

A FORENSIC ANALYSIS OF RECLINER RELEASE VIA CONNECTING ROD IN REAR IMPACT AUTOMOTIVE COLLISIONS

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ABSTRACT

Occupant safety in rear impact automotive collisions relies heavily on freestanding seats to restrain front seated occupants without intruding into the survival space of occupants in the rear seat [1] [2]. The seatback must absorb crash energy while remaining sufficiently upright to prevent occupant ramping and injurious contact with rear seated occupants and / or rear vehicle structures. Additionally, the front seats must be designed to accommodate all different occupant statures comfortably [3]. Adjustability is typically achieved by equipping the seats with a number of features including fore / aft adjustment, recline adjustment, and often seat height adjustments. These adjustment features are either manually, or electrically adjustable.

A failure mode in manually adjustable dual recliner seats has been identified wherein the recliner connecting rod can disengage one, or both, recliners during a rear impact event, undermining the seat back's ability to restrain the relative rearward movement of the front occupant. This catastrophic failure mode presents both front and rear seated occupants with higher risks of severe injury.

Three real world cases are presented wherein manually adjustable recliners were found to release in a rear impact due to the recliner connecting rod. Testing and / or demonstration of the failure mode is shown in each case which shows matching evidence between the accident and test seats.

INTRODUCTION

In rear impact collisions, the force to the impacted vehicle accelerates it forward. As the vehicle accelerates forward, the occupant's seatback applies force to the occupant in order to also accelerate the occupant forward. Failure of the seatback to accelerate the front occupants forward can result in the occupants moving rearward relative to the vehicle, allowing them to make forceful contact with rear vehicle structures, and / or occupants seated in the rear seat, increasing potential for serious injury.

Early vintage automotive seats were generally designed with a single recliner mechanism on the outboard side of the seat, and a simple pivot on the inboard side of the seat. Under rearward impact loading, the asymmetry of the single recliner design can allow the seatback to twist, providing uneven, and suboptimal support to the occupant's upper torso. Automotive manufacturers and seat suppliers have recognized this issue and have migrated to mostly dual recliner seat systems. The dual recliner system replaces the inboard seat back pivot with a second recliner, allowing the inboard side of the seatback to evenly provide support for the occupant in a rear impact event.

In order for a manually adjustable seatback recline angle to be adjusted to accommodate different size users and recline positions, the two recliners must disengage simultaneously when the user pulls on the recliner adjustment handle, and re-engaged simultaneously when the user releases the recliner adjustment handle. This is commonly achieved by the use of a recliner connecting torsion rod.

MANUAL DUAL RECLINER MECHANISM WORKINGS

A typical design for dual manual recliner seats contains two pawl and sector recliners controlled by a cam in each recliner. The two cams are connected via a recliner connecting rod, and the recliner adjustment handle is connected to the recliner connecting rod itself, or controls one of the cams (see Figure 1). As the recliner handle is pulled up by the user, the outboard cam rotates while the recliner connecting rod rotates the cam in the second recliner at the same time. The rotation of the cams allow the pawls to disengage from the sectors, releasing the recliners, and the

seat back is then able to be adjusted in recline (see Figure 2). As the user releases the spring loaded handle, the cams are both rotated back, pushing the pawl teeth back towards the sector teeth to re-engage both recliners and prevent further movement of the seatback at the recliners.

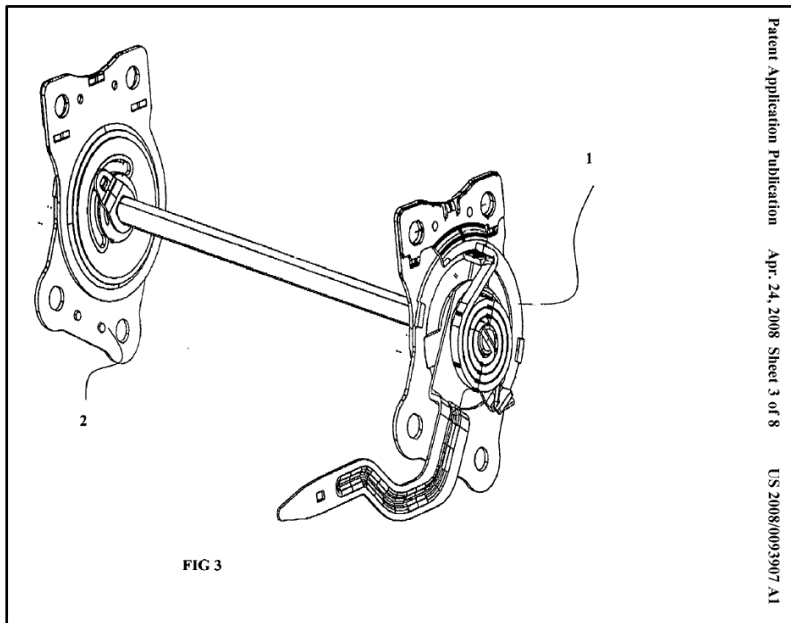


Figure 1: Drawing of dual recliner system with pawl and sector gears and connecting rod [4].

