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Aviation Child Safety Device Performance Standards Review

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16. Abstract

The design and performance requirements for Child Restraint Systems (CRS) in TSO-C100b and SAE AS5276/1 were developed to enable proper restraint of infants and small children traveling on transport airplanes. They complement and extend those in the Federal Motor Vehicle Safety Standard for Child Restraint Systems (FMVSS-213), which, prior to their development, were the only approval means for CRS used on aircraft. Development of CRS able to comply with the aviation standards has proven challenging, as the test requirements call for a combination of worst-case belt anchor location, belt tension, and seat cushion properties/dimensions that were typical at the time the specifications were written. These parameters no longer appear to be representative of the majority of transport airplane seats. As such, difficulty complying with the standards based on these test parameters may be inadvertently hindering the availability of aviation-specific CRS.

Aviation-specific CRS, now commonly referred to as Aviation Child Safety Devices (ACSD), have been recently developed that provide upper torso restraint for forward-facing children. Alternative regulatory procedures have been adopted for certification of these devices, requiring demonstration of an equivalent level of safety with TSO-approved devices. Revision of the regulatory requirements in order to accommodate these new devices included removal of the explicit requirement for these systems to meet FMVSS-213. This action has inadvertently removed some applicable requirements that are not duplicated in the TSO. Such requirements include: design specifications for occupant support surfaces, belt/buckle strength and durability tests, and defined occupant restraint configuration, geometry, and adjustment range. In addition, FMVSS-213 has been revised significantly since TSO-C100b was written, improving several aspects that could benefit existing aviation standards and provide a safety benefit for ACSD. These include use of advanced test dummies, enhanced test dummy preparation and positioning procedures, improved head injury assessment, and better CRS installation procedures.

Analysis of AS5276/1, TSO-C100b, FMVSS-213, and the current seat population in the U.S. transport airplane fleet suggests that revisions to both the Aerospace Standard and the TSO based on technological evolution, improvements to test equipment, and test procedures that are more representative of the aircraft environment would advance the development of ACSD while maintaining or improving child safety.

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Aviation Child Safety Device Performance Standards Review

INTRODUCTION

The SAE International (SAE) Aerospace Standard (AS)5276/1, Performance Standard for Child Restraint Systems in Transport Category Airplanes, was developed to ensure proper restraint of children in the aircraft environment (1). The need for this standard was based on the poor performance observed when child restraints qualified to the Federal Motor Vehicle Safety Standards were tested in some aircraft seat configurations (2). Since the publication of SAE AS5276/1 in 2000 and SAE Aerospace Recommended Practice (ARP)4466 (3) in 1997, many of the rules, standards, policies, and aircraft seat designs that affect the design and performance of child restraint systems (CRS) have changed.

Federal Motor Vehicle Safety Specification (FMVSS)-213 (4) has been revised to include:

- Requirements that CRS provide rigid bar lower anchorage attachments and a top tether strap for attachment to the vehicle seat
  - A larger, more advanced small test dummy (CRABI 1-year-old)
  - More advanced 3-year-old, 6-year-old, and 10-year-old test dummies (Hybrid–III)
  - A test seat fixture with a steeper bottom and back cushion angle, rigid bar lower anchorage, and top tether anchorage points
  - An easier-to-produce deceleration pulse
  - Requirements for specific padding on aft-facing infant seats replaced by an assessment of head- impact protection using the Head Injury Criteria (HIC)
  - Specific strength, durability, and width requirements added for CRS harness webbing

- FMVSS-225 (5) has been issued to require rigid bar lower anchorages and top tether anchorages be installed in new cars
- Title 14 Code of Federal Regulations (CFR) parts 91, 121, 125, and 135 (6) were revised to allow use of child restraints that may not have received FMVSS-213 approval. These devices, referred to as Aviation Child Safety Devices (ACSD), were granted approval under:
  - Type Certificate or Supplemental Type Certificate for aircraft-specific installation cases,
  - Technical Standard Order (TSO)-C100b (7) for forward- and aft-facing ACSD intended for use on any aircraft, and
  - Part 21.305(d) (Equivalent Level of Safety to TSO-C100b) (8). Requires development of device-specific testing parameters for each new type of proposed device to show that it provides an equivalent level of safety to TSO-C100b. To date, one device has been approved using this procedure.

- Advanced Notice of Proposed Rule Making 63FR8324 Child Restraint Systems (9) issued in 1998, which proposed mandatory CRS usage in aircraft, was withdrawn in 2005.
- The number of aircraft seats in the U.S. fleet that meet TSO-C127a (10) (effective in 1998) continues to increase as newer aircraft fitted with these safer, dynamically qualified seats enter service. This TSO revision required seats meeting that standard to have their lap belt anchor points no more than 2 in. forward of the seat reference point, a geometry that tends to improve the performance of forward facing CRS (2). These seats also incorporate energy-absorbing seat backs that tend to improve the performance of ACSD that attach to the seat back. Conversely, ACSD that attach to the seatback may affect the ability of the seat back to provide the intended head injury protection for an occupant seated behind it.
- The specifications in AS5276/1 and TSO-C100b were developed to complement those in FMVSS-213; however, removing the requirement for ACSD to meet FMVSS-213 may have removed some requirements that are useful in ensuring safety.

