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Distribution of Belt Anchorage Locations in the Second Row of Passenger Cars and Light Trucks

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ABSTRACT

Seat belt anchorage locations have a strong effect on occupant protection. Federal Motor Vehicle Safety Standard (FMVSS) 210 specifies requirements for the layout of the anchorages relative to the seating reference point and seat back angle established by the SAE J826 H-point manikin. Sled testing and computational simulation has established that belt anchorage locations have a strong effect on occupant kinematics, particularly for child occupants using the belt as their primary restraint. As part of a larger study of vehicle geometry, the locations of the anchorage points in the second-row, outboard seating positions of 83 passenger cars and light trucks with a median model year of 2005 were measured. The lower anchorage locations spanned the entire range of lap belt angles permissible under FMVSS 210 and the upper anchorages (D-ring locations) were distributed widely as well. Combined with the findings from concurrent research on the effects of belt geometry, these results suggest that occupant kinematics in frontal impact can be expected to differ widely across vehicles due to differences in belt geometry.

INTRODUCTION

In the United States, the locations of the anchorages of seat belt systems are regulated by Federal Motor Vehicle Safety Standard (FMVSS) 210. Anchorage locations are referenced to the seating reference point (SgRP), which is measured using the SAE J826 H-point manikin. The H-point manikin torso line is also interpreted as the seat back angle for purposes of FMVSS 210. In vehicle design, a two-dimensional template representing the profile of the J826 H-point machine is often used. This template, which is depicted schematically FMVSS 210, is used to define the upper anchorage location range. Lap belt anchorages must be positioned such that a vector from the anchorage to the SgRP in side view forms an angle of between 30 and 75 degrees with the horizontal. Upper anchorages must be located within a side-view zone defined with respect to the SAE J826 two-dimensional template with the template H-point aligned with the SgRP.

Recent work at the University of Michigan Transportation Research Institute (UMTRI) has demonstrated that belt anchorage locations have a strong effect on occupant kinematics [1,4,5]. More-rearward or higher lower anchorages (flatter lap belt angles) tend to reduce lower-body excursion, except when submarining occurs due to the belt slipping off the pelvis and into the abdomen. More-forward and higher upper anchorage locations tend to increase head excursion, except when submarining occurs.

As part of a broader effort to improve the protection of child passengers who use the belt for primary restraint, UMTRI has undertaken a series of studies that have included measurements of the rear-seat environment, with a focus on the second row [3, 11]. Second-row seat cushions are much longer than the typical thigh lengths of children younger than 12 years. Long seats are associated with slouching, more-forward hip locations, and poorer belt fit [7, 13].

The current analysis examines the locations of belt anchorages in second-row, outboard seating positions. As part of several vehicle-measurement projects, the seating environment in the second rows of 84 vehicles was measured. The belt-anchorage locations are compared with the FMVSS 210 criteria.

METHODS

The anchorage locations of the driver-side, second-row passenger positions of a convenience sample of eighty-three passenger vehicles with rear seats were measured between 2007-2011. The sample consisted of 57 passenger cars, 17 SUVs, 6 minivans, and 3 pickup trucks, of which sixty-six were model year 2000 or newer, and 8 were model year 1995 or older. A complete list of the vehicles is in Appendix A.

Figure 1. CMM (FARO Arm) attached to a vehicle.

The SAE J826 machine was installed in the rear seat position and the location of the H-point was recorded with a portable coordinate measurement machine (CMM) (FARO Arm, FARO Technologies, Lake Mary, FL) as shown in Figures 1 and 2. The locations of safety belt anchorages, reference points on the seat frame, and other aspects of the vehicles geometry were also recorded. If the seat was adjustable, the back angle (H-point manikin torso angle) was set to 23 degrees and the seat travel set to the most rearward location on the seat track.

Figure 2. Using CMM to measure seat H-point.