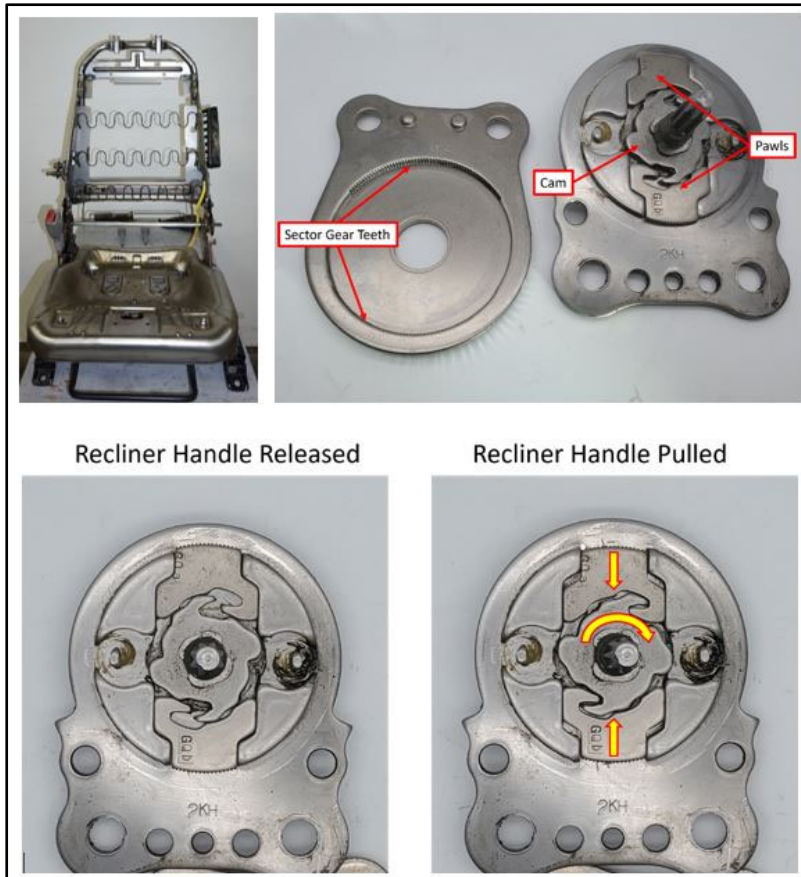


Figure 2: Typical dual manual recliner seat with pawl and sector recliners.

During the analysis of real-world cases with seats of this design, it has been found that inadvertent and / or unintended rotation of the recliner connecting rod during occupant seat back loading, can release one, or both, of the recliners. Such a release allows the seat back to freely rotate rearward in recline thereby undermining the seat structure's ability to deform / yield, absorb crash energy, and provide effective occupant ride down and restraint.

CASE 1 – RECLINER RELEASE VIA ASSYMETRIC DEFORMATION BELOW RECLINER ASSEMBLY

The first case involves a 2011 passenger vehicle which was slowing for stopped traffic when it was rear impacted by a minivan. As a result of the collision, the driver sustained serious head injuries.

During inspection of the subject rear ended vehicle, the driver's seat was found with the seat back angle at a recline angle further rearward than would be expected. The seat was removed from the vehicle, and the cloth upholstery was removed for further inspection and analysis. During the analysis, the following was identified:

- The inboard lower recliner attachment to the seat base was torn (see Figure 3).
- The inboard lower recliner attachment and outboard lower recliner attachment were asymmetrically designed, with the inboard side having a hole in the middle (see Figure 4).
- The tear across the inboard lower recliner attachment allowed the inboard recliner to rotate rearward.
- The inboard and outboard recliners were found post-crash in different adjustment positions.
- Additionally, the recliners were disassembled to inspect the teeth of the pawls and sectors. The outboard sector gear teeth and pawls were found to be damaged.

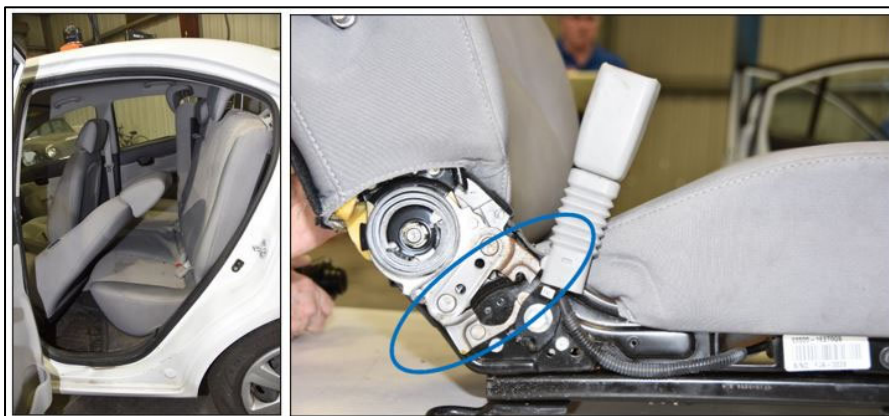


Figure 3: Subject rear-ended vehicle seat with torn inboard lower recliner plate.

