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# Belt Integrated Vehicular Seat Rear Impact Studies

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Static and dynamic studies were conducted with conventional and belt integrated vehicular seats. Most conventional seat backs failed with a static FMVSS 207 rearward torque of approximately 700 to 800 Newton meters (Nm) while integrated seats sustain a comparably measured torque of up to approximately 3,500 to 4,000 Nm. Correspondingly greater rearward changes in speed can be sustained by integrated seats with less likelihood of injury to front and rear seated occupants. The dynamic tests demonstrate the importance of testing within the full vehicle interior structure to insure that floor strength is compatible with seat strength to attain optimum occupant protection in stronger seat designs and to assess injury risk to occupants in collapsing seat designs. The tests indicate that quasi-static seat strength measurements using a more realistic torso body block device can provide reasonable estimates on the ultimate dynamic load capabilities of the seat systems if the seat systems are properly mounted to the vehicle. Quasi-static seat strength results are presented for a variety of conventional collapsing seat designs and stronger seat systems like the belt integrated designs. In addition to the above, some sled buck tests were run with simulated rear seated infants to demonstrate a hazard of front seat collapse into the rear seat area. The results of these tests are also provided and further demonstrate the need for dynamic testing to assess full seat system performance in rear impacts.

Keywords: Belt Integrated Seats, Rear Impact, Vehicular Seat Strength

## INTRODUCTION

A limited number of commercially available belt integrated motor vehicle seats were introduced in the United States and Europe during the 1980 time frame [1,2]. A primary purpose of the belt integrated seat designs was to provide improved safety over conventional collapsing seat systems for front seat occupants in all modes of impact, including rear impact. In 1989 the National Highway Traffic Safety Administration was petitioned to improve the Federal Motor Vehicle Safety Standard (FMVSS) 207 regarding seat strength [3]. As part of this petition it was recommended that the seat strength requirements of 207 be increased substantially, and it was also strongly recommended that dynamic tests be used to assess the performance of seat systems during rear impact. In addition, it was recommended that during a severe rear impact the front seat systems should be able to safely support up to a 95th percentile adult male with a limited rearward rotation of the seat system, so as to provide protection to the front seat occupant, and rear seat occupants who may be struck and injured if the front seat system and its occupant collapsed into rear seat area.

During the 1990 time frame an even larger number of manufacturers offered the belt-integrated seats as standard equipment in a growing number of motor vehicle lines. Since the restraints in a belt integrated seat are attached directly to the seat structure, rather than the motor vehicle structure, the belt integrated seats are designed with substantial strength increases that exceed conventional collapsing seat strength by several hundred percent. In a study published in 1993, it was found that energy absorbing capacity of typical conventional collapsing seat systems was less than adequate for even average rear impact situations and this study concluded that stronger seats are more likely to provide improved safety benefits over seat systems that collapse at relatively low energy levels [4]. By the mid-1990 time frame the NHTSA contracted with designers and manufacturers of motor vehicle seat systems to investigate and recommended safer seat systems. The results of this research generally concurred with the recommendations made in the 1989 petition [5]. For instance, both the 1989 petition and the NHTSA sponsored study recommend dynamic tests using a 95th percentile adult male surrogate, in a simulated severe rear impact, with similar limits on the amount of rearward rotation of the seat back.

In addition to the outside contracted research, the NHTSA also conducted in-house research to measure seat performance and analyze injury costs of collapsing seats [6,7]. It was estimated that, over a 10 to 54 kph Delta V range, if all seat backs collapsed the injury cost would be at least 2.83 times as much as if all seat backs maintained their initial position [6]. The NHTSA also began instrumenting one of the two surrogates used during NHTSA sponsored FMVSS 301 testing. The amount of seat back rotation was also measured during these 301 tests. The preliminary results of the in-house NHTSA study indicated that the current 207 standard required inadequate seat strength to insure that seats do not fail when a motor vehicle is subjected to a severe rear impact.

In spite of the above, there has been some criticism of the use of stronger seats [8,9]. The suggestion has been made that conventional collapsing seats may actually be more beneficial for the occupants during a rear impact because occupants in stronger seats may be susceptible to whiplash injuries if they are leaning forward or to the side, grossly out-of-position. However, Viano made an evaluation of 1,915 field observations on front-seated occupant posture and headrest positions [10]. The results of the Viano studies indicate, among other things, that the "out-of-position" configurations used in the critical studies [8,9] are much greater than those likely to occur in real world situations. Thus, the use of unrealistic "grossly out-of-position" test surrogates provides, at best, an unlikely possible hazard for stronger seats. In addition, most critical studies of stronger seats fail to test the conventional collapsing seat designs within the full constraints of the vehicle rear area interior and therefore, hazards associated with uncontrolled collapse into rear structures or rear passengers are not properly addressed.

One means for more accurately assessing the concerns of opponents of stronger seat systems is through the use of dynamic side-by-side testing of conventional collapsing seats and the stronger belt integrated seat designs, within the full confines of the motor vehicle system. Generally, dynamic testing is more costly than quasi-static testing. However, quasi-static testing with instrumented surrogates can provide valuable insight into the potential limitations of certain seat systems during rear impact situations.

This study uses a more realistic torso body block to spread the load over the seatback during quasi-static strength testing. Sled buck tests were used to correlate collapse levels of conventional seats during rear impact, with strength levels obtained from the quasi-static tests. The stronger belt integrated seat designs were dynamically tested simultaneously with the conventional collapsing seat designs during the sled buck tests. Some tests were also run with simulated infant surrogates placed behind the collapsing conventional seat systems, so as to demonstrate some of the dangers of collapsing seats. In some tests the stronger seats were mounted to the original floor design and these tests illustrated the importance of dynamic testing with the actual vehicle compartment and floor to insure that the floor strength is compatible with the improved seat strength.