Measuring Anchorage Locations

The CMM was used to measure the locations of the three belt anchorages. The lower anchorages were measured two ways: at the bolt attached to the frame and at the point where the belt attaches to the anchorage assembly. The latter of the two corresponds best with the definition in FMVSS 210 of the "nearest contact point of the belt with the anchorage." In cases were only the bolt was measured, the pivot point was calculated as 20 mm forward of the bolt, based on the average of measurements of belt-mounting hardware on other vehicles.

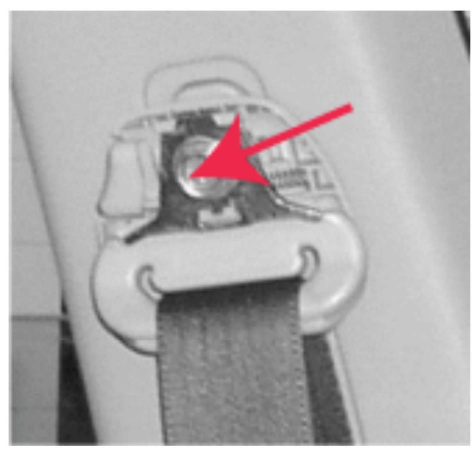

Figure 3. Point recorded on upper anchorages that were mounted with a pivoting D-ring.

In cases where the upper anchorage consisted of a D-ring that was attached to the vehicle frame with a bolt around which the D-ring pivoted, the upper anchorage location was measured at the center of the bolt, as shown in Figure 3. If the upper anchorage was not a D-ring (as in cases where the upper belt exits the pillar, seat or trim through a piece of plastic or over a metal bar) and the anchorage point was not accessible, the center of the exit point was considered the pivot/anchorage point, as shown in Figure 4. Adjustable upper anchorages were measured at the midpoint of the adjustment range, which is the setting specified in FMVSS 210.

Figure 5. Point recorded on upper anchorages that were not on a pivoting D-ring or did not have an accessible bolt

RESULTS

Figures 6, 7, 8, 9 and Tables 1 and 2 show the measured belt anchorage locations relative to SgRP and the FMVSS 210 zones. The lower anchorage locations spanned the entire allowable range of side-view angles. Upper anchorage locations also spanned a wide range, reflecting the wide variety of upper belt anchorage configurations, including those mounted in the C-pillar, package shelf, and integrated into the seat. Inboard (buckle-side) lower anchorages had slightly steeper (higher) lap belt angles, and the inboard anchorage was generally closer to the occupant centerline than the outboard anchorage.

A statistical analysis did not show a significant effect of model year on belt locations among passenger cars. Comparisons of passenger cars with other vehicles categories were not conducted because the small numbers of vehicles in the other categories limited generalization for those groups.

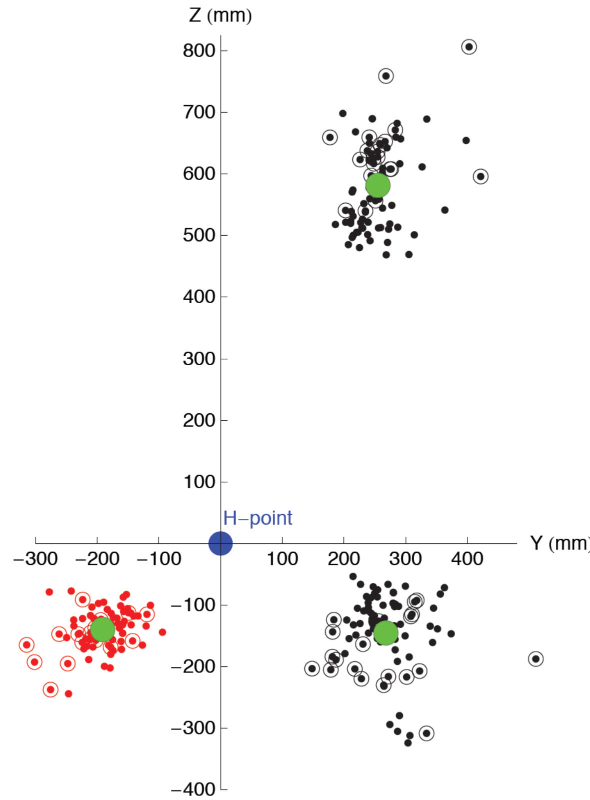

Figure 6. Front view of anchorage locations relative to seat H-point (red =inboard, black =outboard, circled points =trucks, minivans and SUVS, and green circle = mean anchorage location)