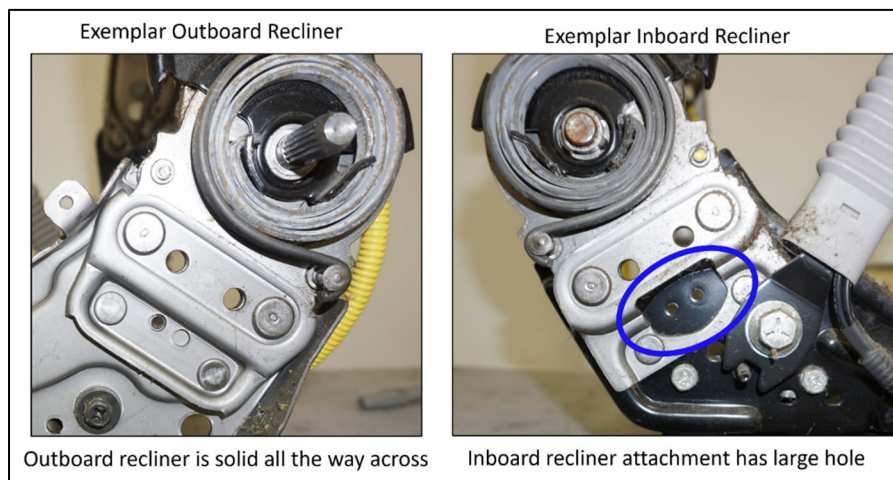


Figure 4: Exemplar seat with asymmetric lower recliner plate designs.

A sled test was performed by SAFE Laboratories of an exemplar seat in an exemplar test buck, with a modified 50th percentile Hybrid III Anthropomorphic Test Device (ATD) to match the seated height and weight of the driver of the rear impacted vehicle [5] [6]. The sled was subjected to an approximately 11.2 m/s (25 mph) rear delta-V, consistent with the accident reconstruction of the subject rear collision. The seatback was seen to rotate rearward in recline such that it failed to restrain the ATD, and the ATD made forceful head contact with the rear seat back (see Figure 5).



Figure 5: Sled test with ATD head contact at rear seat.

Further analysis of high-speed test video and inspection of the tested seat revealed the inboard lower recliner attachment plate tore similar to the accident seat (see Figure 6). The tearing occurred early in the seat loading phase of the test and caused the inboard recliner mechanism to rotate rearward. This rearward rotation of the inboard recliner also rotated the recliner connecting rod which in turn released the outboard recliner. This chain of events resulted in the failure of the seatback to provide any additional support to the ATD in the rear impact collision, and occupant containment was lost. The evidence identified on the test seat was found to be remarkably similar to the evidence identified on the subject accident seat. The posttest recliner inspection further revealed that the seat recliners became adjusted to different positions as a result of the release of the outboard recliner during the occupant loading event.

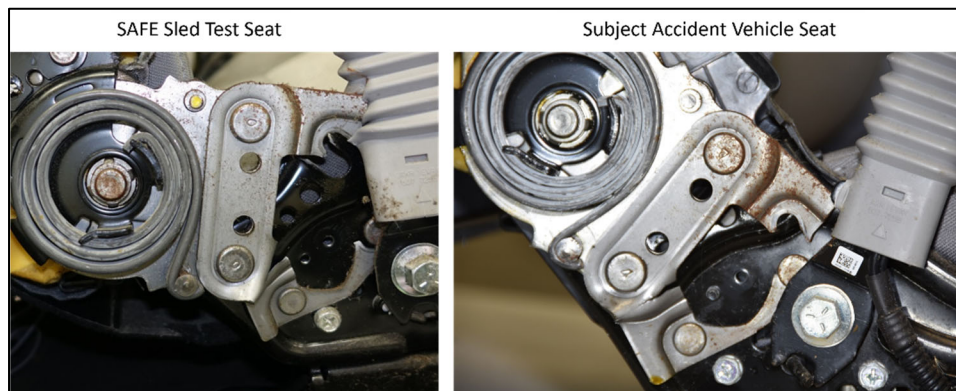


Figure 6: Sled test and accident vehicle seat comparison of inboard lower recliner attachment plates.

CASE 2 – RECLINER RELEASE VIA ASYMMETRIC DEFORMATION BELOW RECLINER ASSEMBLY DEMONSTRATION

The second case occurred when a 2013 light pickup truck was stopped behind a pickup truck at a controlled intersection. The subject pickup truck was rear ended by an SUV and pushed into the pickup truck stopped in front of it.

An inspection of the subject rear-ended vehicle post-crash revealed the occupied right front passenger's seat was reclined to a point such that it was in contact with the second row bench seat. The seat was removed and detrimmed for further analysis and comparison to an exemplar seat. The following was identified during the analysis:

- The seat base and lower recliner attachment plate were deformed on the outboard side (see Figure 7), whereas the inboard side was relatively undeformed.
- The inboard recliner was found in a further rearward recliner adjustment than the outboard recliner (see Figure 8).

- The forward portion of the “banana slot” for the recliner release rod pin was visible on the inboard side, but not the outboard side (see Figure 9).