## QUASI-STATIC MEASUREMENTS OF SEAT STRENGTH CHARACTERISTICS

Several types of seat systems from various vehicle types were tested statically using an upper torso body block. Table 1 presents information from tests run on conventional "original equipment manufactured" (OEM) collapsing seat systems using "single" recliners.

| OEM Seat Types with Single Recliners | Seat Wt. - Kg (lbs) | Peak Horizontal Load- kN (lbs) | Average Stiffness- kN/m (lbs/inch) | Peak Structure Torque- N-m (foot-lbs) |
|---|---|---|---|---|
| 84' Mazda 626 {2 test ave.} | 20.45 (45) | 2.31+/- 0.9 (520+/- 20) | 27.1+/- 0.175 (155+/ 1.0) | 826+/- 40.6 (610+/- 30) |
| 87' Plymouth Horizon | 17.27 (38) | 3.11 (700) | 17.5 (100) | 889 (656) |
| 88' Ford Aerostar | 18.64 (41) | 3.02 (680) | 26.3 (150) | 960 (708) |
| 89' Ford Bronco RF | 24.09 (53) | 3.02 (680) | 22.8 (130) | 954 (704) |
| 91' Jeep Wrangler | 16.82 (37) | 3.00 (675) | 21.9 (125) | 908 (670) |
| 91' Plymouth Voyager | 22.27 (49) | 2.58 (580) | 18.2 (104) | 786 (580) |
| 95' Jeep Grand Cherokee | 15.00 (33) | 3.56 (800) | 30.6 (175) | 1022 (755) |
| 96' Dodge Neon {2 test ave.} | 15.00 (33) | 3.16+/- 0.3 (710+/- 30) | 39.2+/- 0.88 (224+/- 5.0) | 1148+/- 72 (847+/- 53) |
| 98' Ford Expedition (SR) | 25.91 (57) | 4.44 (1000) | 31.8 (182) | 1479 (1092) |
| Average: | 19.50 (43) | 3.13 (705) | 26.1 (149) | 997 (736) |

TABLE 1: Quasi-Static Body Block Test Comparison of Strength Characteristics for Single Recliner Types of Conventional Seats in Various Vehicle Systems

Table 2 presents the same type of information from quasi-static upper torso body block tests run on conventional collapsing seat systems using "dual" recliners on each side of the seatback base and seat cushion junction. Table

3 presents similar information measured from stronger belt integrated seat systems.

| OEM Seat Types with Dual Recliners | Seat Weight Kg (lbs) | Peak Horizontal Load- kN (lbs) | Average Stiffness-kN/m (lbs/inch) | Peak Structure Torque-N-m (foot-lbs) |
|---|---|---|---|---|
| 76' Mercury Capri (DR) | 15.91<br>(35) | 3.73<br>(840) | 21.9<br>(125) | 1077<br>(795) |
| 84' Toyota Camry (DR) | 20.00<br>(44) | 5.91<br>(1330) | 61.8<br>(353) | 1829<br>(1350) |
| 84' Volvo 760 (DR) | 20.00<br>(44) | 7.22<br>(1625) | 40.1<br>(229) | 2141<br>(1580) |
| 88' Saab 9000 (DR) | 18.18<br>(40) | 6.53<br>(1470) | 73.9<br>(422) | 2033<br>(1500) |
| 94' Saturn SL1 (DR) {2 test ave.} | 13.18<br>(29) | 3.64+/-0.4<br>(820+/-90) | 51.8+/-0.7<br>(296+/-4.0) | 1003+/-190<br>(740+/-140) |
| 95' Mazda Millenia (DR) | 24.55<br>(54) | 4.91<br>(1105) | 41.1<br>(233) | 1310<br>(967) |
| Average: | 18.64<br>(41) | 5.32<br>(1198) | 48.7<br>(276) | 1565<br>(1155) |

TABLE 2: Quasi-Static Body Block Test Comparison of Strength Characteristics for Dual Recliner Types of Conventional Seats in Various Vehicle Systems

Figure 1 illustrates the body block load device applied to a seat system during quasi-static rearward loading. The upper torso body block was used to spread loads against the seat back structure in a manner similar to what a human body would do during a rear impact. Saczalski presented this method of assessing the performance of a seat back structure during a 1995 SAE TOPTECH on "Seat Design for Automotive Safety" [11].

The torso body block method of testing applies the loads over the seatback through a position more closely in line with the upper torso center of gravity of an actual occupant, rather than at the upper cross member specified in the 207 test. Another distinction between the 207 testing and the torso body block method is that the torques in this study are calculated about the structural junction of the seat back structure and the seat base structure, rather than being calculated about a hypothetical "H" point or "seating reference" point (SgRP). As a result of the difference of the location for calculation of torque values, the structural torque measurements are generally about 15 to 30 percent greater than the torques calculated by the 207 method. Table 4 provides a comparison of torques calculated with a 207 method and the quasi-static torso body block structural method for some of the seats of Table 1.

The quasi-static body block measured information on both single and dual recliner seat systems are made from various vehicle types that include sedans, mini-vans and sport utility vehicles (SUV). Generally, these seat systems weigh about 20 kilograms and have a peak horizontal load capacity of about 3,000 to 5,000 Newtons. In some instances repeat tests were run. The average values and plus or minus variations are indicated for these tests.

