CHARACTERIZATION OF AUTOMOTIVE
SEAT BELT BUCKLE INERTIAL RELEASE

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ABSTRACT

The objective of this research program was to determine the dynamic conditions under which a restraint system will unlatch due to inertial loading. This question must be answered in order to provide the basis for understanding whether or not inertial release of seat belt buckles can occur in real-world automobile collisions. Controlled laboratory dynamic tests were conducted on several different manufacturers' seat belt buckles to determine the conditions which would result in inertial unlatching. The two key variables evaluated were:

1. Velocity Change at Release.
2. Acceleration -Time History.

These tests provided a characterization of the acceleration and delta velocity conditions necessary to inertially unlatch a wide range of seat belt buckles. Future research is required to determine if these conditions actually occur in real-world collisions.

INERTIAL RELEASE OF PUSH-BUTTON SEAT BELT BUCKLES has been a concern of certain automotive safety advocates and experts for nearly 30 years. Many concerns seem to be rooted in the ability to cause the opening of push-button seat belt buckles by impacting the latch buckle assembly. This is often demonstrated with an impact input to the latch buckle by slapping the assembly over one's knee. The May 2, 1966 issue of Automotive News makes reference to such a knee-slapping demonstration, attributing the common label of "parlor trick" to then Ford Motor Company Consulting Vice President John S. Bugas (1966). Tapping the latching mechanism with a rubber hammer is described as part of the 1979 test program conducted by the Department of Transportation, National Highway Traffic Safety Administration (Chiang, 1979). More recently, the automatic release phenomena has been the subject of national television news broad
casts in which automatic release of push-button seat belt buckles was reported to occur (1993). Knowledgeable researchers and research organizations have concluded that inertial release will not occur in the real world. Yet persistently over the years, inertial release has been used to explain, or at least inflame speculation about, the cause of vehicle occupant injuries in certain crashes.

It is a fact that many seat belt buckles will unlatch when sufficiently accelerated. The real question of interest is not whether the buckle will come open, but will it come open when used (or misused) in the environment that a passenger car or truck seat belt buckle (or any device employing a buckle restraint) may encounter. Questions arise as to whether a slap on the knee or a rap with a rubber hammer represents some meaningful description of buckle performance in the real operating environment of the seat belt buckle assembly.

The problem addressed by this work is contributed to by all aspects of the above discussion. The nature of the phenomena (its demonstration by simple experiment), the mass reporting of the problem, and the body of research to date all raise questions about whether the inertial release phenomena occurs in real crashes. Legitimate concerns arise in the context of the problem stated above with regard to user confidence of seat belt systems and corresponding effects on seat belt system usage.

**LITERATURE SEARCH**

A literature search was conducted to review work available in the public domain on the issue of seat belt buckle inertial release. The possibility of a problem with buckle inertial release was first made public by Ralph Nader in 1966. Mr. Nader claimed at a hearing before the Committee on Interstate and Foreign Commerce that Ford's deluxe seat belt which was to be used on all of its 1967 models was unsafe (1966). Ford's response to Mr. Nader's claim was that the inertial unlatching of the buckle was a "parlor trick," and that the "parlor trick" was carried out by imparting a force on the back of the buckle that could not be replicated in a real world collision.

The issue of seat belt buckle inertial release came to light again in 1977 when a 1975 Chevrolet Monza 2+2 was involved in a rollover collision resulting in an ejection. A preliminary collision investigation raised the concern that a defect may exist in the latching mechanism used in the restraint system of this vehicle. The National Highway Traffic Safety Administration (NHTSA) conducted an investigation to determine if the 1975 Chevrolet Monza seat belt latching mechanism would inadvertently unlatch (Bayer, 1978a). This investigation revealed that the latching mechanism of the 1975 Chevrolet Monza 2+2 will release when subjected to a sharp blow to the back of the buckle.