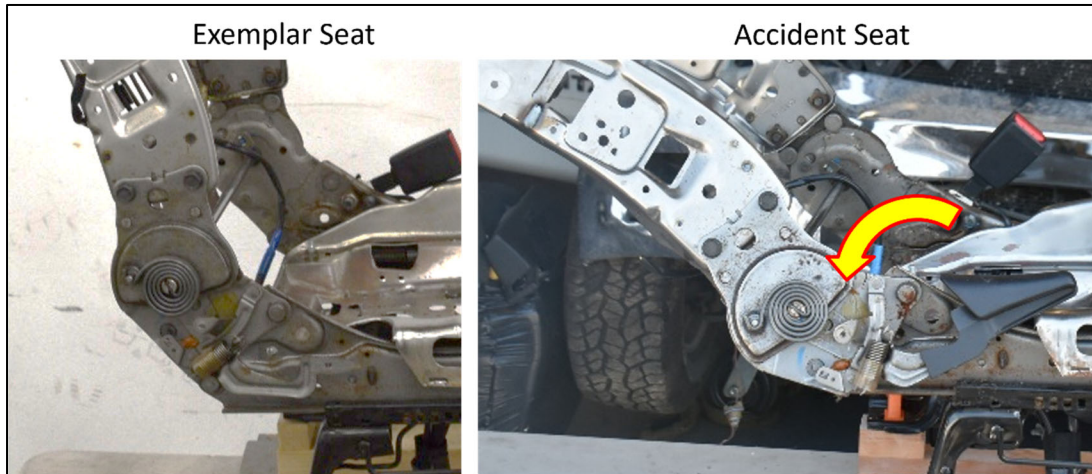


Figure 7: Deformation below outboard recliner.

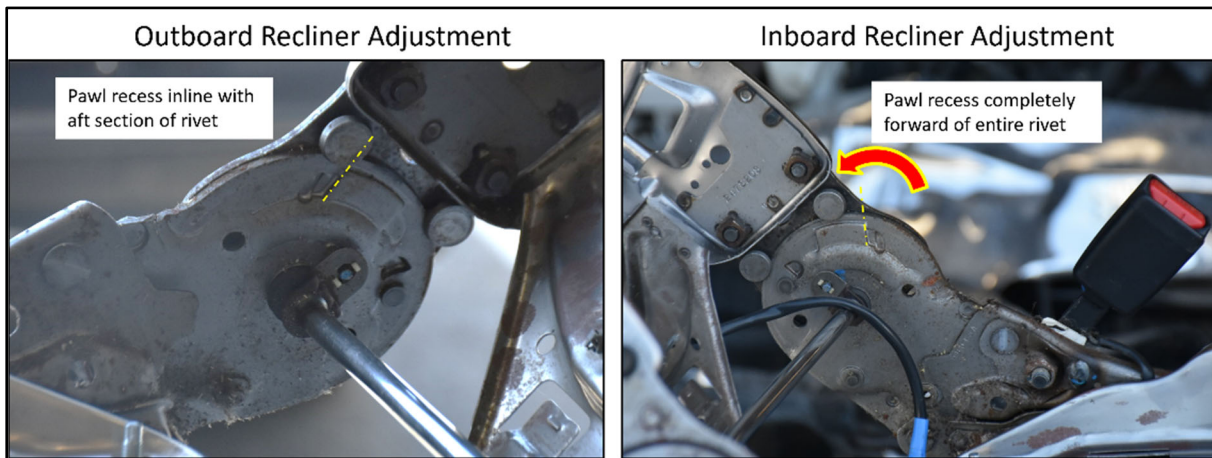


Figure 8: Inboard recliner adjusted further rearward than outboard recliner.

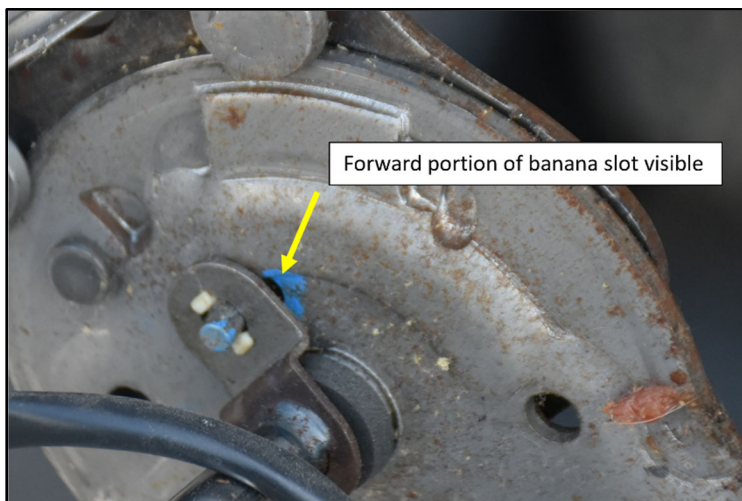


Figure 9: Forward portion of “banana slot” visible.

Inspection and analysis of an exemplar seat showed that during normal operation, pulling up on the recliner adjustment lever (located on the outboard side of the seat) moves the outboard recliner release pin rearward, while rotating the recliner release tube which also moves the inboard recliner release pin rearward, allowing both recliners to then be in the released position and the seatback recline angle to be adjusted. Comparing this to the condition of the accident seat reveals the accident seat inboard recliner was found in the released position while the outboard recliner was engaged. This condition is the result of the outboard seat base and recliner plate deforming below the recliner, causing recliner rod rotation, while the inboard side stayed relatively undeformed.

