Seat strength in rear body block tests

David C. Viano\textsuperscript{a} and Samuel D. White\textsuperscript{b}

\textsuperscript{a}ProBiomechanics LLC, Bloomfield Hills, Michigan; \textsuperscript{b}Collision Research & Analysis, Inc., Torrance, California

**ABSTRACT**

**Purpose:** This study collected and analyzed available testing of motor vehicle seat strength in rearward loading by a body block simulating the torso of an occupant. The data were grouped by single recliner, dual recliner, and all belts to seat (ABTS) seats.

**Methods:** The strength of seats to rearward loading has been evaluated with body block testing from 1964 to 2008. The database of available tests includes 217 single recliner, 65 dual recliner, and 18 ABTS seats. The trends in seat strength were determined by linear regression and differences between seat types were evaluated by Student’s \( t \)-test. The average peak moment and force supported by the seat was determined by decade of vehicle model year (MY).

**Results:** Single recliner seats were used in motor vehicles in the 1960s to 1970s. The average strength was 918 ± 224 Nm \((n = 26)\) in the 1960s and 1,069 ± 293 Nm \((n = 65)\) in the 1980s. There has been a gradual increase in strength over time. Dual recliner seats started to phase into vehicles in the late 1980s. By the 2000s, the average strength of single recliner seats increased to 1,501 ± 335 Nm \((n = 14)\) and dual recliner seats to 2,302 ± 699 Nm \((n = 26)\). Dual recliner seats are significantly stronger than single recliner seats for each decade of comparison \((P < .001)\). The average strength of ABTS seats was 4,395 ± 1,185 in-lb for 1989–2004 MY seats \((n = 18)\). ABTS seats are significantly stronger than single or dual recliner seats \((P < .001)\). The trend in ABTS strength is decreasing with time and converging toward that of dual recliner seats.

**Conclusions:** Body block testing is an quantitative means of evaluating the strength of seats for occupant loading in rear impacts. There has been an increase in conventional seat strength over the past 50 years. By the 2000s, most seats are 1,700–3,400 Nm moment strength. However, the safety of a seat is more complex than its strength and depends on many other factors.

**Introduction**

The history of FMVSS 207 related to the strength of seats has been covered by Severy et al. (1976), Strother and James (1987), Warner et al. (1991), and Viano (2002). In summary, the Society of Automotive Engineers (SAE 1963) approved a recommended practice and performance standard J879 for passenger seats and adjusters. The J879 standard specified 2 tests. The first test established a minimum strength for horizontal inertial loadings of the seat in front and rear impacts of 20 g. This represented about a 900 kg (2,000 lb) seat track anchorage load for a typically large domestic bench seat and evaluated the retention capability of the adjuster mechanism and seat anchorages. The second test addressed the seatback strength and established a minimum moment of 480 Nm (4,250 in-lb). In 1965, the General Services Administration (GSA) released Federal Standard 515–6 on “Anchorage of Seats” that became effective for 1967 model year automobiles. GSA adopted the SAE J879 recommendations with no major changes for government purchased vehicles.

In the mid- to late 1960s, Severy started a series of rear crash tests and research on the strength and height of the seatback (Severy et al. 1967a,b, 1968a,b, 1969a,b). The testing addressed many aspects of rear impact safety from whiplash to occupant retention to crashworthiness and to fuel system integrity. In 1967, they reviewed the Liberty Mutual “capsule chair” safety seat with integrated 4-point crossing belts and crash testing of intersection collisions at 48–64 km/h (30–40 mph; Severy et al. 1967a). The seat was constructed of titanium alloy tubing and had integrated seat wings. Severy et al. (1968a,b) tested seats with strength up to 3,960 Nm (35,000 in-lb) and found severe hyperextension of the neck with 610–710 mm (24–28 in.) seatback heights. This work was contemporaneous with the Cox belt integrated seat described by Hilton (1966). Severy et al. (1976) continued to develop seat concepts including the integral safety seat, which supported a rear load of about 5,880 Nm (52,000 in-lb) or 22.3 kN (5,000 lb). The integrated seat had a 813 mm (32 in.) head restraint height.