Development of ACSD to meet the existing aviation specifications has proven challenging. Potential suppliers of systems meeting the TSO have requested revisions to the requirements, and no systems have yet been granted TSO approval. The existing test requirements emulate a combination of near worst-case belt anchor location, belt tension, seat cushion properties, and seat cushion dimensions that, individually, could be found on in-service aircraft at the time the specifications were written. With the increased use of TSO C-127a seats, this combination of requirements may not be representative of the majority of current aircraft seats; thus, difficulties in developing ACSD that meet these very conservative specifications may be inadvertently hindering the availability of such devices.

PROJECT OUTLINE

To address these issues, a project was conducted to:

- Review FMVSS-213 to identify its requirements that are applicable to CRS intended for aviation use and:
  - » Determine if FMVSS-213 requirements not addressed in the aviation standards would be beneficial.
  - » Determine if the FMVSS-213 requirements offer an improvement over similar requirements currently cited in the aviation standards.

- Evaluate the testing requirements defined in TSO-C100b and AS5276/1 that had been identified by CRS manufacturers as hindering their ability to meet the specifications, namely:
  - » Location of the lap belt anchor on the specified test fixture.
  - » Dimensions and properties of the test fixture and seat cushions.
  - » CRS installation procedure.

FMVSS-213 Requirements Review

An evaluation of each requirement in FMVSS-213 (last amended 7-31-2008) was conducted to determine the applicability and efficacy in the aviation environment. This standard covers a variety of restraint types and occupant sizes. The type corresponding to the systems described in the aviation standards is referred to as an "Add-On" child restraint, which may be forward- or aft-facing and accommodates children from newborn to 40 lb in weight or 44 inches in stature. Some of the requirements are performance-based and cite injury criteria or excursion limits, while others are prescriptive and provide design requirements such as minimum support surface areas. The details of this evaluation are provided in Table 1. The requirements identified as providing a potential benefit for ACSD are cited by paragraph number and topic and are accompanied by an explanation of the potential benefit. Requirements that are currently addressed to any extent in AS5276/1 or TSO-C100b are also cross-referenced by paragraph number.

The evaluation revealed that some potentially beneficial FMVSS-213 requirements are not currently included in the aviation standards. These are:

- **Defined occupant support surfaces**: These requirements ensure that adequately sized and configured support surfaces are provided to limit occupant motion. Limiting occupant motion is one means of reducing the potential for injury.
- **Belt and buckle tests and specifications**: These requirements ensure that integral belt systems have sufficient strength and durability, and that buckles reliably release after being loaded significantly.
- **Belt adjustment range must accommodate all occupants**: This requirement calls for integral belt systems to be adjustable so that they snugly fit the anticipated range of occupants.
- **Defined occupant restraint configuration and geometry**: These requirements specify that shoulder, lap, and crotch belts or supporting surfaces that serve the same function, be provided. It also specifies that the lap belt angle (with respect to the seating surface) be between 45 and 90 degrees. This lap belt angle, in combination with an effective crotch belt, will initially tend to position the belt over the occupant's pelvis, reducing the potential for abdominal injury due to belt intrusion.
- **Temp/humidity range specified during tests**: This requirement enhances consistency and accuracy of test results by ensuring that the test dummies are used within their operational specifications.

The evaluation also revealed that, in some cases, the FMVSS-213 requirements may provide more effective test procedures or utilize more advanced test dummies than are currently cited in the aviation standards. These are:

- **Improved test dummies**: Test dummy technology is improving constantly, with newer designs having better biofidelity and improved injury prediction capabilities. The TNO P3/4 (9-month-old size) anthropomorphic test dummy (ATD) specified for use in FMVSS-213 thru 2005 has been replaced by the 12-month-old size child restraint air bag interaction (CRABI) ATD. Since this is the size at which children are normally switched from aft- to forward-facing orientation, the CRABI is useful for evaluating the performance of both forward- and aft-facing CRS at this critical transition point. It also provides a consistent means to measure head acceleration, allowing head injury potential to be directly evaluated (11). The very important people (VIP) 3-year-old ATD specified for use in FMVSS-213 thru 2005 has been replaced by the Hybrid-III 3-year-old dummy. The Hybrid-III's instrumentation is able to measure many more parameters, allowing a more complete assessment of injury potential than was possible with the VIP test dummy. The major construction differences are a multi-segmented neck, multi-rib thorax, and the ability to monitor changes in pelvic bone loading, indicative of submarining. The Hybrid-III's more biofidelic (human like) response allows a more reliable evaluation of CRS safety features.(12)
- **HIC36**: Head injury potential due to both inertial loading and head impact is evaluated using the HIC36 injury criteria cited in FMVSS-213. The current aviation standards only evaluate head injury potential after head contact occurs.