A demonstrative video was filmed to demonstrate this release mechanism. An exemplar seat was obtained and detrimmed. The recliners were disassembled and modified in order to view the internal pawls in relationship to the sector gears during the demonstration. The recliners were reattached to the seat, however, the lower front attachment was omitted, allowing the seat to experience a “deforming condition” for the demonstration. The “deforming condition” allowed for the outboard recliner to rotate rearward in relation to the inboard recliner, similar to the condition allowed by the outboard lower recliner support structure deformation seen in the accident seat. The top of the seatback was then loaded rearward and the inboard side recliner was seen to release by the rotating connecting rod (see Figure 10).

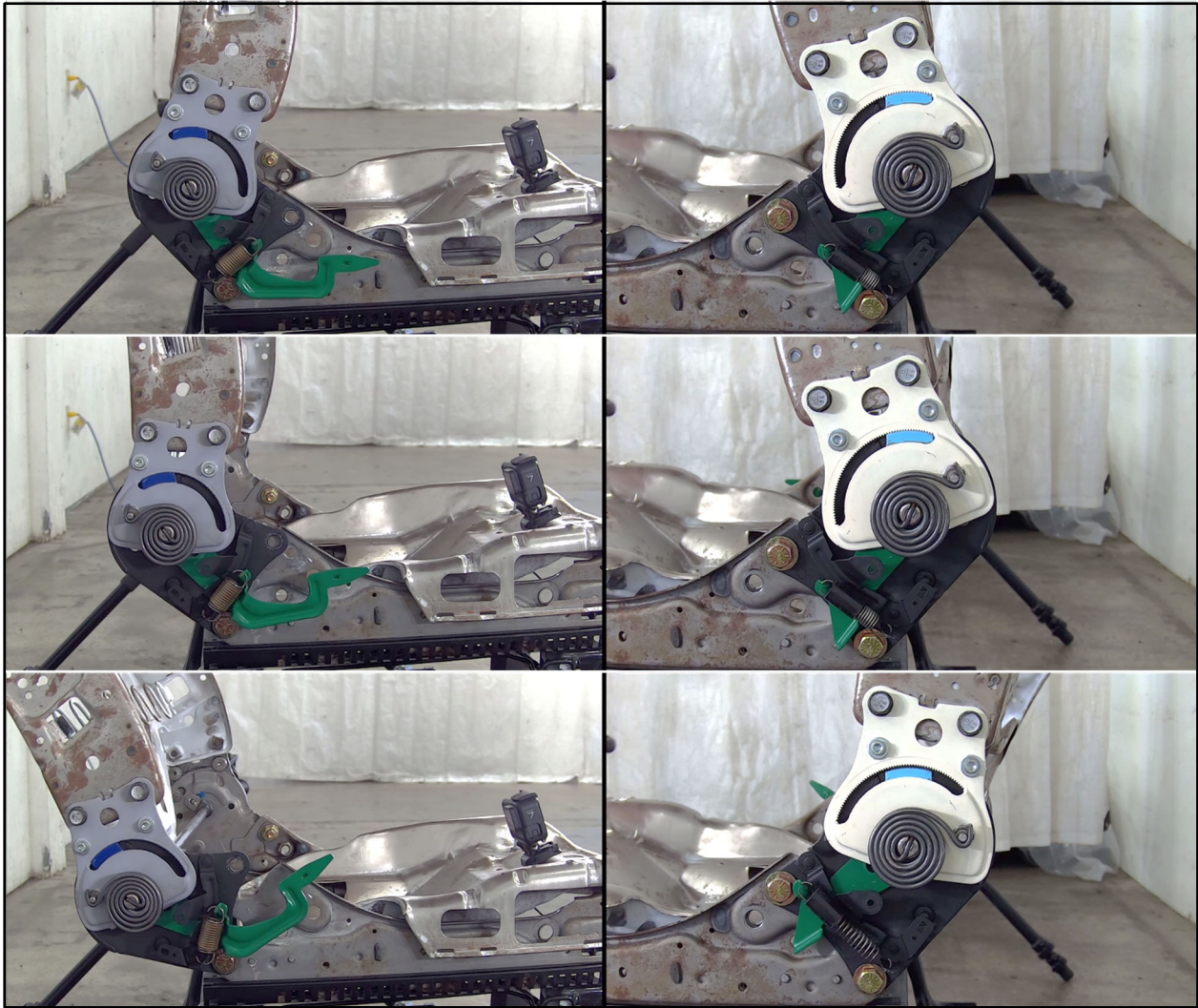


Figure 10: Video demonstration of recliner release via connecting rod.

Analysis of the video demonstration shows that as the outboard side recliner itself rotates rearward, the recliner rotates the recliner connecting rod rearward along with it. As the recliner connecting rod rotates rearward, the inboard cam begins to rotate, and the inboard recliner releases (see Figure 11). At the end of the demonstration, the inboard recliner is found in a further rearward recline adjustment position than the outboard recliner, the front of the “banana slot” on the inboard side is visible, and the inboard recliner remains disengaged, even after load is removed, all consistent with the evidence found on the subject rear impacted vehicle.