In the late 1960s, NHTSA contracted a study to investigate occupant responses in rear impacts (Kihlberg 1969). Based on the new information, FMVSS 207 was issued by the Department of Transportation. It established a minimum 373 Nm (3,300 in-lb) seatback strength for passenger vehicles. This strength was consistent with the GSA and SAE standards, because FMVSS 207 referenced the strength to the H-point (hip pivot point) described in SAE J826b (SAE 2002). The H-point was about 20 cm (8 in.) higher than the reference pivot point at the interface between the seat frame and track adjuster that was used in
SAE J879 and GSA 515–6. FMVSS 207 also included a requirement that fold-forward seatback locks withstand a 20 g inertial load. In 1972, FMVSS 207 was expanded to include front and rear seats in passenger cars, multipurpose vehicles, trucks, and buses.

NHTSA (1974) proposed adding rear impact barrier crash test performance requirements and consolidating FMVSS 207 seat requirements with FMVSS 202 head restraint requirements. NHTSA sponsored research studies to assess occupant protection in rear impacts (Hu et al. 1977, 1978). The proposal was terminated in 1979 based on new field and test data analysis and public comments. NHTSA then decided to focus on a total systems approach for occupant protection and to evaluate vehicle and occupant crash performance in a series of field-relevant crashes.

In 1989, Kenneth Saczalski, Edward Horkey, and Alan Cantor petitioned NHTSA for revisions in FMVSS 207 (see docket 89–20). Dr. Saczalski recommended increasing the seatback torque requirement to 6,330 Nm (56,000 in-lb) to reduce the potential for seatback failure in rear impacts. Mr. Horkey recommended adding seat belt locking requirements for rear impacts to reduce risks for rebound injury. He believed that the seat should be designed to absorb energy in rear impacts and to yield in a controlled manner. He claimed that more rigid seatbacks would exacerbate rebound because of greater release energy in stiff seats than in yielding seats. He predicted that whiplash and other neck injuries would be more likely in stiff seats. Mr. Cantor recommended that FMVSS 207 be revised to eliminate ramping along a collapsed seatback during rear impacts.

NHTSA reviewed the petitions and decided to undertake further investigations. The agency stated that seat performance was a complex issue and that increasing seatback strength was only one aspect of occupant safety in rear impacts. It requested public comments on the petitions and data on the interaction of seatbacks, head restraints, and safety belts in rear impacts. Strother and James (1987) reported that safety belts were beneficial in rear impacts and that seatbelts provided the same protection in rear impacts as in frontal impacts. They also found that seatbelts were effective in reducing fatalities in rear impacts and that seat belts provide the same protection to the chest, head, and face in rear impacts as in frontal impacts.

NHTSA terminated Mr. Horkey’s petition to amend seat belt requirements in 1990 but continued its research on Dr. Saczalski’s petition. James et al. (1991) found that a yielding seatback was beneficial in reducing overall societal harm in rear impacts. Harm was introduced by NHTSA to prioritize safety efforts on the incidence and severity of crash injuries (Malliaris et al. 1982, 1985). Harm was shown to be minimal with ejection and contact with the vehicle rear interior with yielding seatbacks. The field accident data also confirmed that seat belt restraint use in rear impacts had a substantial injury-reducing effect.

NHTSA contracted an investigation of seatback safety performance and comfort through accident analysis and in-depth study (Digges et al. 1993). The authors found that noncontact injuries (no direct contact at the site of injury) were most harmful and that contact injuries were most commonly attributed to the seat and frontal components. More than half of the occupants in severe crashes received injuries from frontal contact, and some were in seats that did not deform during the crash. This conclusion was consistent with findings of Parttyka (1990, 1992). All noncontact neck fractures were in non-deformed seats. The authors also found that secondary frontal impacts contributed to rebound injuries.

NHTSA has been addressing the safety performance of seats for almost half a century. Occupant protection in rear impacts is complex because it affects not only seatback strength but also head restraints and seat belt performance in all crash modes (NHTSA 1992). Optimal protection depends on crash severity, occupant biometrics, and other factors. Saunders et al. (2003) found that seats of 2–3 times the strength of FMVSS 207 were performing well in FMVSS 301 crash tests. NHTSA decided not to revise FMVSS 207 in 2004, closing out the petitions by Dr. Saczalski and Mr. Cantor.

The strength of seats has changed over the past 50 years. FMVSS 207 involves testing the seat frame with a centered, point-load rearward from the top cross-member of the seatback. The test does not include the seat foam and trim and does not involve an occupant loading of the seatback. Severy et al. (1958, 1968a,b, 1969a,b) initially developed rear static testing of seats by pulling a dummy rearward into the seatback. They refined a method where a body block with the shape of an occupant’s torso was pulled rearward into the seatback. Over the past 50 years, many tests have been performed on production seats. These data provide a unique representation of how seats have changed with rearward loading. This study provides a review of that data and average seat strength based on the available body block testing.