Based on the results of the NHTSA investigation on the 1975 Chevrolet Monza 2+2, a second investigation was undertaken by NHTSA to evaluate the seat belt latching mechanisms on all domestic cars produced between the years of 1971-1978 (Bayer, 1978b). Of the 225 vehicle seat belt latching mechanisms tested, 50 would unlatch when subjected to an impact of 300-340 G's on the back of the buckle. It was concluded in both NHTSA investigations that there was no evidence to suggest, based upon laboratory tests, that inertial unlatching could occur in real world collisions.
Failure Analysis Associates, Inc. (FaAA) conducted a test program in 1992 for General Motors Corporation to gather data on the accelerations that seat belt buckles in a vehicle experienced in staged crash tests and sled tests (Thomas, 1992). They then completed a series of laboratory tests on the vehicles' belt buckles to establish the characteristics under which the belt buckles would unlatch due to inertial loads. All of the tests conducted by FaAA were done using a 1984 Chevrolet S-10 Blazer and Blazer seat belt buckle components. FaAA concluded from this study that the S-10 Blazer seat belt buckle requires an input pulse that is substantially different than that seen in real-world collisions for it to unlatch due to inertial loads.

On September 11, 1992, the Institute for Injury Reduction (IIR) petitioned NHTSA to conduct a defect investigation on seat belt buckles that unlatched due to inertial loading. NHTSA responded by conducting a review and analysis on all of the available data pertaining to inertial unlatching (Boehly, 1992). NHTSA concluded from this review that there was no evidence to support that inertial unlatching was occurring in seat belt buckles.

Collision Safety Engineering (CSE) published a paper which provided a technical overview of the issues surrounding seat belt buckle inertial release in March of 1993 (James, 1993). Seat belt buckles from several automobile makes and models were evaluated to determine the acceleration that must be experienced by the buckle in order for it to unlatch (steady state acceleration). Through the use of analysis, CSE demonstrated the types of acceleration time histories that would be necessary to have a hypothetical buckle unlatch due to inertial loads. This data, along with the steady state acceleration data was then compared to the expected real world vehicle collision environment. From this, CSE concluded that the inertial loads experienced by seat belt buckles in real world collisions are substantially different from those required to cause the seat belt buckle to release.

PURPOSE OF RESEARCH

The ultimate goal of any investigation into the possible inertial unlatching of a seat belt buckle is to be able to quantitatively demonstrate that the phenomena does or does not happen on any specific buckle or population of buckles. Two key pieces of information were missing from all the literature reviewed which are necessary to form the basis to make such a determination for the population of buckles. The first portion of missing information is well-defined data on the input conditions required to cause seat belt buckles to unlatch due to inertial loads. The only data that has been collected was by NHTSA in 1977 and by FaAA in 1992. The NHTSA data was incomplete in that only a single input pulse was investigated. That input pulse was not fully defined in the literature. A peak acceleration was given, but not the duration or shape of the pulse. The other data provided was for the 1984 Chevrolet S-10 Blazer tested by FaAA in 1992. Again, the acceleration pulse was not fully defined and data was provided for only one seat belt buckle type. This work, and research by CSE, clearly show large differences in steady state accelerations required for inertial unlatching of various seat belt buckles. The second piece of missing information is the anticipated range of acceleration time histories the seat belt buckle will experience in real-world crashes. Again, the FaAA test of 1992 provides some qualitative insight into
acceleration environments of seat belt buckles, but the test and conclusions are for one vehicle, one belt and one surrogate, and the acceleration vs. time plots are not provided.

We propose a two phased approach which will demystify the phenomena of push button seat belt buckle inertial release. First, physical characterization, testing and computer modeling should be used to quantify various properties of seat belt buckle assemblies. This property collection should occur on a variety of seat belt buckles to gain insight into the range of buckle properties which exist. Although there is no guarantee, one would hope to capture within this data base seat belt buckle assemblies which inertially release at each end of an impulse continuum defined by low velocity/low acceleration and those that require high velocity/high acceleration. Second, a quantitative description of the operating environment of seat belt buckles needs to be developed. This includes evaluating a range of vehicles, crashes, occupants, seat belt buckles, and other parameters that may affect seat belt buckle inertial release. Components of existing research have partially developed this aspect. In fact, the work by FaAA seems most complete and consistent with the above-outlined approach, except that it is useful by itself only in evaluating the S-10 Blazer seat belt buckle. Only when both phases of work have been completed, can the two be combined to make generalized conclusions about whether this phenomenon can or cannot occur in all vehicles in the real world.