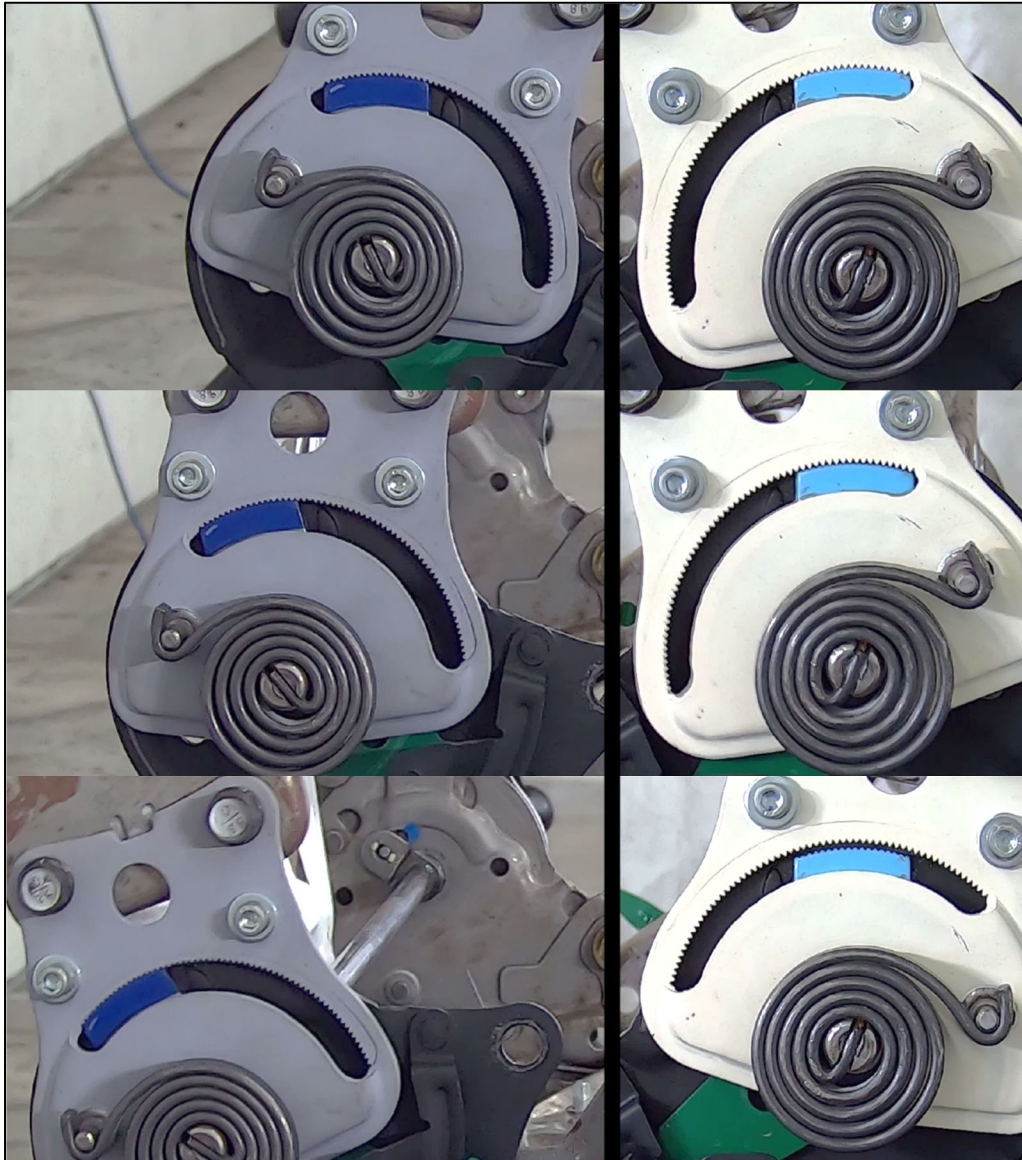


Figure 11: Video demonstration zoomed in.

CASE 3 – RECLINER RELEASE VIA OCCUPANT INTERACTION WITH CONNECTING ROD

The third case occurred when a 2012 passenger vehicle was slowing for stopped traffic when it was rear ended by a sedan. The impact pushed the subject passenger vehicle into another sedan slowed / stopped in front of it and came to rest against a guard rail. As a result of the accident, the child sitting in the left rear seat sustained serious anterior head injury.

A post-crash analysis of the plastic deformation of the driver’s seat revealed very little static deformation when compared to an exemplar seat (see Figure 12). There was no gross asymmetrical tearing or deformation below the

recliners as seen above in case 1 and case 2 however the recliner connecting rod was noted to be bent rearward (see Figure 13). This minimal deformation was inconsistent with the relatively high energy rear end collision as determined by the rear delta-V and occupant weight.