In a rear impact, the vehicle is accelerated forward and experiences a change in velocity (delta V). As the vehicle is displaced forward, the seat loads the occupant. This force accelerates the occupant through the delta V of the crash. About 70% of the occupant’s weight is loaded by the seat. The seat must be strong enough to transfer energy to an unbelted occupant without ramping off of the seatback as it deforms from the loading. The energy transfer is $E = \frac{1}{2}m\Delta V^2$, where $m$ is 70% of the occupant’s mass and $\Delta V$ is the change in velocity of the impacted vehicle. Static testing of seats has been compared to dynamic testing on the sled to show that seat strength is proportional to the energy transfer capability of a seat (Viano 2002). The body block testing reported here has 2 useful purposes: it determines the (1) strength of the seat, which is related to the energy transfer capability of the seat, and (2) loads that the seat attachments apply to the floor of the vehicle.

**Methods**

**Body block test**

The Collision Research & Analysis (CRA) body block test is a modification of the FMVSS 207 test procedure. It is a quasistatic rearward pull on the seatback using a body block configuration developed by Severy et al. (1967a,b) and used by Strother and James (1987) and Warner et al. (1991) with slight modifications.

Figure 1 shows a schematic of the test setup with a horizontal and centered direction of rearward pull ($0^\circ$ orientation).
Figure 1. Schematic of the body block test setup.

Figure A1 (see online supplement) shows a photograph of a body block seat test. The body block is positioned on the seat and loaded 35.6 cm (14 in.) above the seat cushion. The seat is mounted to a portion of the vehicle floor pan so that the support for the seat tracks is equivalent to its installation in the vehicle, because the tracks are normally bolted to the floor.

Figure 2 shows the dimensions of the body block, which is attached to a hydraulic ram and provides a distributed rearward load on the seatback. The body block simulates the force of an occupant's torso on the seatback in a rear crash. The block weighs 13.6 kg (30 lb). It is placed on the seat cushion and rests against the seatback.

The seat is positioned mid-track with the seatback in the full upright position or approximately 22° rearward of vertical, if the upright position is deemed too vertical. The rearward pull is horizontal to the fixture and is terminated when one of 3 conditions is met: (1) the seat angle reaches approximately 45°, (2) the seat structure cannot support an increase in load, or (3) the body block migrates upwards more than a few inches.

Instrumentation

Data measurements are made during the test. A load cell (SWO-5K, Transducer Techniques) is mounted at the end of the hydraulic ram. A linear potentiometer (DPT250, Celesco) is placed in line with the ram and digital inclinometers (Seika N4s) are placed on either side of the seat above the pivot axis. The data is digitally collected (IOTech Daq/50), filtered, and stored in engineering units.

The seat is photographed and measured before and after the test. Two or more video cameras (various models over the years, currently HD versions) are used to record the application of force and seat deformation.

Data analysis

The force is plotted against the linear displacement of the body block. The force is multiplied by the 35.6 cm (14 in.) moment arm to determine the moment applied to the seat. The peak force and peak moment are measures of the seat strength. The energy transfer to the seat is determined by integration of the force over displacement from the linear potentiometer.

The trend in seat strength was evaluated using the linear regression function in Excel, which fit a line to the single and dual recliner moment data and the ABTS data versus seat (vehicle) model year (MY). This provided a slope, intercept, and regression coefficient for the goodness of fit for the change in strength over time.

The difference in the average strength of single and dual recliner seats by decade was evaluated by the Student's t-tests assuming unequal variance. The analysis was performed in Excel to determine the significance of difference in the mean strength. The t-value and P-value are reported along with the degrees of freedom.

Data on body block tests

Body block seat tests were available for 1964 to 2008 MY vehicles from various sources. There were 300 seat tests. This is a convenience sample that includes all available test data. Most of the tests were run by Severy et al. (1967a,b), Blaisdell et al. (1993), or CRA. Some of the test data came from Strother and James (1987), Warner et al. (1991), and Saczalski et al. (2001), where there were some differences in methodology that can be found in the source references.