Table 1 – FMVSS-213 Review

FMVSS-213 Paragraph	Topic	Potential Benefit for ACSD	AS5276 Paragraph
4	Definitions	Provides a common understanding of the terminology used.	Not Addressed
5.1.1, a, b, c	Child Restraint System Integrity	Prevention of sharp edge creation and occupant loading due to structural failure, avoiding pinching hazards, and preventing entrapment of occupant.	6.4
5.1.2.1, a, b	Head Injury Assessment	Using HIC36 limits head injury risk even in non-contact cases. Limiting chest acceleration to 60 G's reduces torso injury risk.	6.2 and 6.3
5.1.3.1, a	Occupant excursion of forward-facing child restraints	Retaining the occupant's torso within the system can reduce flailing injuries. Limiting head excursion can prevent head contact with forward vehicle surfaces. Limiting knee excursion can reduce the potential for lap belt intrusion into the abdomen.	6.1.1
5.1.3.2	Occupant excursion of rear-facing child restraint systems	Retaining the occupant's torso within the system can reduce flailing injuries. Limiting head excursion beyond the forward end of the child restraint limits rearward rotation of the head and may prevent contact with interior structure.	6.1.2
5.1.4	Back support angle	Limiting the back angle tends to reduce restraint loads applied to the shoulders and the potential for ejection from the CRS.	6.1.2
5.2.1.1, a, b, c	Minimum head support surface	Adequate support can reduce rearward movement of the head relative to the child.	Not Addressed
5.2.1.2	Minimum head support surface, applicability to front-facing child restraints	Provides adequate head support to the largest occupant that the CRS is intended for.	Not Addressed
5.2.2.1, a, b, c	Torso Impact Protection, back, side and forward support surfaces	Ensures that back and side surface areas provide uniform support and prevent concentrated loading. Rounded contacts on forward support surfaces prevent concentrated loading.	Not Addressed
5.2.2.2, a, b	Torso Impact Protection, surfaces forward of the child	Prohibits any surface forward of the child that does not specifically meet the design requirements for support surfaces, and prohibits any surfaces passing through the test dummy.	Not Addressed
5.2.4	Protrusion limitation	Avoids concentrated loading on child.	Not Addressed
5.3.1, a	Installation means	Ensures that the CRS is properly secured in the vehicle seat.	3.2
5.3.2	Restraint solely by specified means	Ensures that the CRS is properly secured in the vehicle seat.	3.2
5.4.1.2, a - d	Belts, belt buckles, and belt webbing, Performance Requirements	Evaluates durability and strength of restraint system.	Not Addressed
5.4.1.3	Belt Width Test	Provides a consistent means to verify belt width.	Not Addressed
5.4.2	Belt buckles and belt adjustment hardware	Ensures that restraint system hardware is both corrosion and temperature resistant.	Not Addressed

Table 1 (continued) – FMVSS-213 Review

FMVSS-213 Paragraph	Topic	Potential Benefit for ACSD	AS5276 Paragraph
5.4.3.1	Belt Restraint, General	Ensures restraints fit the child snugly.	Not Addressed
5.4.3.2	Belt Restraint, Direct Restraint	Ensures that belts do not apply excessive loads to the child due to the mass of the CRS or vehicle seat.	3.2
5.4.3.3, a, b, c	Seating System, Restraint Configuration	Provides effective upper and lower torso restraint.	Not Addressed
5.4.3.5 a - d	Buckle release	Ensures reliable release by adults and inhibits release by small children.	5.4 and 6.5.1
5.7	Flammability	Provides consistency with the flammability standards met by automotive CRS already approved for aircraft use.	3.3
5.9 a - d	Attachment to child restraint anchorage system	Provides appropriate lower anchorage and tether attachment components in the event that these anchor points are available on an aircraft seat.	3.2.5
6.1.1.d	Test Conditions, Temperature and Humidity Range	Enhances consistency of test results by ensuring ATD's are used within their operational specifications.	Not Addressed
6.1.2 d (1)	Dynamic Test Procedure, Belt Adjustment	Ensures that both belts restraining the occupant and belts attaching the CRS to the seat are tightened consistently.	5.1 and 5.3
6.2	Buckle Release Test procedure	Evaluates buckle release reliability under load.	Not Addressed
7.1.2 a - e	Dummy Selection	Ensures that tests are conducted with dummies in the appropriate size and weight range.	4.1
8	Child restraint systems for aircraft	Evaluates the CRS ability to retain occupants during 1g vertical loading.	3.5
9	Dummy clothing and preparation	Enhances test consistency.	4.1.2
10	Positioning the Dummy and attaching the system belts	Enhances test consistency.	5.2

- **ATD preparation and positioning**: FMVSS-213 provides installation procedures that are specific to the new dummies now specified. The procedures in the current aviation standards were derived from the general procedures in SAE AS8049a (13) for seating adult-size ATDs in aircraft passenger seats.
- **CRS installation procedure**: The FMVSS-213 procedure enhances test consistency by requiring that the belt securing the CRS to the test fixture be tightened to a specific tension range. The procedure in the current aviation standards allows significantly varying tension levels.

Belt Anchor Location Evaluation

Previous research (2) indicated that the relative fore-aft location of the passenger seat lap belt anchor point, with respect to the seat's cushion reference point (CRP), is a major factor affecting the dynamic performance of a forward-facing CRS attached to the seat using the passenger lap belt. (The CRP is the point of intersection between the front of the back cushion and top of the bottom seat cushion.) Seats with belt anchors further forward tended to have more CRS excursion than seats with belt anchors further aft. This is why selection of this crucial test parameter is important to ensure proper evaluation of ACSD.