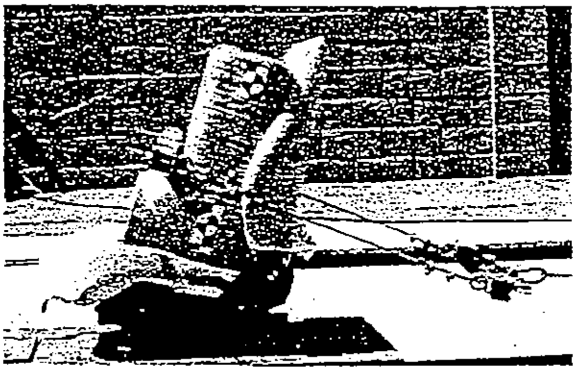

Figure 1. Quasi-static Torso Body Block Test Set-up

Typically, the dual recliner seat strength and rearward torque resistance are about 60 to 70 percent greater than that of the single recliner systems. Also, although not shown, the calculated energy absorbing capacity of the dual recliner systems can be at least 60 percent greater than that of the single recliner systems.

In some cases, however, the "dual" recliner seat systems, like the single recliner types, can experience catastrophic failure of the recliners, and if that type of catastrophic failure occurs before the seat system deflects or rotates more than 20 to 25 degrees the "dual" recliner seat system may not even reach the energy level of some single recliner systems. The seat system shown in figure 1 utilizes a dual recliner seat system where both recliners failed in a repeatable fashion; first one side and then the other. Figure 2 illustrates the "horizontal" load versus displacement curve for this test, as well as the sudden load release resulting from stripping of the gear teeth.

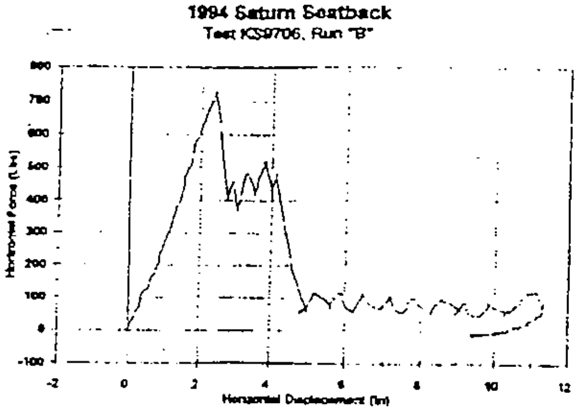

Figure 2. Load Curve Showing Recliner Teeth Failure

The sudden load drop-offs, and subsequent "saw-tooth" or "ratcheting" load patterns, are displays of the failure of first one recliner and then the other, with the "saw-tooth" patterns indicating stripping of the recliner gear teeth. It should be noted that the recliner teeth were examined visually and photographed, and video documented, before and after each test to insure that the surfaces of the gear teeth were in good shape before each test was run. In short, most "conventional" seat systems can fail in a multitude of ways which include, among other things: failure of the recliner mechanisms and attachments; failure or peeling apart of the adjustment tracks; and buckling or some other form of failure of the seat frame support structures or floor attachments.

In order for a seat system to safely retain and protect an occupant during a rear impact, the seat system must play a role analogous to that of the seat belt during a frontal impact. For instance, in a frontal impact the seat belt and it's anchorages must support more than 10,000 Newtons of load, with limited displacement, in order to fully support the belted occupant inertial loads, and safely "decelerate" the occupant at a rate similar to that of the vehicle, as external crush takes place around the outside of the occupant compartment. Likewise, for the reverse direction of impact, the seat system is the best means for "accelerating" an occupant up to the new higher speed of a vehicle that is impacted from the rear and shoved forward.

Typical rear impact loads for most automotive vehicles subjected to an average rear-impact change in velocity of about 30 kilometers per hour (kph) would be in the range of about 12 to 15 G's at the vehicle center of gravity [11]. Using 60 percent of an occupant's total weight as the "upper body" weight that acts against the seat back of the seat system during rear impact, the seat load capacity necessary to accelerate an average size male occupant (i.e. about 75 kg) up to speed during an average rear impact would require that a seat support peak loads of about 5,300 to 6,600 Newtons. It is unlikely that conventional single recliner seat systems will reach this level but some of the dual recliner seat systems shown in Table 2 may achieve the necessary load level.

| Stronger Belt Integrated Seat (BIS) Types | Seat Wt. -Kg (lbs) | Applied Horizontal Load- kN (lbs) | Average Stiffness- kN/m (lbs/inch) | Peak Structural Torque- N-m (foot-lbs) |
|---|---|---|---|---|
| 89' BMW 850 BIS | 30.91<br>(68) | 15.56<br>(3500) | 102.1<br>(583) | 5732<br>(4229) |
| 92' Starcraft Van Integrated Belt Seat | 23.18<br>(51) | 10.44<br>(2350) | 55.7<br>(318) | 3716<br>(2742) |
| 95' Ford Transit Van BIS (Europe) | 30.45<br>(67) | 14.00<br>(3150) | 91.1<br>(520) | 4641<br>(3425) |
| 97' Chrysler Sebring BIS | 21.82<br>(48) | 14.67<br>(3300) | 105.1<br>(600) | 4336<br>(3200) |
| 97' Buick Park Avenue BIS | 44.10<br>(97) | 9.91<br>(2230) | 63.8<br>(364) | 4743<br>(3500) |
| Author Modified 88' Aerostar (BIS) | 28.63<br>(63) | 16.00<br>(3600) | 86.9<br>(496) | 5556<br>(4100) |
| Author Modified 95' Jeep Grand Cherokee (BIS) | 15.91<br>(35) | 15.11<br>(3400) | 93.0<br>(531) | 4810<br>(3550) |
| Average: | 27.7<br>(61) | 13.67<br>(3076) | 85.3<br>(487) | 4790<br>(3535) |