The seats were grouped by single recliner designs, dual recliner designs, and all belts to the seat (ABTS) designs. For this study, there were 217 single recliner seat tests from 1964–2008 MY vehicles, 65 dual recliner seat tests from 1976–2007 MY vehicles, and 18 ABTS seat tests from 1989–2004 MY vehicles. Some of the data presented here have been discussed by Viano et al. (2009), but the test results have not been grouped by single or dual recliners or subjected to statistical analysis.

Results

Single versus dual recliner seats

Figure 3 shows the individual result for the peak moment in single recliner and dual recliner seats with a rearward body block pull. A line was fit to the data and shows that both types of seat have had a steady increase in moment strength over time. The dual recliner seats are stronger than the single recliner seats. However, the strongest seat tested was a single recliner design. The strength of the seat is not necessarily defined by the number of recliners.

Figure 4 shows the average seat strength by decade for single and dual recliner designs. The average seat strength has increased to 1,501 ± 335 Nm for single recliner designs (n = 14) and 2,302 ± 699 Nm for dual recliner designs (n = 26) in the 2000 MYs.

Dual recliner seats are significantly stronger than single recliner seats. In the 1980s, the average strength of dual recliner
seats was $1,815 \pm 209$ Nm ($n = 8$), significantly greater than $1,069 \pm 293$ Nm ($n = 65$) for single recliner seats ($t = 9.05$, $P < .001$, df = 11). In the 1990s, dual recliner seats were $1,975 \pm 550$ Nm ($n = 31$), significantly greater than $1,403 \pm 611$ in-lb ($n = 83$) for single recliner seats ($t = 4.79$, $P < .001$, df = 59). In the 2000s, dual recliner seats were $2,302 \pm 699$ Nm ($n = 26$), significantly greater than $1,501 \pm 335$ Nm ($n = 14$) for single recliner seats ($t = 4.89$, $P < .001$, df = 38).

**ABTS seats**

Figure 5 shows the data from Figure 3 with the inclusion of ABTS seat tests. ABTS seats have the upper shoulder belt anchor attached to the seatback so the belt system is integrated with the seat. The linear regression through the ABTS data shows that the strength of ABTS seat has declined with time. The average strength of ABTS seats was $4,395 \pm 1,185$ Nm ($n = 18$) from 1989 to 2004. The trend in strength seems to be converging downward with the increasing strength of dual recliner seats. ABTS seats are significantly stronger than dual or single recliner seats. For seats from 1989 to the 2000s, ABTS seats were $4,395 \pm 1,185$ Nm ($n = 18$), significantly greater than $2,105 \pm 636$ Nm ($n = 59$) for dual recliner seat ($t = 7.86$, $P < .001$, df = 20) and $11,400 \pm 568$ Nm ($n = 103$) for single recliner seats ($t = 10.51$, $P < .001$, df = 18).

**Discussion**

Brennan (1949) provided one of the earliest descriptions of the strength of front seats for rearward loading. He explained that the "customary test procedure required that 2-door seatbacks individually be capable of withstanding a rearward load of three hundred pounds at the top of the seatback without suffering any permanent deflection" (p. 2). The procedure resulted in 755 Nm (6,675 in-lb) strength, because the prevailing height of seatbacks was 565 mm (22¼ in.).

Anderson (1961) conducted a broad-based study of seats in rear impacts that included crash tests, modeling, and anthropometric evaluations. The study concluded that seats of 724 Nm (6,400 in-lb) moment strength provided a balance of occupant restraint and reduction in neck extension forces. He confirmed the benefits of yielding seats to control forces on the occupant in rear crashes.

For the 1960s, the strength data from body block testing indicate that bucket seats were single recliner designs with moment strength of 918 ± 224 Nm and load of 2.58 ± 0.63 kN ($n = 26$). This is consistent with the minimum requirements laid out by Brennan (1949) and Anderson (1961).

At that time, single recliner seats typically included lateral braces across the seatback to transfer loads from an outboard recliner adjustment mechanism, which locked the seatback on the outboard side, to the pivot on the inboard side. This made the seatback like an “ironing board” that an occupant loaded during a rear impact and deformed rearward, primarily by rotation of the seatback in the area of the recliner.

The yielding behavior of the single recliner seats was primarily through seatback rotation. This has the effect of dropping the height of the head restraint while the occupant is being pushed forward. The head restraint is moving forward and downward when it contacts the back of the occupant’s head. This causes the head and neck to displace over the head restraint, resulting in neck extension, which increased the risk for whiplash and more serious neck injuries.
The design of front seats did not change much from the 1960s to the 1980s, except for the addition of comfort, adjustments, and usability features and a gradual increase in the height of the seatback and head restraint. In the 1980s, some seats adopted dual recliners, although they continued to include cross-bracing in the seatback even though they had locking recliners on both sides of the seat.