Original Selection Basis

The belt anchor location cited in AS5276/1 is based on dimensional information provided by the major seat manufacturers and a 1996 survey of belt anchor locations. That survey included 182,568 seat places, which was about 30% of the U.S. fleet. (14) This sample included a variety of aircraft types from five air carrier operators. The sample was large and diverse enough to be considered reasonably representative of the entire fleet. The results are shown in Figures 1 and 2. Only 5% of the sample had a belt anchor location less than 2 in. forward of the CRP, while 95% of the sample had a belt anchor location less than 4.2 in. forward of the CRP. The dimensional information from the seat manufacturers indicated belt anchors on their products fell in a range from 0.8 in. aft of the CRP to 4.6 in. forward of the CRP. Therefore, specifying the 4.6 inch forward location in the standard made it unlikely that any seat in the fleet would have a belt anchor forward of this location. Selection of this point is conservative since a CRS that performed well in a seat with this anchor location would also perform well in a seat with an anchor located further aft. This conservative approach is consistent with the selection criteria used for other test parameters in the standard.

Since the publication of TSO-C100b, which references AS5276/1 as the minimum performance standard,

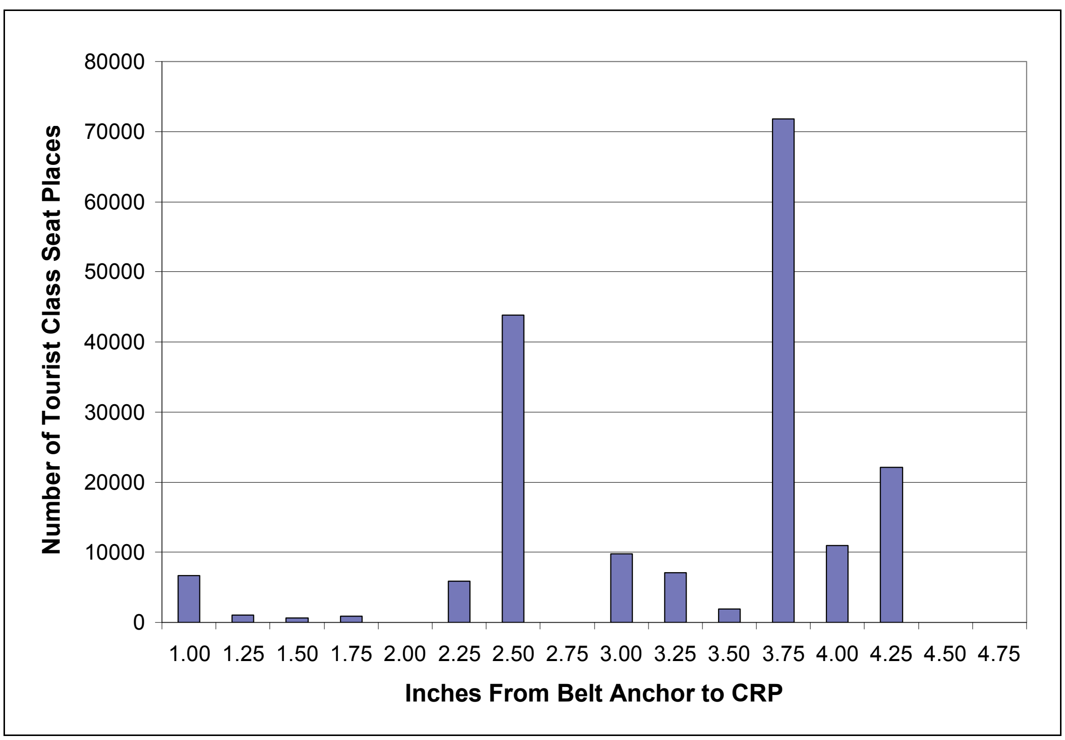

Figure 1 – CRP-to-Lap Belt Anchor Horizontal Distance - 1996 Seat Survey Results

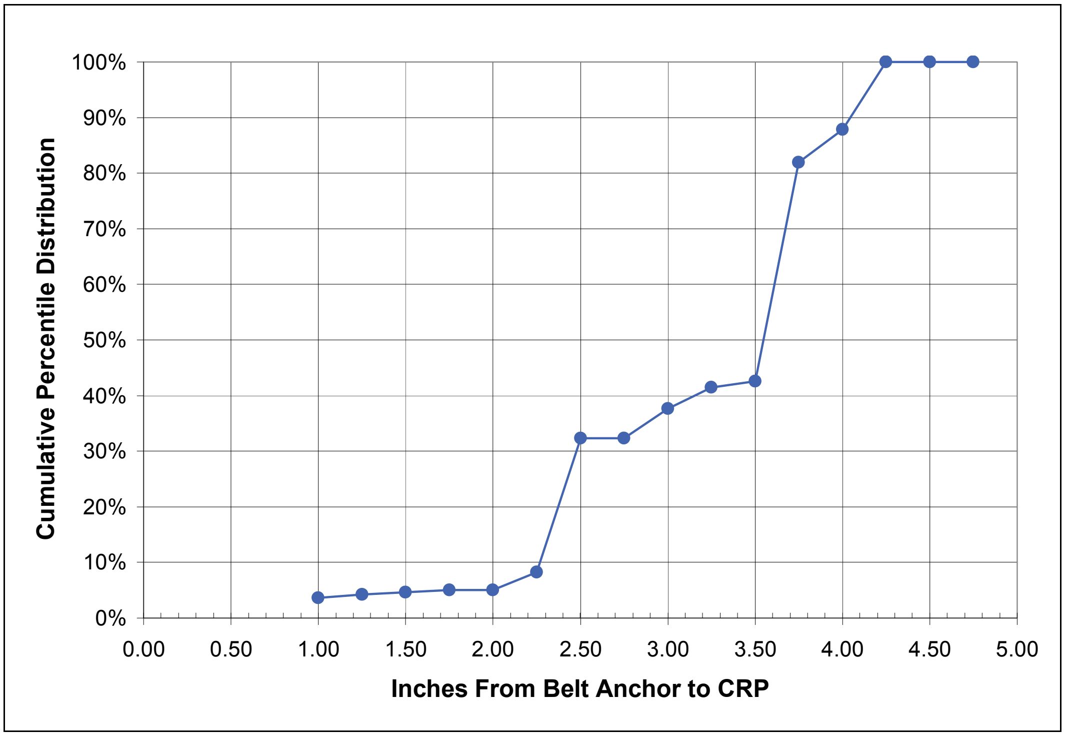

Figure 2 – CRP-to-Lap Belt Anchor Horizontal Distance, Cumulative Percentile Distribution - 1996 Seat Survey Results

improved aircraft seat design requirements and economic forces have intersected to alter the distribution of lap belt anchor locations found on the current fleet. Two important changes are:

- TSO C127a, issued in 1998, limited the maximum forward location of the lap belt anchor to 2.0 in. forward of the seat reference point (SRP). Note that the fore-aft distance from the SRP to the anchor point is similar to the fore-aft distance from the CRP to the anchor point for most economy-class transport seats.
- The accelerated retirement of airplanes manufactured before 1992 has reduced the number of older aircraft in the fleet. After September 11, 2001, operators retired more than 1,360 airplanes or 23.6% of the pre-9/11 fleet, predominately B-727, B-737 100/200/300, MD-80, and L-1011 (15).

Current Fleet Data