TABLE 3: Quasi-Static Body Block Test Comparison of Strength Characteristics for Stronger Belt Integrated Types of Seats (BIS) in Various Vehicle Systems

The uncertainty of the failure modes, and the relatively low load and energy levels associated with the conventional single and dual recliner "collapsing" seat systems, can be improved through the use of stronger seat systems like the "belt integrated" types. Table 3 presents quasi-static "torso body block" measured data for several commercially available belt integrated seat (BIS) systems as well as modifications made to some conventional collapsing seat systems. The "applied" loads from the seat tests cited in this table are not necessarily "peak" loads and as such, in most cases these stronger seats were not loaded to ultimate failure. Dynamic tests indicate that these seat systems can carry much greater loads than those applied statically in this phase of the research. Discussion of the results of the dynamic comparison tests is provided in the following sections of the paper.

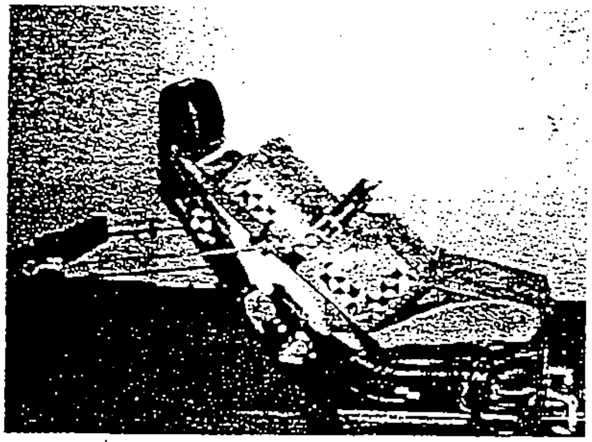

Figure 3. Quasi-static Test of Belt Integrated Seat

Figure 3 illustrates the quasi-static body block test set-up for one type of commercial belt integrated seat where the upper torso and lap belts are attached directly to the seat rather than the vehicle. Since these types of seats must pass a combined 207 and 210 FMVSS test for forward loading of more than 10,000 Newtons for each occupant belt attached to the seat, these seats (i.e. BIS) usually possess similar rearward direction strength levels.

It should be noted that the seats tested with the quasi-static "torso body block" test method are mounted to a rigid base test platform and, as such, the effects of floor flexibility and strength of mountings are not tested in the static tests. That is to say that the seats have "normal use" function, such as recline or moving forward and aft on the seat tracks, but the "original equipment manufactured" (OEM) seat to floor mounts are not used. Thus, during sled buck tests and crash tests the seats are normally mounted to "strengthened floor structures" so as to enable reaching ultimate strength levels for purposes of comparing side by side the surrogate performance of the stronger belt integrated seats and the weaker conventional seat systems. In some cases dynamic tests of the strengthened seats were run with the original mounts and non-strengthened floor structures to demonstrate that the stronger seats can only provide improved performance if they are properly mounted on floor structures of compatible strength.

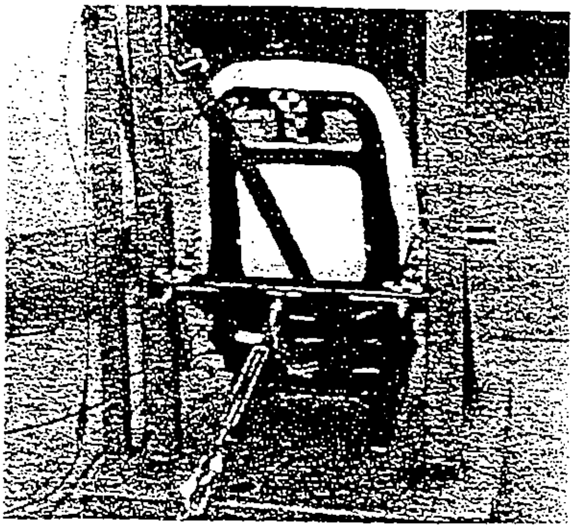

Figure 4. Diagonal Belt Integrated Behind Seatback

Figure 4 illustrates another form of belt integrated seat where a seat belt and retractor are mounted diagonally across the seat back, and connected to the motor vehicle structure such as the "B" pillar, specifically for the purpose of improving seat strength during rear impact. In essence, during a rear impact, the diagonal belt across the seat back acts similar to a shoulder harness during a frontal impact. This concept of mounting a portion of the upper seatback structure to the upper portion of the motor vehicle interior for the purpose of improving seatback strength and resistance to collapse during rear impact goes back to at least the 1970's time frame [12] where a mechanical linkage was suggested from the top of the seatback to the vehicle upper structure. More recently, in 1992, the Starcraft Company patented another version of this concept, specifically using a seat belt behind the seatback. The corresponding load versus deflection data for the seat system shown in figure 4 is comparable to that of the seat shown in figure 3.

As noted earlier, Table 4 provides a comparison of the torque calculated by using a FMVSS 207 type torque arm (i.e. "H" point reference) and the structural torque arm that is measured from the load application point down to the junction of the seatback and seat cushion structures. Obviously, since the "structural torque arm" is greater than the "207 moment arm" then the "structural torque" will also be greater than the "207 torque".