The technical objectives of this research program are:

- to parametrically study a cross-section of seat belt buckle latch mechanisms which are in modern passenger cars.
- to develop seat belt buckle inertial response data by conducting controlled/instrumented tests of seat belt buckle assemblies in isolation of their operating environment.

IDENTIFICATION OF VEHICLES/RESTRAINTS

There are too many seat belt buckles in existence to practically test all of them under this program. It was necessary to limit the total number of seat belt buckles evaluated. The approach used to narrow the field of seat belt buckles investigated was to limit the evaluation to seat belts from late model vehicles (1986 - present). Selecting restraints from the most popular foreign and domestic automobile designs (based on U.S. sales) reduced the number of seat belt buckles evaluated further. Finally, only side button seat belt buckles were evaluated in the study. Figure 1 shows the difference between side, end, and edge button seat belt buckles. Side button seat belt buckles were chosen because they were judged to be the most susceptible to possible inertial release problems. A list of the selected buckles with various properties is provided in Table 1.
BUCKET PROPERTIES

All the seat belt buckles were examined to determine the physical properties that govern seat belt buckle performance. Each seat belt buckle was disassembled and all moving parts measured for dimensions and weight. The results of this examination are provided in Table 1. "Ejection force" is the amount of force that is exerted by the ejector spring. Seat belt buckles without ejector springs are identified by a "T," representing tension exerted on the seat belt buckle by the webbing retractor. The column labeled "Force at Button C_G" is the force required at the center of gravity of the button to cause seat belt buckle to release. "Effective Pawl Height" is the portion of the pawl that directly engages the latch. The effective pawl height determines the distance the pawl must move to disengage the latch. The "calculated static acceleration" is the threshold steady state acceleration, which when applied to the seat belt buckle, will cause the buckle to unlatch. Calculated static acceleration is found by the equation:

$$\text{Calculated Static Acceleration} = \frac{\text{Force at Button C_G}}{\text{Effective Pawl and Button Assy. Weight}}\quad (1)$$

This threshold value established the target starting point for the dynamic testing.
Table 1. Parametric Study Results