In the early 1990s, the concept of a perimeter frame seatback was developed (Viano 2002, 2008). It focused on the idea of an open seatback without lateral bracing across the seatback. This allowed the occupant to “pocket” into the seatback. The seatback included a strong perimeter frame and dual recliners on the inboard and outboard side to eliminate the need for cross-seatback bracing. This resulted in a stronger seat. The rear of the seat cushion was also lowered to allow a clear rearward path for the pelvis in rear impacts. This allowed the pelvis to drop as it pocketed rearward, rather than ramp up the stiff structures of the rear edge of the seat cushion and cross-braces in the seatback. The earlier approach with an ironing board effect was replaced by a “catcher’s mitt” effect of pocketing into the seatback.

The amount of rearward seatback rotation with perimeter frame seats was less than with earlier seat designs, because the seatback included a strong perimeter frame and dual recliners on the inboard and outboard side. The average moment strength was 2,232 ± 393 Nm for 19 high-retention seats introduced into production by General Motors (Viano 2003; Viano and Parenteau 2015a,b). With perimeter frame seats, as the vehicle displaced forward in a rear crash, the occupant penetrated or pocketed between the sides of the seatback frame. This lowered the forces that developed on the occupant and the torso was gradually accelerated forward until the head, neck, and torso were fully supported. These seats also included a higher and more forward head restraint to increase the area of head support. The open seatback seat became known as a “high-retention seat” or “perimeter frame seat.”

High-retention seats were the first to have an initial low stiffness until the occupant pocketed into the seat and attained support of the head and neck from the head restraint. Once the occupant was fully supported, higher loads from the strong seat frame could be placed on the occupant (Viano 2003). This approach applied low loads until the occupant had uniform support, and only then was the force allowed to increase on the occupant through the delta V of the rear crash. Though high-retention seats were initially introduced in GM vehicles, by the end of the 1990s and early 2000s, many vehicle manufacturers, including Chrysler, Ford, Nissan, Honda, VW, Audi, etc., started using the design or variations of the design. It is mainstream today.

The average moment strength was 2,302 ± 699 Nm and 6.47 ± 1.96 kN (n = 26) for 2000 MY vehicle seats with dual recliners. The majority of seats were in the 1,700–3,400 Nm (15,000–30,000 in-lb) range.

ABTS seats were used in a few luxury vehicles without a B-pillar in the early 1990s. These vehicles were primarily convertibles or trucks with bifold rear doors. They represented less than 0.10% of all light vehicles sold in the United States until 1998. At that time, General Motors started using ABTS seats in luxury vehicles, SUVs, and trucks. The penetration of ABTS increased to over 14% of vehicle sales by the early 2000s. However, in recent years, most vehicles with B-pillar structures have been fit with conventional (high-retention type) seats. The use of ABTS seats has been discontinued for reasons of customer comfort and convenience, cost, and complexity of the ABTS designs. By 2010, only a handful of vehicles (<0.25%) used ABTS.

**Limitations**

There are a number of limitations with the body block test in representing an occupant loading of the seat in a rear impact. For example, the weight of the block is a fraction of an occupant’s weight on the seat and the block does not include a pelvic and lower torso shape that is representative of the seated occupant. The height of rearward pull is not consistent with the center of pressure of an occupant in a rear impact. Viano (2002) developed a quasistatic seat test (QST) that used a seated 50th percentile Hybrid II dummy that was pushed rearward by a load on the lumbar spine. The dummy was free to move on the seat, so ramping and lateral motion were included. The center of pressure started at 154 mm (6.06 in.) and during maximum loading was about 152–203 mm (6–8 in.) above the H-point.

The CRA body block loading references the pull height from the seat bite (interface between the seat cushion and seatback), so the moment reported is not about the H-point. FMVSS 207 and the QST procedure reference the moment strength of the seat about the H-point, which would above the seat bite. The H-point is known in the QST procedure because a 50th percentile Hybrid II dummy is placed on the seat in a standard FMVSS 208 seating position. It is not possible to calculate an H-point moment from the body block data, because the H-point location is unknown without the use of a 50th percentile Hybrid III dummy or SAE J826 H-point machine.