The Table 4 also provides data on energy capacity for seatback deflection of 20 to 25 degrees from a start position of about 20 degrees inclination from the vertical. Thus, adding the initial position and deflected seatback angle position would give a final position of 40 to 45 degrees from the vertical. Typically, a single recliner seat system will only absorb about 350 Joules (J) of energy when the seatback is deflected about 20 to 25 degrees from the initial seat back angle position. Allowing the seat to rotate back farther than the position of 40 to 45 degrees from the vertical will provide some small amount of extra energy capacity (i.e. about 25 to 35 percent more) but only at the risk of encroaching into the rear occupant "survival space" and allowing the restrained occupant to slide rearward from the seat belt system. This amount of energy (i.e. 350 J) is less than one third of that required to safely accelerate an average male occupant up to final speed in an average rear impact.

| OEM Seat Types with Single Recliners | Seat Wt. - Kg (lbs) | Approx. 207 Energy @ 42.5 degrees- Joules (foot-lbs) | Approx. 207 Torque N-m (foot-lbs) | Peak Struct. Torque- N-m (foot-lbs) |
|---|---|---|---|---|
| 88' Ford Aerostar (SR) | 18.64 (41) | 305 (225) | 814 (600) | 1023 (755) |
| 91' Plymouth Voyager (SR) | 22.27 (49) | 325 (240) | 705 (520) | 786 (580) |
| Average: | 20.45 (45) | 315 (233) | 759 (560) | 904 (667) |

TABLE 4: Comparison of Quasi-Static Body Block Test Structural Torque with 207 Type Quasi-Static Torque

It should be obvious that, for the same amount of rotational seatback displacement, the stronger belt integrated seats with strength levels several hundred percent greater than conventional OEM collapsing seat systems will also possess greater energy capacity and torsional resistance.

## DYNAMIC RESPONSE COMPARISON - CONVENTIONAL AND STRONGER SEATS

Several sled tests were run with belted surrogates to evaluate the occupant protective performance, and differences, between conventional collapsing seat systems and stronger belt integrated seat systems. Table 5 summarizes some of the pertinent characteristics of one series of tests. In this series of sled tests a 1988 Ford Aerostar mini-van vehicle body was mounted to an 1820 kg movable sled device. Figure 5 shows the pretest configuration of the sled "body buck" just prior to running of tests number 1 and 2. For each test the vehicle front seats and rear seats, as well as the associated structures directly behind the front seats, are included for the purpose of examining potential interaction of front seat occupants with rear interior structure, or other occupants in the rear, in the event of front seat collapse or excessive yield.

| TEST TYPE: Vehicle Body on Sled Buck | SEAT TYPES: DR=Driver RF or LR =Passenger | DUMMY TYPES: DR=Driver RF or LR =Passenger | Target Vehicle Speed Change | Target Vehicle Ave. G's & Pulse Width |
|---|---|---|---|---|
| 88 Ford Mini-van Sled Buck Test 1 | DR = OEM<br>RF = Belt Integrated (BIS) w/ Standard Floor & mounts | DR= H III 50 % male Pedestrian<br>RF = H III 50 % male (Sitting) | 47.0 kph<br>(29.2 mph) | 14.1G's<br>160 ms |
| 88 Ford Mini-van Sled Buck Test 2 | DR = OEM<br>RF = Belt Integrated (BIS) w/ Improved Floor & mounts | DR= H III 50 % male Pedestrian<br>RF = H III 50 % male (Sitting) | 46.0 kph<br>(28.6 mph) | 14.0G's<br>160 ms |
| 88 Ford Mini-van Sled Buck Test 3 | DR = OEM<br>LR = Infant Seat on std. Rear Middle Bench Seat | DR = H III 50 % male Pedestrian<br>LR = Child Rag Doll | 47.3 kph<br>(29.4 mph) | 14.1G's<br>160 ms |

TABLE 5: Sled Test Parameters for Comparison of Occupant Response in Stronger versus Conventional Seats & An Example of Hazards to Rear Passengers

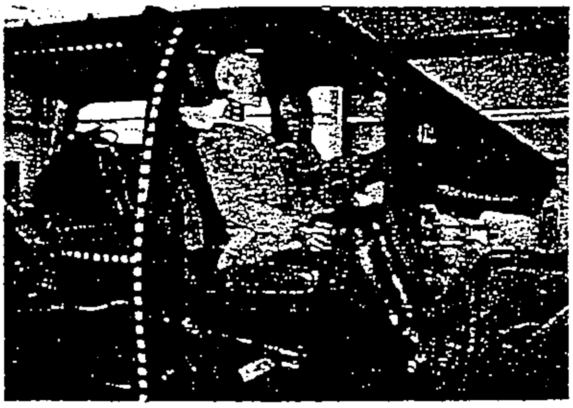

Figure 5. Aerostar Body Buck with BIS and OEM Seats

During each of the three tests listed in Table 5 the sled buck system is towed rearward into a crushable barrier that produces a crash pulse on the vehicle similar to a specified rear impact crash pulse. In this series all three tests were run with a crash pulse that produced a speed change of approximately 47 kilometers per hour (kph) and an average G loading of 14 G's. The vehicle crash pulse shape for this series was trapezoidal. A crushable honeycomb barrier material, built into a wedge shape, was used to produce the desired pulse shape and crash characteristics. A vehicle-to-vehicle crash test verified that the change in speed and average G levels were consistent with the actual crush characteristics of the actual vehicle.