<table>
<thead>
<tr>
<th>Vehicle Restraint</th>
<th>Ejection Force (N)</th>
<th>Force @ Button CG (N)</th>
<th>Effective Pawl Height (cm)</th>
<th>Pawl CG Length (cm)</th>
<th>Pawl Weight (gf)</th>
<th>Button CG Length (cm)</th>
<th>Button Length (cm)</th>
<th>Button Weight (gf)</th>
<th>Latch Weight (gf)</th>
<th>Calculated Static Acceleration (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>'88 Toyota Camry</td>
<td>12.466</td>
<td>8.014</td>
<td>0.216</td>
<td>1.334</td>
<td>10.9</td>
<td>2.235</td>
<td>3.594</td>
<td>1.6</td>
<td>61</td>
<td>115</td>
</tr>
<tr>
<td>'86 Toyota P/U</td>
<td>6.233</td>
<td>6.233</td>
<td>0.216</td>
<td>1.207</td>
<td>10.9</td>
<td>2.235</td>
<td>3.594</td>
<td>1.6</td>
<td>66.9</td>
<td>97</td>
</tr>
<tr>
<td>'86 Nissan Pulsar</td>
<td>12.466</td>
<td>16.918</td>
<td>0.208</td>
<td>0.762</td>
<td>12.1</td>
<td>2.350</td>
<td>4.826</td>
<td>5.4</td>
<td>37.9</td>
<td>199</td>
</tr>
<tr>
<td>'86 Toyota Corolla</td>
<td>7.123</td>
<td>6.678</td>
<td>0.216</td>
<td>1.283</td>
<td>10.9</td>
<td>2.235</td>
<td>3.607</td>
<td>1.6</td>
<td>68.9</td>
<td>98</td>
</tr>
<tr>
<td>'87 Suzuki Samurai</td>
<td>12.021</td>
<td>26.713</td>
<td>0.145</td>
<td>0.838</td>
<td>10.2</td>
<td>2.146</td>
<td>4.91</td>
<td>10</td>
<td>56.4</td>
<td>322</td>
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<tr>
<td>'91 Chevrolet S-10</td>
<td>5.343 T</td>
<td>16.028</td>
<td>0.216</td>
<td>1.676</td>
<td>16.5</td>
<td>2.210</td>
<td>4.204</td>
<td>3.7</td>
<td>40</td>
<td>116</td>
</tr>
<tr>
<td>'87 Ford Taurus</td>
<td>4.897</td>
<td>11.130</td>
<td>0.203</td>
<td>0.686</td>
<td>7.7</td>
<td>1.791</td>
<td>3.363</td>
<td>2.6</td>
<td>35.2</td>
<td>N/A</td>
</tr>
<tr>
<td>'87 Pontiac Grand Am</td>
<td>4.897 T</td>
<td>15.583</td>
<td>0.191</td>
<td>1.651</td>
<td>*22.4</td>
<td>*N/A</td>
<td>*N/A</td>
<td>2.4</td>
<td>37.5</td>
<td>109</td>
</tr>
<tr>
<td>'91 Pontiac Sunbird</td>
<td>5.788 T</td>
<td>16.918</td>
<td>0.191</td>
<td>1.575</td>
<td>*22.1</td>
<td>*N/A</td>
<td>*N/A</td>
<td>22.1</td>
<td>37.5</td>
<td>126</td>
</tr>
<tr>
<td>'87 Chrysler Le Baron</td>
<td>9.795</td>
<td>11.130</td>
<td>0.191</td>
<td>1.008</td>
<td>7.3</td>
<td>1.549</td>
<td>3.236</td>
<td>2.7</td>
<td>94</td>
<td>249</td>
</tr>
<tr>
<td>'88 Ford Mustang</td>
<td>7.569 T</td>
<td>20.480</td>
<td>0.196</td>
<td>1.681</td>
<td>16.3</td>
<td>1.979</td>
<td>4.191</td>
<td>4.2</td>
<td>77</td>
<td>148</td>
</tr>
<tr>
<td>'89 Buick Century</td>
<td>6.678 T</td>
<td>12.911</td>
<td>0.206</td>
<td>1.651</td>
<td>*22.3</td>
<td>*N/A</td>
<td>*N/A</td>
<td>22.3</td>
<td>93</td>
<td>91</td>
</tr>
<tr>
<td>'88 Chevrolet Sprint</td>
<td>9.350</td>
<td>18.699</td>
<td>0.152</td>
<td>0.876</td>
<td>11.0</td>
<td>2.261</td>
<td>4.953</td>
<td>10.0</td>
<td>92.7</td>
<td>214</td>
</tr>
<tr>
<td>'88 Ford Bronco II</td>
<td>N/A</td>
<td>18.254</td>
<td>0.178</td>
<td>1.549</td>
<td>15.6</td>
<td>2.261</td>
<td>4.194</td>
<td>3.7</td>
<td>77.9</td>
<td>145</td>
</tr>
<tr>
<td>'86 Chevrolet Sprint</td>
<td>3.562</td>
<td>12.021</td>
<td>0.188</td>
<td>1.588</td>
<td>15.7</td>
<td>2.032</td>
<td>3.454</td>
<td>6.5</td>
<td>78.8</td>
<td>81</td>
</tr>
</tbody>
</table>

* Button & pawl are a single component.
OBSERVED LATCH CONFIGURATIONS

Push button seat belt buckles all have spring loaded buttons that release a latch upon sufficiently depressing the push button. Depressing the button moves a pawl from the slot in the latch plate disengaging the belt assembly. The majority of the seat belt buckles evaluated are of the type shown in Figure 2. This common buckle design consists of a button/pawl assembly that deflects a single-leaf spring in the direction of the button/pawl motion. A sufficient acceleration force applied normal to the button deflects the spring/pawl assembly allowing release of the latch plate.