Table 1. Mean location of anchorages relative to H-point for all vehicles

Anchorage	X *mm* (SD)	Y *mm* (SD)	Z *mm* (SD)
Upper	411 (102)	254 (44)	581 (71)
Lower Outboard	109 (55)	267 (53)	145 (62)
Lower Inboard	120 (81)	191 (42)	140 (33)

Table 2. Mean (SD) angle of anchorages to H-point for all vehicles

Anchorage	Side-view (XZ) angle deg. (SD)	Front-view (YZ) angle deg. (SD)
Upper*	35 (9)	24 (4)
Lower Outboard**	53 (13)	28 (10)
Lower Inboard**	48 (12)	37 (7)

*Down from vertical
**Up from horizontal

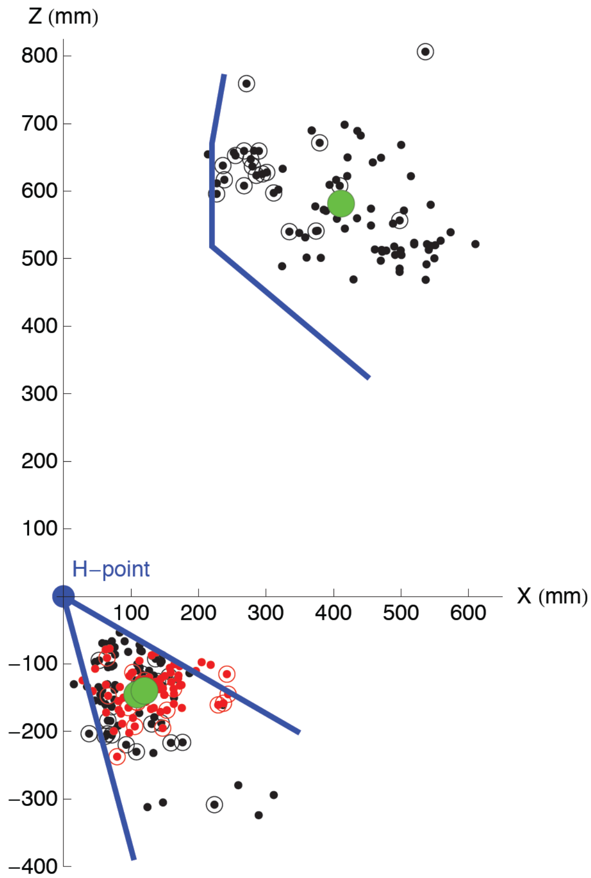

Figure 7. Side view of anchorage locations relative to seat H-point (SgRP) with FMSS 210 acceptable range (seat back angle at 23°) in blue (red =inboard, black =outboard, circled points = trucks, minivans and SUVS, and green circle =mean anchorage location).

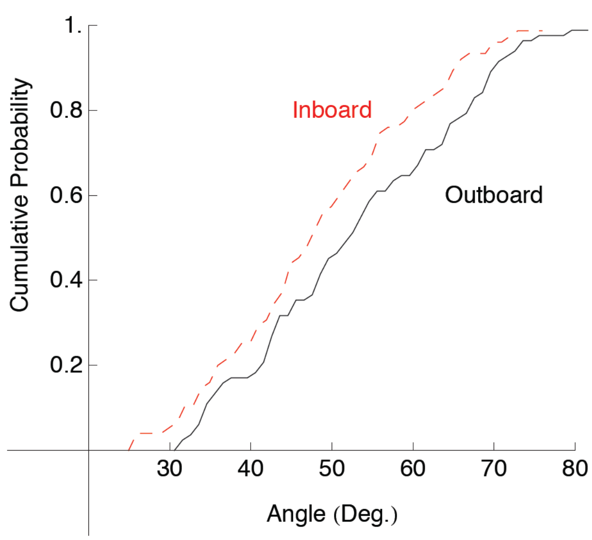

Figure 8. Cumulative probability of the side-view angle from inboard and outboard lower anchorages to H-point.