In all three tests, the driver seat was an original equipment manufactured (OEM) conventional collapsing seat. In tests 1 and 2, a stronger belt integrated seat replaced the OEM right front seat. Figure 5 illustrates the right front surrogate seated in the stronger belt integrated seat, and the left front (i.e. driver) surrogate seated in the conventional OEM collapsing seat. Hybrid III 50 percentile male surrogates each occupied both front seats with the exception that a standing pelvis was used with the dummy in the collapsing seat so as to more realistically replicate the flexible body kinematics of a human subject during seatback collapse. The heads of the front seat surrogates were chalked so as to determine contact impact points, if any, in the rear area. In test 3 the right front surrogate was removed and a child seat with a rag doll surrogate was placed behind the OEM collapsing driver seat so as to demonstrate one of the serious risks to rear occupants, like children, in the event of front seat collapse into the rear occupiable area. Figure 6 illustrates the child seat and rag doll surrogate behind the OEM driver seat prior to impact during test 3.

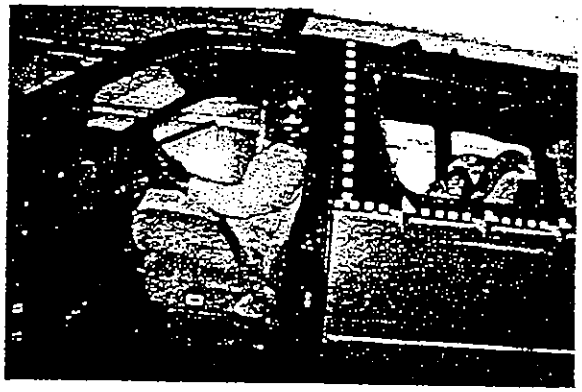

Figure 6. Child Seat Behind OEM Seat Prior to Test 3

In test 1, the right front stronger belt integrated seat (BIS) was mounted to the original floor structure with OEM bolts. During this test (1) the body loads on the stronger seatback caused the front floor mounts of the seat to be pulled loose from the OEM floor structure. This allowed the stronger seat and its surrogate to pivot rearward into the rear seat area. In spite of this failure, the stronger seatback and seat base retained their angular relationship to each other allowing the surrogate to be retained in place within the confines of the seat system. The adjacent OEM driver seat also failed, but the seatback totally collapsed rearward from the seat base due to metal tearing and buckling at a "notch cut-out" in the seat base frame near the recliner bracket attachment. This failure allowed the driver surrogate to recline more horizontally and slide back from the lap restraint, causing the head and neck to strike forcefully into the bench seatback directly behind. This was evidenced by the pronounced rear seat head contact-impact chalk mark left by the surrogate of the collapsing driver seat.

Conversely, no head-impact chalk marks were noted on the rear seatback side of the stronger seat even though it eventually collapsed rearward. Consistent with the above head contact or impact observations, the HIC value for the surrogate in the weaker OEM seat of this test was much higher than the surrogate of the stronger seat, as shown by the results of Table 6. This is in part, because the stronger seat absorbed more energy than the weaker conventional seat, even though the floor mounts ultimately failed. In fact, in all cases the surrogate seated in the conventional collapsing seat has much higher HIC values than does the comparison surrogates in the stronger seats. Similarly, the neck loads were less severe on the stronger seat surrogate of this test than were the corresponding loads on the surrogate of the collapsing OEM driver seat as shown in figure 7.

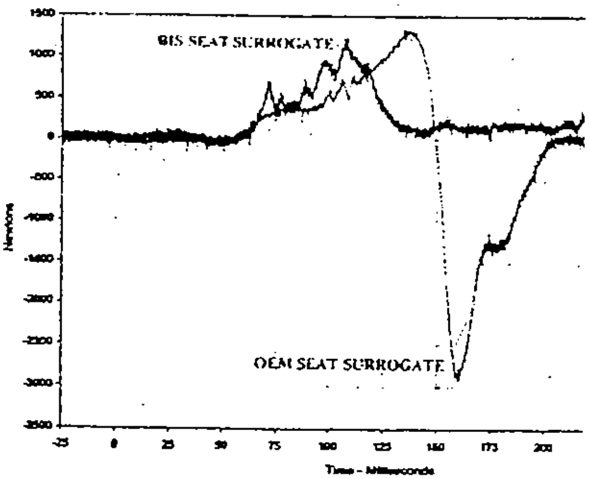

Figure 7. Test 1 Axial Neck Load Comparisons for OEM and BIS Seated Surrogates

Some pertinent injury criteria for a Hybrid III 50 percentile male surrogate, based on NHTSA information [13], includes: head injury criteria (HIC) less than 1000; neck axial tension limit of 3300 N (742 lbf); neck axial compression limit of 4000 N (899 lbf); and neck torque limits about the Y axis for flexion of 190 Nm (140 lbf-ft) and neck extension of 57 Nm (42 lbf-ft).

| Dummy/ seat & test # | HIC Value | T1 / T2 (ms) | Avg. G's |
|---|---|---|---|
| Driver/ OEM Test 1 | 583.6 | 137.0/159.1 | 58.6 |
| Passenger/ Stronger RF (BIS)-Test 1 | 111.4 | 212.5/232.4 | 31.5 |
| Driver/ OEM Test 2 | 753.8 | 136.7/149.1 | 81.5 |
| Passenger/ Stronger RF (BIS)-Test 2 | 378.4 | 84.8/120.7 | 40.6 |
| Driver/ OEM Test 3 | 1136.2 | 121.1/154.2 | 65.1 |
| LR Child Seat & rag Doll- Test 3 | NA | NA | NA |

Table 6: Comparison of Head Injury Criteria Results

Although the test 1 head and neck loads on the surrogate in the stronger seat were generally lower than those of the surrogate in the weaker OEM collapsing seat, the intrusion into the rear occupant area was considered unsatisfactory, and thus this test was rerun with an improved mounting of the stronger seat to the floor. This test also underscored the need to have floor structures and mounts that are compatible in strength with the improved strength of the stronger seat system. Thus, in test 2, the stronger BIS was mounted to a reinforced floor structure so as to eliminate pulling loose and collapsing rearward. The improved floor mounts on the stronger seat in test 2 allowed this seat system to remain upright during this test. Figure 8 illustrates the posttest conditions for the seats of this test.