Since conducting a completely new survey of the U.S. fleet has not been practicable, the effect of these changes was quantified by analyzing the makeup of the current fleet, using data retrieved from the FAA's Safety Performance Analysis System (SPAS) on June 25, 2008. The transport fleet sample used for this analysis consisted of 4,110 aircraft, which represented about 62 % of the U.S. fleet (14). Of the 4,110 total aircraft, 1,708 should have had 16g or 16g-compatible seats on board, according to their certification basis. 16g seats are those meeting all requirements in 14CFR25.562 (16) and TSO C127a. 16g-compatible seats, as defined in the Improved Seats Rule preamble (15), are seats which meet at least the structural integrity requirements in 14CFR25.562. The sample included 609,168 total seat places, of which 225,422 (or 37%) were 16g or 16g compatible. This total does not include seats on aircraft initially delivered without improved seats, but which had them installed later.

Most Conservative Analysis

A conservative approach to estimating the anchor location distribution on seats in the current fleet was made by using the retrieved fleet data, the 1996 survey results, and following assumptions. By *conservative* we mean an approach indicating that the distribution of anchor locations is further forward than they actually are.

- All 16g-compatible seats have belt anchors in a similar location to the TSO C127a (fully compliant 16g) seats. This assumption is based on the observation that even before issuance of the revised TSO, many dynamic seat designs already incorporated anchor locations that met the 2-in. requirement. This change had occurred because that location produced an improved initial lap belt angle for an adult occupant, which tended to reduce occupant excursion and resultant seat loading during dynamic tests.
- No 16g or 16g-compatible seats were included in the 1996 survey. This is because few aircraft with a

certification basis calling for 16g or 16g-compatible seats were delivered before 1996.

- The distribution of belt anchor locations found in the 1996 survey is representative of the remaining aircraft with 9g seats in the current fleet. This assumption would be the most conservative retirement scenario since the new overall distribution would still include many seats with belt anchors near the furthest forward location.

Based on these assumptions and data, a new distribution of estimated lap belt anchor locations was created by reducing the quantities of each seat model reported in the 1996 survey by 37% (67,550 total seat places removed), then adding the same number of seats with a belt anchor location 2 in. forward of the CRP to the dataset. (See Figures 3 and 4.) As a result, the estimated percentage of seats with belt anchors further aft has risen significantly. Although the 95 percentile and 75 percentile locations are nearly unchanged from the original 4.2 and 3.7 in., the 50 percentile belt anchor location has changed from 3.6 to 2.4 in.