![Diagram of Typical Side Button Buckle](image)

Figure 2.
Typical Side Button Buckle

One other seat belt buckle configuration stood out as an example of a seat belt buckle that will not inertially unlatch. This was the 1987 Ford Taurus seat belt buckle shown in Figure 5. The location of the pawl is above the latch plate. The spring loaded pawl ramp slides perpendicular to the direction of the pawl movement to move the pawl from the slot of the latch plate. This perpendicular travel is initiated by movement of the diagonal contact planes at one end of the pawl ramp and button. Although acceleration normal to the button will create force against the pawl ramp, the pawl cannot move due to balancing inertial forces keeping the pawl in the latch slot. The Taurus seat belt buckle will not inertially release while applying an acceleration normal to the seat belt buckle button.
Dynamic tests were performed on all of the target seat belt buckles (Table 1). The testing apparatus chosen to provide the desired input was a drop cage. The drop cage was selected because it provides predictable and repeatable acceleration pulses. Additionally, this apparatus is very efficient since four buckles can be mounted to the drop cage and tested simultaneously. The desired input pulse was achieved by dropping the cage onto stacks of paper honeycomb a height that would produce the desired impact velocity. The paper honeycomb was placed under the cage to decelerate it at the prescribed level. The input pulse can easily be tailored by varying the shape of the honeycomb stack.

Seat belt buckles were attached to the drop cage show in Figure 4. It was necessary that the drop cage be very stiff and lightweight to achieve the high accelerations desired. This was accomplished by constructing the drop cage frame with welded-thin wall aluminum tubing. The cage base is made of an aluminum/honeycomb sandwich structure. The aluminum/honeycomb structure was then bonded to the welded tube structure. The aluminum tubing was filled with a two component urethane foam to reduce resonance of the structure. The seat belt buckles were rigidly clamped to the tubing of the fixture. An accelerometer was mounted on the tubing as well.
Each seat belt buckle was instrumented to determine time of release if it occurred. Copper foil was bonded to the buckle housing and to the latch plate (Figure 5). When the latch plate was inserted into the buckle, the copper foil of each component would come into contact completing a circuit. Upon inertial release, the time was measured indicating the precise time of release with respect to the start of impact. This can then be plotted on the acceleration-time history as shown in Figure 6.
Some seat belt buckles do not have an ejection spring to push the latch plate out of the buckle when the button is depressed. Each seat belt buckle, including those with ejection springs, had an elastic band attached to the latch plate with the other end attached to the drop fixture. The tension applied to the latch plate was equivalent to the force that would be exerted by the seat belt retractor. The elastic band assists in the ejection of the latch plate from the seat belt buckle when inertial release occurs.

DATA ANALYSIS

Acceleration pulses were acquired and plotted for each buckle. Each acceleration pulse was averaged between the beginning calculated static threshold acceleration value and the last static threshold acceleration value for the seat belt buckle tested. Buckles that released prior to the last static threshold acceleration value were averaged to that data point. These averaging methods are demonstrated in Figures 7 and 8, respectively.

![Graph](image1)

**Figure 6.**
Buckle Release on Acceleration-Time History

![Graph](image2)

**Figure 7.**
Release After Accel. Drops Below Threshold
All of the acceleration pulses were integrated to determine the Delta Velocity at release for each buckle. A Delta Velocity plot is shown in Figure 9 with the release times intersecting the integration curve.

Average acceleration vs. Delta Velocity plots were compiled for each seat belt buckle to develop a release/non-release boundary. The data for these plots partially define the regions for release and non-release for each seat belt buckle. Plots of average acceleration vs. delta velocity for four buckles representing the range of static threshold accelerations of the seat belt buckles evaluated are shown in Figures 10-13.
Figure 10.
Chrysler LeBaron Acceleration versus ΔVelocity

Figure 11.
Buick Century Acceleration versus ΔVelocity

Figure 12.
Ford Mustang Acceleration versus ΔVelocity
DISCUSSION

All tests were conducted with tension on the seat belt buckle to simulate that provided by a typical seat belt retractor only (approximately 6.7 N). The acceleration required to cause inertial release increases as the tension on the seat belt buckle is increased. The button force required to unlatch the seat belt buckles evaluated varies from 6.2 - 26.7 N with no tension. Figure 14 shows the effect of seat belt tension on button force for five different seat belt buckles. The increase in button force required for release is a result of friction between the latch plate and pawl. The possibility that an inertial release will occur diminishes as tension increases in the restraint webbing. Research conducted by Failure Analysis (Thomas, 1992) indicates that over 450 N of tension exists in the restraint during the majority of the tested collision sequence.