The pull test is stopped when the seatback gets to about 45°. Because the initial seatback angle is about 22°, this gives data on 23° of angular deformation of the seat. In a severe rear crash or a crash including obese occupants, the loading on the seat can occur at angles greater than 45°. In addition, after 45°, the orientation of the load on the seat is no longer horizontal. Sled testing shows that the motion of the occupant in a rear impact is initially horizontal and rearward, but as the seatback rotates, there is a moment of the angular rotation of the occupant that includes a downward force on the seatback. This aspect of an occupant loading is not captured in the body block testing or the FMVSS 207 or QST procedures. Sled testing is needed to determine the later phases of occupant loading or some other orientation of body block loading. In addition, crash and sled testing are the primary means of collecting biomechanical data from the Hybrid III dummy.

The body block data summarized in Figures 3–5 do not detail which seats structurally resisted the quasistatic pull with controlled deformation. That has to be determined by studying the force–deflection trace and examining the seat after the test.

Finally, the body block test does not include the lap–shoulder belts or pretensioners that are used by occupants in rear crashes. The initial loading on the occupant is primarily by the seat, but as the seat deforms the seat belt can play a role in restraining the occupant. These aspects of the occupant restraint system are not included in the body block test.
References

Anderson JO. Dynamics of Occupants in Automotive Accidents Involving Rear Impacts. Warren, MI: Research Laboratories General Motors Corporation; 1961. Report R-34-1295.

Blaisdell DM, Levitt AE, Varat MS. Automotive Seat Design Concepts for Occupant Protection. Warrendale, PA: Society of Automotive Engineers; 1993. SAE 930340.

Brennan JE. Seat Frames. New York, NY: Society of Automotive Engineers; 1949. SAE 490047.

Digges KH, Morris JH, Maliliaris AC. Safety Performance of Motor Vehicle Seats. Warrendale, PA: Society of Automotive Engineers; 1993. SAE 930348.

General Services Administration Standard 515-6 Anchorage of Seats for Automotive Seat Design and Collision Performance. Washington, DC: U.S. Government Printing Office. June 30, 1965.

Hilton BC. Design of low cost seating for effective packaging of vehicle occupants. Proceedings of the 10th Stapp Car Crash Conference, (SAE 660797), November 8-9, 1966.

Hu AS, Bean SP, Zimerman RM. Response of Belted Dummy and Cadaver to Seat Frames. Warrendale, PA: Society of Automotive Engineers; 1977. SAE 770929.

James MB, Strother CE, Warner CY, Decker RL, Perl TR. Occupant protection in rear-end collisions. I: Safety priorities and seat belt effectiveness. Paper presented at: 35th Stapp Car Crash Conference; 1991.

Kihlberg KK. Flexion–Torsion Neck Injury in Rear Impact. Buffalo, NY: Automotive Crash Injury Research, Cornell Aeronautical Laboratory, Inc.; 1969. CAL Report No. V1-2721-R2.

Maliliaris A, Hitchcock R, Hansen M. Harm Causation and Ranking in Car Crashes. Warrendale, PA: Society of Automotive Engineers; 1985. SAE 850090.

Maliliaris A, Hitchcock R, Helllund J. A Search for Priorities in Crash Protection. Warrendale, PA: Society of Automotive Engineers; 1982. SAE 820242.

Molino L. Preliminary Assessment of NASS CDS Data Related to Rearward Seat Collapse and Occupant Injury. Washington, DC: Light Duty Vehicle Division, Office of Crashworthiness Standards, NHTSA; 1997.

NHTSA. Part 571—Federal Motor Vehicle Safety Standards. Washington, DC: Author; 1974. 49 CFR Part 571, Docket No. 74–13.

NHTSA. Summary of Safety Issues Related to FMVSS No. 207, Seating Systems. Washington, DC: Author; 1992.

Partyka SC. Comparison of Belt Effectiveness in Preventing Chest, Head and Face Injuries in Front and Rear Impacts. Washington, DC: NHTSA; 1990.

Saczalski K, Burton J, Lewis P, Saczalski T, Baray P. Evaluation of rear impact seat system performance using a combined load neck injury criteria and Hybrid III surrogates. ASME International Mechanical Engineering Congress; 2001.

Saunders JW, Molino LN, McKoy FL. Performance of seating systems in a FMVSS No. 301 rear impact crash test. Paper presented at: 18th Enhanced Safety of Vehicles (ESV) Conference; 2003.