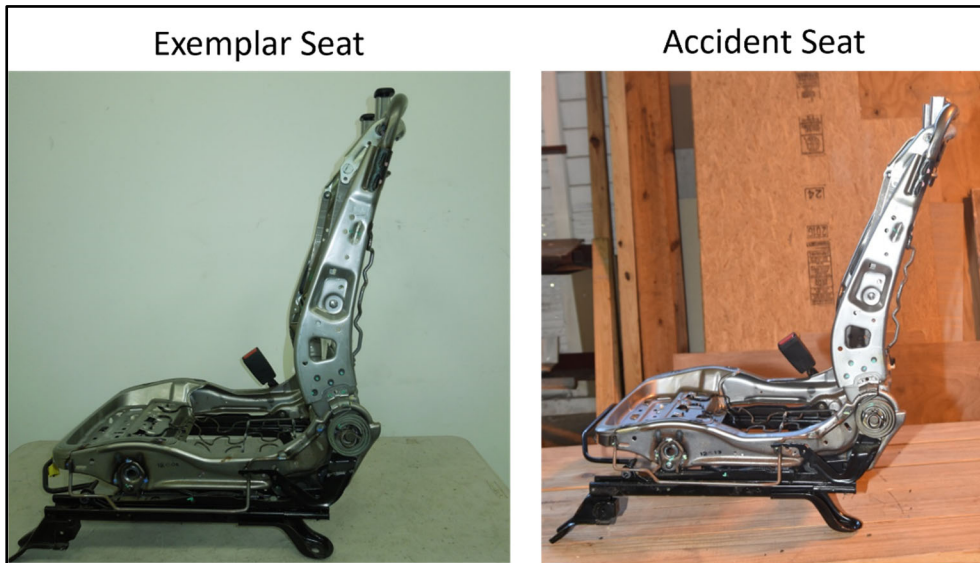


Figure 12: Comparison of exemplar seat and accident seat – minimal deformation.

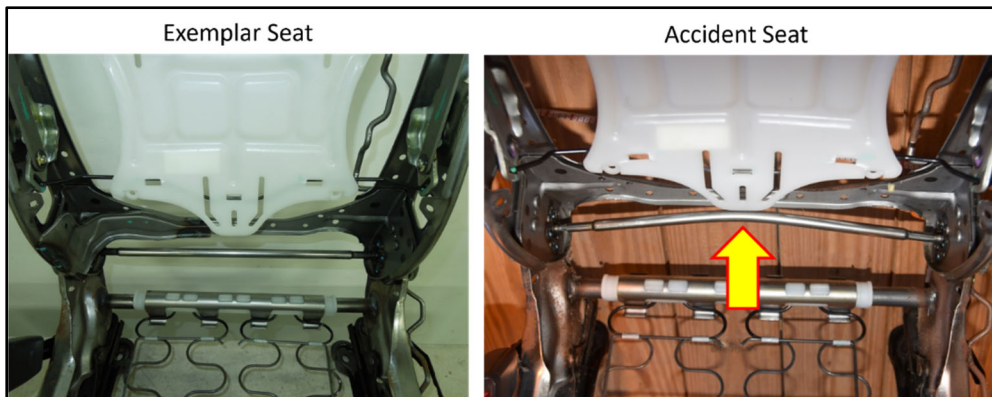


Figure 13: Comparison of exemplar seat and accident seat – recliner connecting rod deformation.

A Failure Mode and Effect Analysis (FMEA) concluded that the occupant's buttocks / lower torso had loaded the recliner connecting rod rearward and then downward, such that it could create a moment on the connecting rod and rotate it sufficiently far to release the recliners during the early phase of the rearward occupant loading the seat (see Figure 14).