Inertial release probably will not occur during a time when significant belt webbing tension exists. If inertial release does occur, it happens when the seat belt buckle is subjected to an acceleration above its static threshold acceleration and when there is little or no tension in the restraint. This suggests that inertial release may occur early in the collision sequence, during rebound, or in a rollover sequence when tension is released.
Delta velocity of the seat belt buckle also plays a role in whether inertial release will occur. It is difficult to generate a large buckle impact-related delta velocity in a real-world collision due to the physical layout of restraint systems. This creates great interest in the performance of the seat belt buckles at low delta velocities (less than 4.6 m/s) and high average accelerations. However, it is very difficult to generate this kind of acceleration pulse in a test. Computer modeling may be one way that the seat belt buckles performance can be analyzed under these conditions.

A finite element computer model was developed to predict whether the seat belt buckles would unlatch given various input pulses. The computer model is being validated against the test data developed during this program. Once validated, the model will be used to predict the performance of seat belt buckles when subjected to low velocity/high acceleration input pulses. Some preliminary results of this analysis are shown in Figure 15. These results show that the buckle will come unlatched at change in velocities as low as 2.36 m/sec. However, the acceleration required for the buckle to unlatch at this change in velocity is 480 G’s. Additional validation and analysis using the computer model is ongoing. The results of this modeling effort will be the subject of a future paper.

![CAMRY BUCKLE DATA](image)

**Figure 15.**

Predicted Buckle Release/Non-Release Boundary

As future research is performed into the operating environment of seat belt buckles, it is anticipated that thresholds will be established over which buckles are not expected to encounter higher accelerations or higher changes in velocity. The curve developed in Figure 15 is dependent on certain buckle parameters over which a designer has control. The inertial release of seat belt buckles could be designed to occur outside the anticipated impact environment defined by these thresholds.

**CONCLUSIONS**

- Two key pieces of information are missing from the body of research reviewed that are necessary to form the basis to determine if inertial unlatching of seat belt buckles occurs in the population of seat belt buckles in real-world collisions.

- This work defines data which characterizes conditions required to cause inertial unlatching of seat belt buckles. More buckles within the population should be characterized.
The impact environment of seat belt buckles in real-world collisions is presently not adequately developed.

- The calculated static threshold acceleration can be used to predict the release/non-release threshold at delta velocities greater than 4.6 m/sec in most cases.

- Seat belt buckle designs with side buttons (Ford Taurus) exist that will not inertially release under the conditions tested during this program.

- Very low delta velocity (less than 3.0 m/sec)/high acceleration (greater than 150 G) input pulses could not be produced using the test apparatus chosen for this program.

- Preliminary results from a computer model successfully predict the results demonstrated through testing.

- Preliminary results indicate that computer modeling may be used to predict seat belt buckle performance at low delta velocity/high acceleration pulses.

- It would be useful to develop impact threshold data of real-world acceleration and change in velocity over which seat belt buckles are not likely to be subjected, thus, providing a design boundary for seat belt buckle performance.

**FUTURE RESEARCH REQUIREMENTS**

Future areas of research on this subject might include the following:

1. Characterize additional seat belt buckles to expand the existing database.
2. Experimentally and theoretically investigate seat belt buckle inertial release in low velocity, high acceleration events.
3. Investigate the performance envelope in which buckles are expected to operate without release for the population of vehicle, occupants, and crashes.

**Availability of Data** - Test data generated during this program is available from Arndt & Associates, Ltd., Tempe, Arizona.

**REFERENCES**