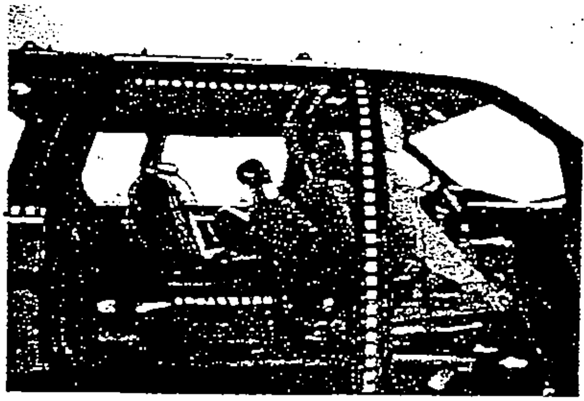

Figure 8. Upright BIS and Collapsed OEM Seat of Test 2

The head injury criteria results given in Table 6 once again indicate lower likelihood of head injury to the surrogate in the stronger seat. Figure 9 compares the resultant head accelerations for both surrogates in test 2. The comparison of torque loads, and neck axial loads, for the surrogates in the stronger BIS (right front) and weaker conventional OEM driver seat of test number 2 are shown in figures 10 and 11, respectively. Positive torque values indicate flexion and negative values indicate extension. Figure 10 shows that the surrogate in the OEM seat exceeded the neck extension injury level.

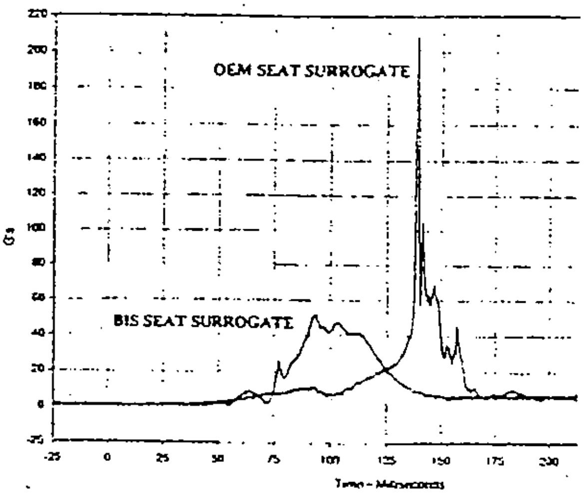

Figure 9. Resultant Head Acceleration Comparison-Test 2

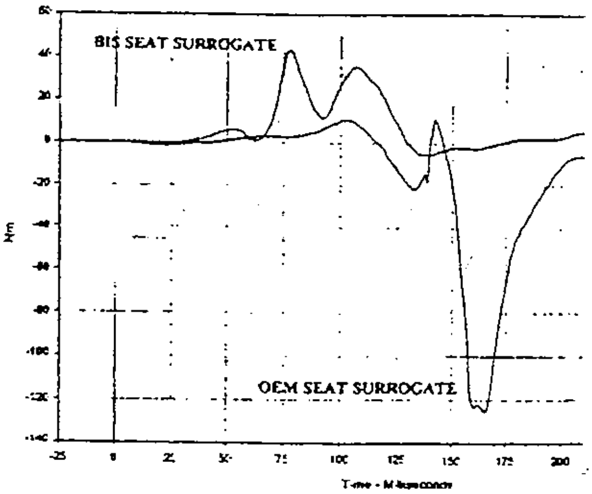

Figure 10. Neck Torque Comparison about Y Axis-Test 2

It should also be noted that in this test 2 the only seat that was replaced from test 1 was the OEM driver seat. The stronger right front belt integrated seat used in test 1 was reused in this test with the only change being that the floor mounts were strengthened so that the BIS seat would stay up during this test. The axial neck loads for test 2 are shown in figure 11. An increase of the tensile loads on the neck of the surrogate in the stronger BIS system is noted when compared to test 1. This may be due in part to the reuse of the BIS seat from test 1, or possibly a non-optimum design of the headrest.

Also, in this test the driver seat peeled loose from the seat tracks rather than tear metal on the seat frame near the recliner, as was the case in the test 1 driver seat failure. The variation in failure modes of a specific conventional seat design is consistent with variations noted during the quasi-static tests.