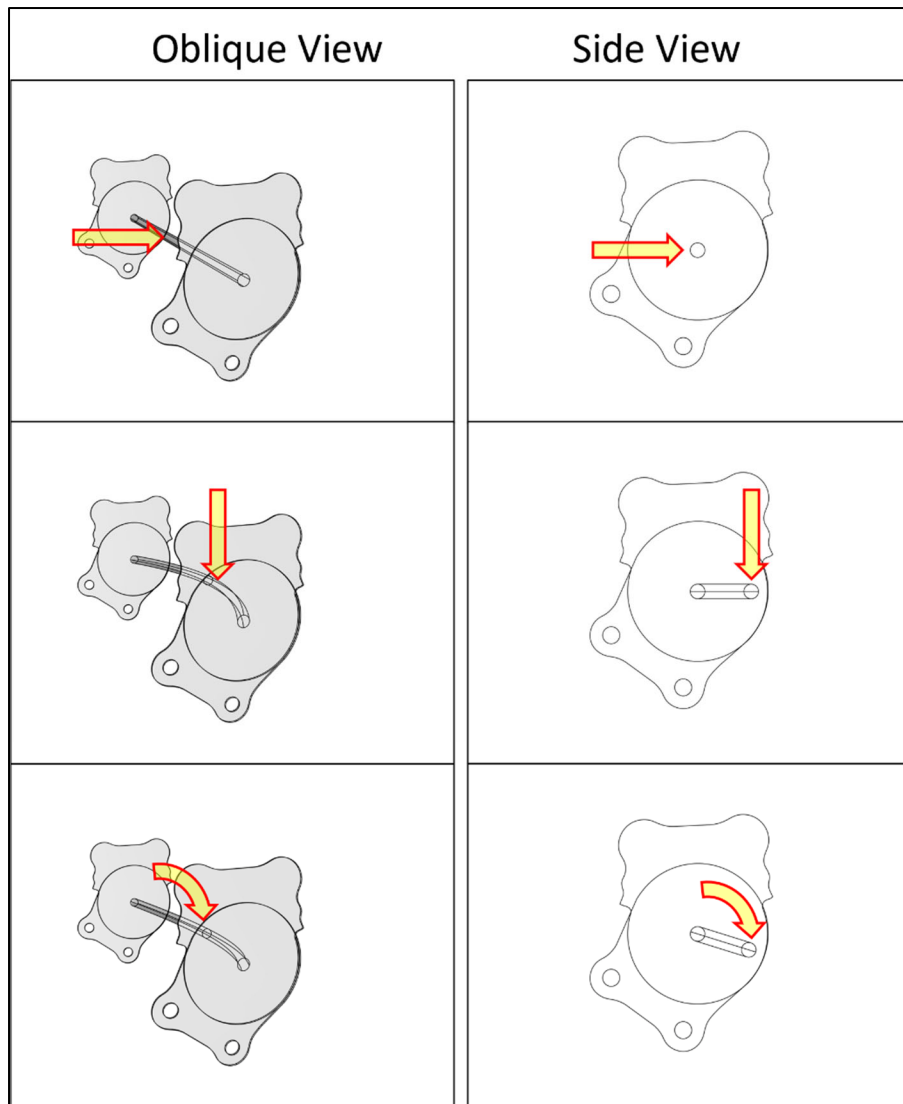


Figure 14: Recliner release mechanism from occupant loading of recliner connecting rod.

Two sled tests were conducted in order to evaluate seat deformation under occupant loading in two different scenarios. An exemplar test buck substantially similar to the subject rear-ended vehicle was obtained and mounted to a sled fixture. A forward-facing child seat was placed in the left rear seat with spacers between the child seat and left rear seat to model the intrusion resulting from the rear end collision. A 3-year-old Hybrid III ATD was placed in the child seat and belted. Sled test #1 was conducted with an OEM seat and a modified 50th percentile Hybrid III ATD to match the seated height and weight of the driver of the subject rear-ended vehicle. The test buck was subjected to a delta-V consistent with the accident reconstruction. Sled test #2 was conducted with the same Hybrid III ATD configuration, however the seat was modified to model the recliner connecting rod releasing the recliners during the rear impact.

In sled test #1, the driver's seat recliners both remained engaged and transferred load into the seat structure such that the seat structure yielded rearward as the occupant loaded the seatback and moved towards the 3-year-old ATD. The seat contained the driver ATD and injurious head contact to the 3-year-old was avoided (see Figure 15). The seat statically deformed rearward in recline approximately 19 to 20 degrees (approximately 15 degrees more than the subject seat) (see Figure 16).



Figure 15: Sled test #1 occupant kinematics – no head-to-head contact.

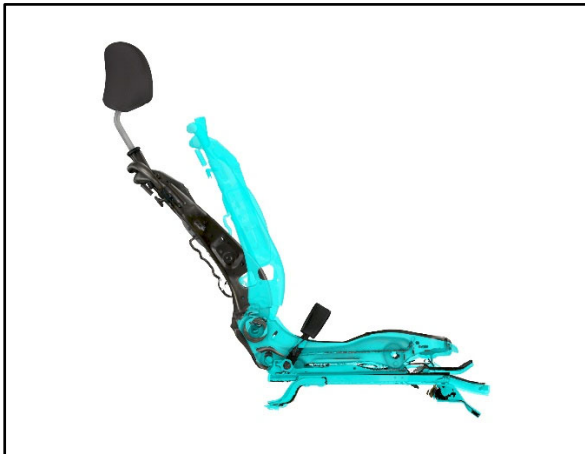


Figure 16: Sled test #1 seat deformation.

In sled test #2, the seatback was seen to rotate rearward in recline without transferring occupant load into the seat structure to provide crash energy absorption, occupant ride down, and occupant restraint. The driver ATD was seen to move rearward relative to the occupant compartment and made heavy head to head contact with the anterior of the 3-year-old ATD head seated in the child seat (see Figure 17). Posttest analysis showed the seat in test #2 was minimally deformed (similar to and consistent with the evidence seen in the subject seat) due to the recliners being disengaged throughout the entire occupant loading phase (see Figure 18).



Figure 17: Sled test #2 occupant kinematics – heavy head to head contact.



Figure 18: Sled test #2 seat deformation – minimal deformation.

CONCLUSIONS

One design challenge of creating modern manually adjustable dual recliner automotive seats is to actuate both recliners in unison in order to be able to adjust the seatback angle for a variety of users. The use of pawl and sector type recliners with an intermediate recliner connecting rod has been seen to result in unintended recliner release during rear impacts. Causes of this unintended release include asymmetric structural deformation below the recliners and occupant interaction with the recliner connecting rod. During the course of post-crash investigation, signs of a single recliner release include asymmetric deformation or structural failure below the recliners and differing recliner adjustment positions between the inboard and outboard recliners. Indicators of dual recliner release include a bent recliner connecting rod and less than expected static seat deformation. Incorporation of rotary continually engaged recliner designs, rather than the sector pawl designs, or use of boden type cables for recliner pairing rather than the torsion recliner connector rods are effective countermeasures to eliminate these risks of unintended or inadvertent recliner release in rear impact collisions.

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