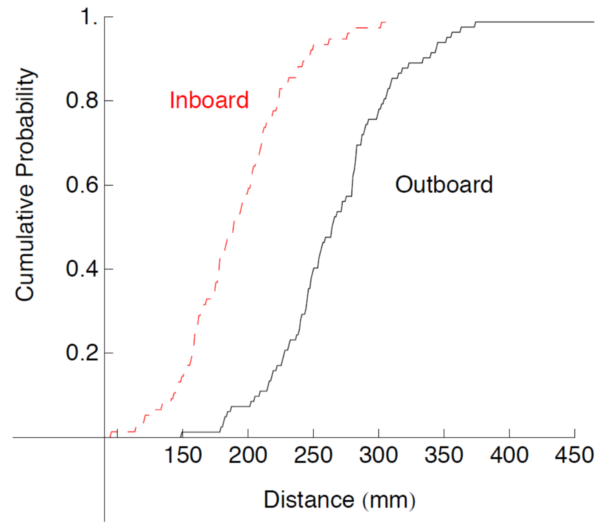

Figure 9. Cumulative probability of the lateral distance between H-point and the inboard and outboard lower anchorages.

DISCUSSION

This study is the first to report second-row belt anchorage locations for a large number of vehicles using standard measurement procedures from SAE Recommended Practices and FMVSS. The results indicate that seat belt anchorage locations in second rows vary widely. The range of lower anchorages, which spans the allowable range, is of particular concern for belt performance in frontal impact. In general, flatter belt angles are associated with better pelvis restraint but a higher likelihood of submarining [1, 2, 4, 10], although submarining is influenced by many other factors [14]. Steeper lap belt angles are needed to prevent submarining for smaller occupants, particularly children seated on vehicle seats with long seat cushions that produce slouched postures [1, 2, 4, 6, 10]. Upper anchorage locations affect the risk of torso rollout in frontal crashes [5] and can contribute to discomfort due to contact between the belt and the occupant's neck if the anchorage is too high or too far inboard. The fore-aft location of the anchorage can also affect head excursion and chest loading in frontal crashes [10].

The reasons for the wide range of anchorage locations observed in this vehicle sample are unclear, and the safety consequences of this variability are unknown. It is possible that each configuration provides optimal restraint for second-row occupants given each vehicle's particular seating environment and crash pulse. Because frontal crash performance in the second row is not regulated under FMVSS, no standardized data are available to evaluate this possibility. However, belt anchorage locations significantly affect belt fit for children and adults, with flatter lap belt angles associated with poorer lap belt fit relative to the pelvis [12, 13]. Sled testing at UMTRI with a range of belt conditions in exemplar second-row seats has shown the belt anchorage locations strongly influence the kinematics of 6YO and 10YO Hybrid-III ATDs [5, 10], although these findings are limited by the biofidelity of the Hybrid-III ATDs, particularly with respect to submarining [6]. Optimization studies using computer simulation have shown that optimal belt anchorage locations for children using the belt as primary restraint are different from those of adults [1], highlighting the challenge of optimizing restraints in the second row, where half of crash-involved occupants are age 12 and younger [7].

These data are limited by the sample of vehicles, which was assembled largely by convenience. No effort was made to compare belt geometry between passenger cars and other categories of vehicles, for example, because the small numbers of vehicles in other categories and the lack of a meaningful weighting scheme meant that the results by vehicle category could not be generalized. However, the relatively large size of the database suggests that the results may be broadly representative of the U.S. vehicle fleet, particularly for passenger cars.