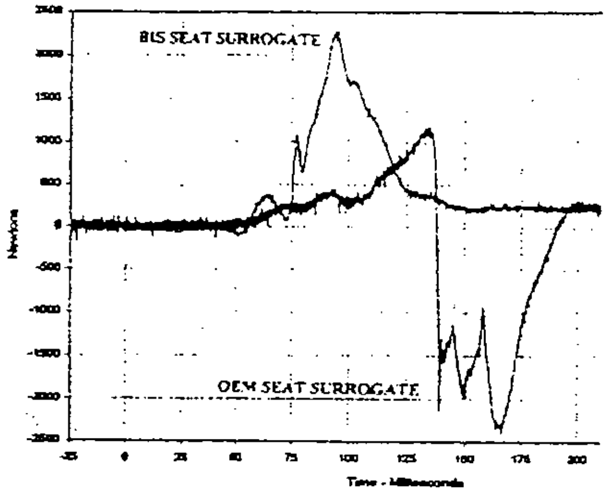

Figure 11. Neck Axial Load Comparisons -Test 2

An estimate of the dynamic failure load levels likely to be experienced by most conventional collapsing seats (either single or dual recliner type) during a rear impact, with various sizes of individuals, can be made by simply dividing the "upper body" weight of the individual into the quasi-static measured "peak horizontal" load capacity of the seat system. The resulting calculation will give an estimate, in gravitational "G" units, of the level at which seat collapse can be detected dynamically, by observing when the horizontal "chest acceleration" curve begins to level out and then drop off. If this "leveling" of the horizontal chest acceleration takes place at a G level lower than the horizontal peak "G" of the vehicle center of gravity then the seatback will likely collapse prematurely, allowing the occupant to catapult rearward where that occupant, or others seated behind, like infants or children, may be injured.

For example, using the quasi-static seat data, a Ford Aerostar mini-van seat with an average size male surrogate would collapse at about 7 G's dynamic load. In figure 12, which shows the dynamic horizontal chest loads on the surrogate in the OEM Aerostar seat, it is noted that the driver chest was accelerated up to about 9 G's at 100 ms before the acceleration dropped off about 6 G's. This drop off in chest acceleration is indicative of seat collapse since the 9 G chest acceleration level is below the average vehicle acceleration level of 14 G's. Subsequently the loads go up when the surrogate contacts forcefully into the rear seat.

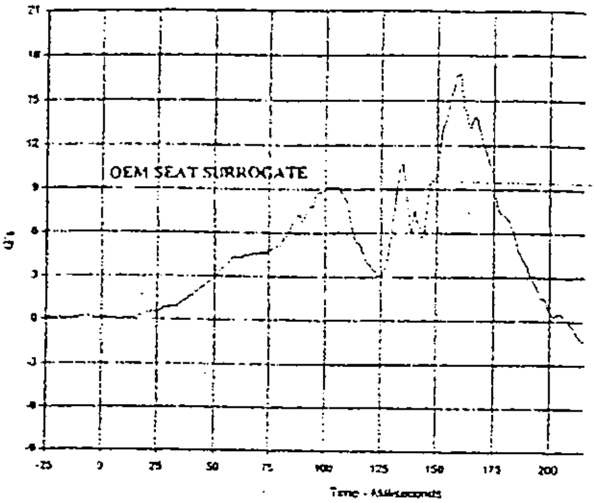

Figure 12. OEM Surrogate Chest X-Acceleration- Test 2

In test 3 the right front surrogate was removed and a child seat with a rag doll surrogate was placed in the left rear behind an undamaged OEM driver seat. As in the previous tests the OEM driver seat collapsed rearward, this time due to shearing of recliner teeth, and this allowed the front seat surrogate to strike forcefully into the rag doll surrogated seated in the rear. Figure 13 shows the head chalk impact marks from the back of the front seat surrogate on the face of the rag doll. Also, this figure

Figure 13. Post Test 3 Child Surrogate Contact Evidence

shows the feet of the rag doll trapped in the headrest cutout of the collapsed front driver seat. Fractured legs and head or chest injuries have usually resulted to rear seated children from this type of impact. The HIC value for the driver surrogate of this test exceeded the injury threshold value of 1000. This indicates that a child in the rear would also likely receive serious head injury. Several actual instances of injury to rear seated children caused by collapsing front seats and occupants have been noted.

## CONCLUSIONS

Based upon the results of this study, it is concluded that: 1) Dual Recliner Seat Systems can provide greater energy absorption and load support than single recliner systems if the recliners do not fail catastrophically such as by sheering of recliner teeth or other catastrophic failure mechanisms; 2) Belt Integrated Seat (BIS) systems, and those with the belts mounted diagonally behind the seats, provide much greater seat strength and energy capacity than do either single or dual recliner conventional seat systems; 3) collapse of weaker conventional seat systems provides some small amount of energy absorption, but far less than is needed to absorb the energy of an average adult male in an average level of rear impact; 4) weaker collapsing seat systems tend to collapse into the rear occupant area and pose a hazard to rear seated occupants as well as those seated in the collapsing seat; 5) use of belt restraints does not provide a positive means for retaining the occupant in a collapsing seat or preventing severe contact-impact with rear structures or occupants; 6) surrogates in the stronger belt integrated types of seats tend to have lower injury producing load levels than do the surrogates of the collapsing seat types; 7) head rest designs on current belt integrated seat systems do not appear to be optimally designed and could be improved; 8) a body block or more realistic upper torso load device should be used for quasi-static testing of seat strength; and 9) dynamic rear-impact tests, with full interiors and the related vehicle crash pulse, should be conducted with instrumented adult surrogates in the front, and child surrogates in the seat behind (if applicable), to assess seat performance, as well as structural compatibility of seat mountings and occupant protection levels within the true confines of the entire vehicle interior. Finally, dynamic testing with front seated 95th percentile male surrogates, and rear seated child surrogates, should also be conducted to more fully assess the safety of not only various sized front seat occupants but also the safety of smaller occupants seated behind the front seats.

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