Severy DM. Engineering studies of motorist injury exposures from rear-end collisions. Trauma. 1970;12(2):81–106.

Severy DM, Blaisdell DM, Kerkhoff JF. Automotive Seat Design and Collision Performance. Warrendale, PA: Society of Automotive Engineers; 1976. SAE 760810.

Severy DM, Brink HM, Baird JD. Collision Performance, LM Safety Car. Warrendale, PA: Society of Automotive Engineers; 1967a. SAE 670458.

Severy DM, Brink HM, Baird JD. Preliminary Findings of Head Support Designs: Paper presented at: 11th Stapp Car Crash Conference; 1967b.

Severy DM, Brink HM, Baird JD. Backrest and Head Restraint Design for Rear-end Collision Protection. Warrendale, PA: Society of Automotive Engineers; 1968a. SAE 680079.

Severy DM, Brink HM, Baird JD. Vehicle Design for Passenger Protection from High-Speed Rear-end Collisions. Warrendale, PA: Society of Automotive Engineers; 1968b. SAE 680774.

Severy DM, Brink HM, Baird JD. Rigid seats with 28-in seatback effectively reduce injuries in 30+ mph rear-end impacts. SAE J. 1969a;77(4):20–25.

Severy DM, Brink HM, Baird JD, Blaisdell DM. Safer Seat Designs. Warrendale, PA: Society of Automotive Engineers; 1969b. SAE 690812.

Severy DM, Mathewson J. Automotive Barrier and Rear-end Collision Performance. Warrendale, PA: Society of Automotive Engineers; 1958. SAE 580335.

Severy DM, Mathewson J, Bechtol O. Controlled automobile rear-end collisions and investigation of related engineering and medical phenomena. Can Serv Med J. 1955;11:727–759.

Society of Automotive Engineers. 1879—Motor Vehicle Seating Systems. Warrendale, PA: Author; 1963.

Society of Automotive Engineers. J826—H-Point Machine and Design Tool Procedures and Specifications. Warrendale, PA: Author; 2002.

Strother CE, James MB. Evaluation of seatback strength and seat belt effectiveness in rear end impacts. Paper presented at: 31st Stapp Car Crash Conference; 1987.

USPTO. Kolena DP, Glinski PA, Crane RS, Humer M, Viano DC, Neely, RJ. General Motors. Vehicle seat with perimeter frame and pelvic catcher. US Patent 5 509 716. April, 1996.

Viano DC. Role of the Seat in Rear Crash Safety. Warrendale, PA: Society of Automotive Engineers; 2002. SAE R-317:1-491.

Viano DC (ed.). The Debate Between Stiff and Yielding Seats: A New Generation of Yielding Seats with High Retention in Rear Crashes. Warrendale, PA: Society of Automotive Engineers; 2003. SAE Book PT-106.

Viano DC. Seat design principles to reduce neck injuries in rear impacts. Traffic Inj Prev. 2008;9:552–560.

Viano DC, Parenteau CS. Serious Injury in Very-Low and Very-High Speed Rear Impacts. Warrendale, PA: Society of Automotive Engineers; 2008. SAE 2008-01-1485.

Viano DC, Parenteau CS. Severe injury to near- and far-seated occupants in side impacts by crash severity and belt use. Traffic Inj Prev. 2010;11:69–78.

Viano DC, Parenteau CS. BioRID dummy responses in matched ABTS and conventional seat tests on the IIHS rear sled. Traffic Inj Prev. 2011;12:339–346.

Viano DC, Parenteau CS. NASS-CDS analysis of high retention seat performance in rear impacts. Traffic Inj Prev. 2015a;16:491–497.

Viano DC, Parenteau CS. Update on the effectiveness of high retention seats in preventing fatal injury in rear impacts. Traffic Inj Prev. 2015b;16(2):154–158.

Viano DC, Parenteau CS, Burnett, R, James M. Influence of Seating Position on Dummy Responses with ABTS Seats in Severe Rear Impacts. Warrendale, PA: Society of Automotive Engineers; 2009. SAE 2009-01-0250.

Warren, MI: Research Laboratories General Motors Corporation; 1961. Report R-34-1295.

Centers for Disease Control and Prevention. 2015. Injury Facts. Atlanta, GA: CDC/NCHS. Available at: http://www.cdc.gov/injury/facts.html.