Least Conservative Analysis

While the previous analysis assumed that the 9g seats that were replaced by 16g seats were equally distributed with regard to the range of belt anchor locations, a less conservative retirement scenario can be examined if it is assumed that seats in the older aircraft that were retired had belt anchors with the most forward of the reported locations. Under this premise, the current fleet statistics can be combined with the results of the 1996 survey by replacing the 37% of the survey's seat types having the most forward belt anchors with seats having belt anchors 2 in. forward of the CRP.

The estimated lap belt anchor distribution based on this revised assumption and the estimation based on the original assumption are shown in Figures 5 and 6. In assuming that the seats with the most forward belt anchor locations were retired first, the percentage of seats with belt anchors further aft in this estimate has risen significantly, and the 95 percentile location has changed from 4.2 to 3.7 in. The 75 percentile location has changed from 3.7 to 3.0 in., and the average location has changed from 3.6 to 2.3 in. See Table 2 for the summarized results of these two analytical approaches and the original survey data.

Belt Anchor Evaluation Conclusions

One factor that adds conservatism to both of these estimates is that 16g-compatible seats may have been installed on many aircraft produced after 1992 and on some of the older aircraft during refurbishment (15). Since specific data were unavailable, this group of aircraft was not included in the 16g-compatible data. The effect on the current estimate, if these were included in the analysis, would be to move the typical belt anchor location further aft.

Another factor that adds conservatism to these estimates is that the continued retirement and refurbishment of

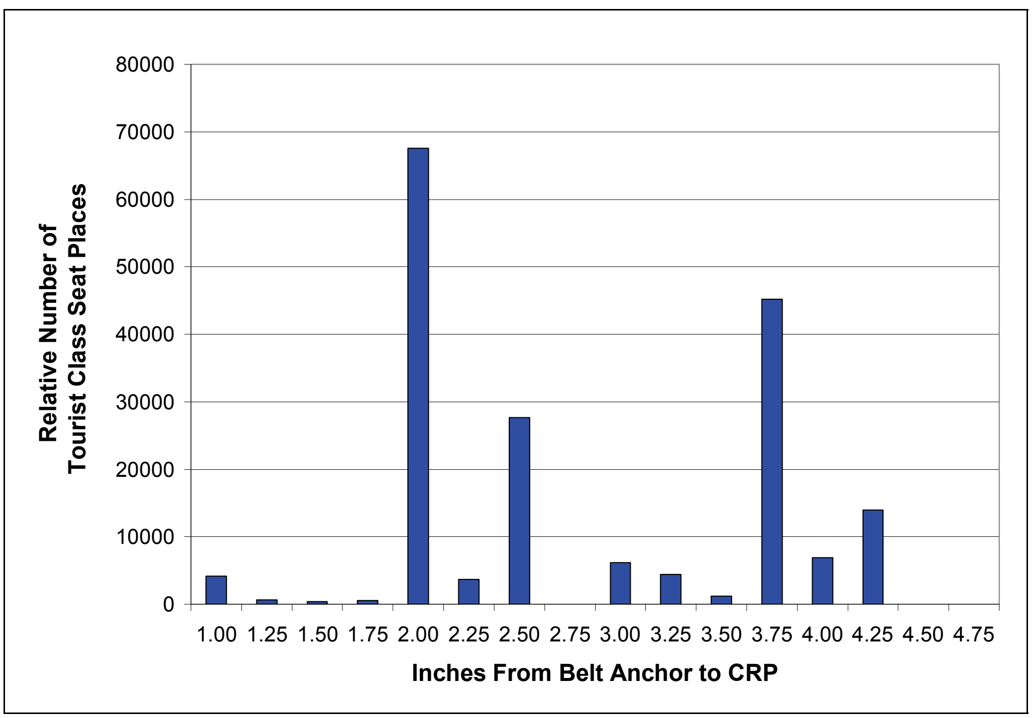

Figure 3 – CRP-to-Lap Belt Anchor Horizontal Distance - Current Conservative Estimate