Each measurement was made in a single exemplar vehicle in use, which may differ due to manufacturing and use variability from other nominally identical vehicles. The anchorages were located relative to a single H-point measurement; variability in H-point location would contribute to anchorage location variability, but that effect would be small relative to the range of anchorage locations observed across vehicles. Access to the belt anchorages, particularly the inboard (buckle) and upper anchorage was challenging in many vehicles. Some judgment was exercised in determining the appropriate point to record for each anchorage. For any individual vehicle, this could lead to the measurements differing from the design intent or from what another team would measure. These effects would be expected to be small relative to the range observed, although they could contribute a systematic bias.

Further research is needed to determine whether second-row belt anchorages could be better located to improve occupant protection. Many considerations come into play, including the need to secure child restraints using belts, the availability of appropriate vehicle structure for belt attachments, the desire for seats that can be folded and stowed, and the relatively low occupancy rates in rear seats.

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APPENDIX

Vehicle List

Passenger Cars

Make	Model	Year
Acura	Integra GS	1992
Audi	A4 1.8T	2004
Buick	Regal	2003
Cadillac	DeVille	1997
Cadillac	Deville	2004
Chevrolet	Nova	1988
Chevy	Aveo L5	2011
Chevy	Impala	2004
Chevy	Impala LT	2011
Chevy	Malibu	2003
Chevy	Traverse	2011
Ford	Contour SVT	1998
Ford	Explorer Limited	2011
Ford	Fiesta	2011
Ford	Focus	2004
Ford	Focus	2001
Ford	Freestyle	2005
Ford	Mustang Cobra SVT	1999
Ford	Probe GT	1994
Ford	Taurus GL	1991
Ford	Taurus Limited	2011
Ford	Taurus LX	2001
Ford	Taurus SE	2002
Ford	Taurus SG	2006
Honda	Accord EX	2004
Honda	Accord LX	1992
Honda	Civic	2000
Honda	Civic	2010
Honda	Civic EX	2004
Honda	Fit	2009
Hyundai	Accent	2010
Hyundai	Sonata	2011
Kia	Soul	2011
Mazda	6	2004
Mazda	626 LX	1998
Mazda	Mazda3	2011
Mazda	Protégé 5	2003
Nissan	Altima	2003
Nissan	Cube	2011
Nissan	Versa	2011
Oldsmobile	Ciera S	1990
Oldsmobile	Intrigue	2002
Pontiac	Bonneville SLE	2000
Pontiac	Grand Prix SE	2001
Saturn	S-Series	2002
Subaru	Forester L	1998
Subaru	Legacy Outback	1999
Toyota	Camry	2002
Toyota	Camry DX	1991
Toyota	Corolla	2009
Toyota	Corolla	2003
Toyota	Corolla DX	1996
Toyota	Prius hybrid	2006
Toyota	Solara	2006
Toyota	Tercel STD	1992
Volkswagen	Eos	2012
Volkswagen	Passat	2002

SUVs

Chevrolet	Tracker	2000
Chevy	Tahoe LTZ	2011
Chrysler	Pacifica	2005
Ford	Expedition	2006
Ford	Explorer Sport	1996
Ford	Windstar GL	1997
GMC	Envoy	2004
GMC	Yukon XL	2005
Honda	CRV	2003
Infinity	FX45	2004
Jeep	Grand Cherokee	2004
Jeep	Liberty	2002
Mercury	Mountaineer	2002
Mitsubishi	Lancer	2011
Saturn	Vue V6	2007
Toyota	Sienna LE	1999
Volvo	XC60 T6 AWD	2008

Minivans

Dodge	Grand Caravan Crew	2011
Dodge	Grand Caravan SE	2010
Dodge	Caravan	2005
Ford	Freestar SE	2005
Toyota	Sienna XLE	2011
Toyota	Sienna LE	2004

Trucks

Dodge	Ram	2005
Ford	F150	2005
Ford	F150 XLT	2011

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