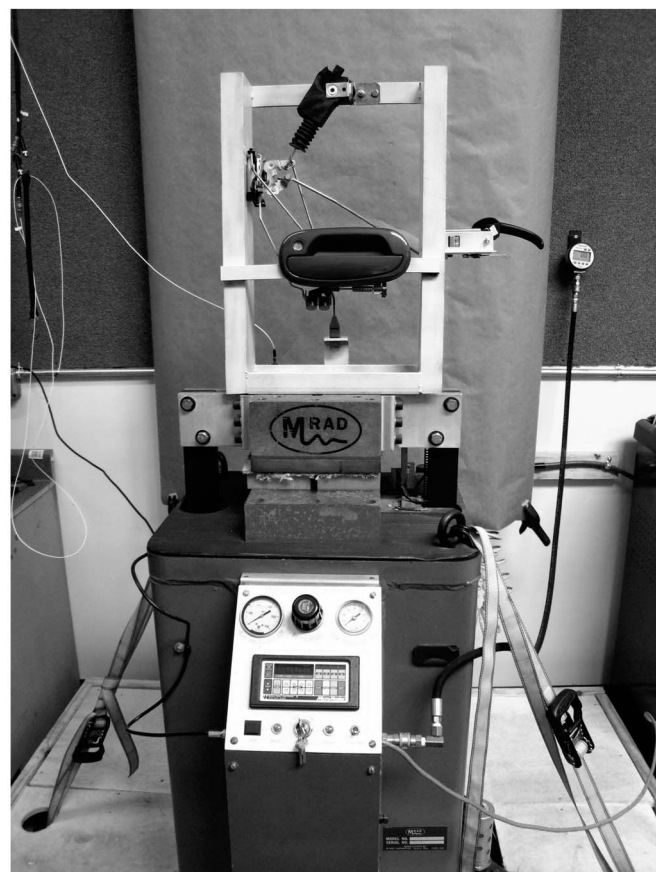


Figure 5. Abbreviated frame for latch, handle and lock linkages and mechanisms mounted directly to MRAD carriage

It was decided to investigate the possibility of constructing a rigid skeletal framework to hold the handles, latch and related linkages in their proper relationship but without the door sheet metal. Figure 5 illustrates one design created for SUV A's front door with rod inside and outside handle systems.

Differing door designs called for different frame designs. Figure 6 illustrates a frame constructed for SUV B's rear door using rod linkages for both the inside and outside handles. As with the SUV A fixture, both handles and their rods were included in addition to the locking system components.