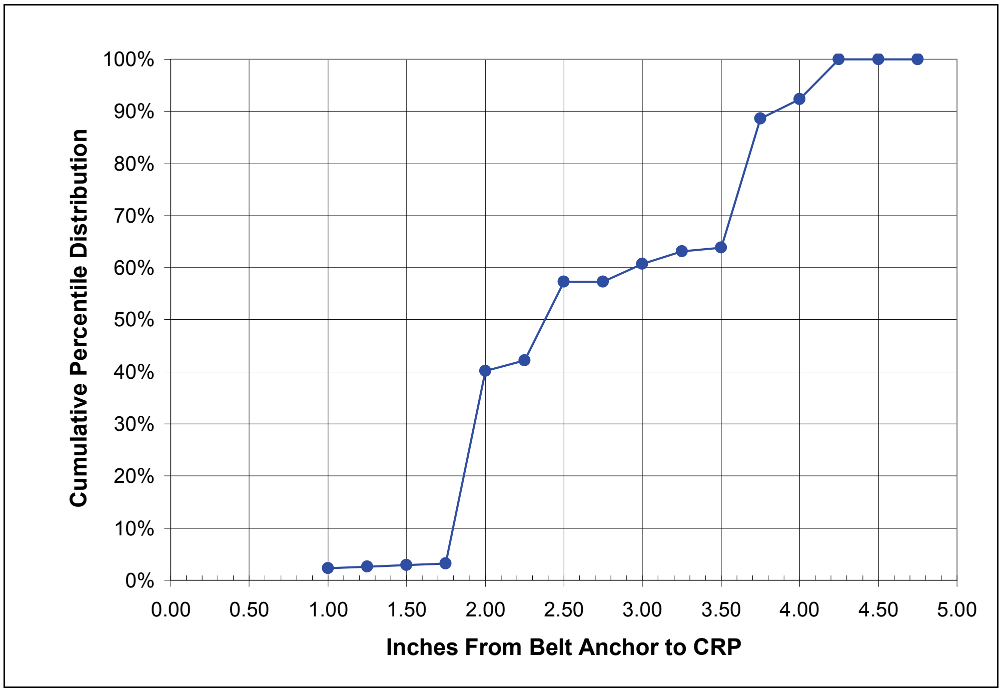

Figure 4 – CRP-to-Lap Belt Anchor Horizontal Distance, Cumulative Percentile Distribution - Current Conservative Estimate

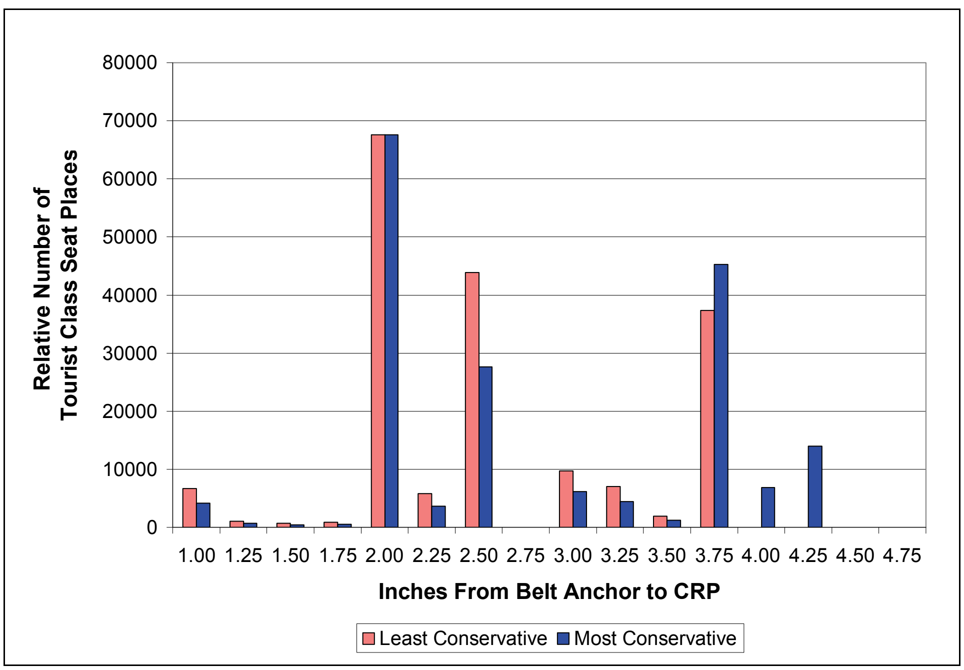

Figure 5 – CRP-to-Lap Belt Anchor Horizontal Distance - Comparison of Most and Least Conservative Estimates

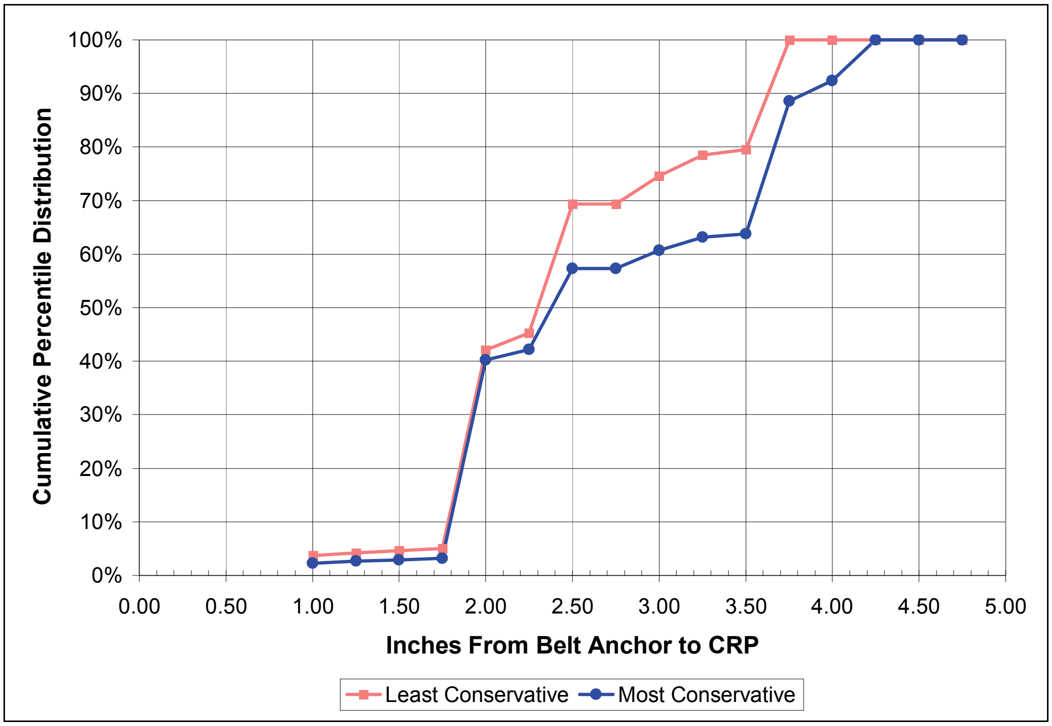

Figure 6 – CRP-to-Lap Belt Anchor Horizontal Distance, Cumulative Percentile Distribution - Comparison of the Most and Least Conservative Estimates

Table 2 – Summary of Anchor Point Analysis

Lap Belt Anchor X Location Estimated Distribution	50 Percentile Location	75 Percentile Location	95 Percentile Location
Original Analysis	3.6	3.7	4.2
Most Conservative Analysis	2.4	**3.6**	4.1
Least Conservative Analysis	2.3	3.0	**3.7**

older aircraft, plus the requirement to install 16g seats on all newly built aircraft, will also tend to move the typical anchor location further aft over time (15).

Thus, the selection criteria applied when choosing the original AS5276/1 belt anchor location may be overly conservative to apply when selecting an updated anchor location considering that the current anchor location estimates already include significant conservatism. Table 2 shows that the 3.7-in. location is bounded by the most/least conservative selection criteria in the current analysis. When combined with the prevalence of the 3.7- in. belt anchor location in the 1996 survey data (accounting for 37% of the locations), this suggests that the 3.7-in dimension would be the most appropriate seat anchor location for a minimum performance standard test procedure until more of the older seats are replaced or until data supporting a more aft-ward location become available.

Figure 7 - CRS Interaction With Front of Seat

SEAT CUSHION DIMENSIONS AND PROPERTIES EVALUATION

The dimensions and material specifications for the seat cushions and supporting structure in AS5276/1 were intended to mimic a combination of both typical and worst-case (regarding their affect on CRS dynamic performance) economy-class features and were chosen in keeping with the conservative philosophy of AS5276/1. The typical features were seating surface angle (5.5 degrees), depth (16.2 in. from CRP), width (18 in.), and support structure depth (14.8 in. from CRP). Features intended to emulate the near-worst-case found in service were cushion thickness over the front support surface (4 in.) and cushion stiffness (21-27 ILD material). These attributes were specified because it has been observed that if a CRS translates forward significantly, it compresses the portion of the cushion above the forward support structure, which then acts as a fulcrum about which the CRS rotates forward. This forward rotation can result in significant head excursion, as shown in Figure 7.

Economy-class seat cushion size and stiffness is governed by the need to comfortably accommodate the range of expected occupant sizes, while also being as compact and lightweight as possible. These conflicting design goals put a practical limit on how much the parameters can vary; it is unlikely that the typical or worst-case parameters have changed significantly since the standard was written.

To investigate this hypothesis, a review of 13 recently constructed, economy-class seats was accomplished. The seats included a variety of designs intended for several different aircraft configurations and customers. The cushion size, top surface angle, cushion thickness, and location of supporting structure with respect to the CRP were measured and compared with AS 5276/1 specifications in Table 3.

Table 3 – Seat Cushion Parameter Comparison

Bottom Cushion Parameter	**AS 5276 Specifications**	**Review Results**
Top Surface Angle	5.5 Degrees	4.5 -7.5 Degrees
Cushion Depth (1)	16.2 in.	17 – 18 in.
Support Structure Depth (2)	14.8 in.	15 – 16 in.
Thickness Above Forward Support	3.5 in. polyurethane + 0.5 in. polyethylene	3 – 4.75 in.
Foam/Cushion Stiffness	21-27 ILD for the polyurethane layer (3)	44 – 81 IFD (4)

(1) From the CRP to the front of the cushion

(2) From the CRP to the front of the forward support tube

(3) Polyethylene layer 2.2 lb/cu.ft. density (no stiffness specified, however, closed cell polyethylene of this density is an order of magnitude stiffer than open cell polyurethane)

(4) Using ASTM D3574-05 procedure B1 to estimate the properties of the area over the forward support tube (17)

Figure 8 - Cushion With Large Front Support Tube

Figure 9 - Cushion With Small Front Support Tube

While this sample was small, it illustrates that most of the pertinent cushion parameters specified in AS5276/1 remain representative of seats produced today, although the softest seat cushion was somewhat stiffer than the foam stiffness specified in the standard. This stiffness difference may not be indicative of an actual difference between entire assemblies, since direct measurement of raw materials does not account for interaction with the dress cover and cushion shape, which likely influences the measured stiffness of a cushion assembly. Even if the actual stiffness difference is in the range indicated, that difference is likely irrelevant, since parametric computer simulations have shown that CRS performance is unaffected by variances in cushion stiffness that fall within the normal range of economy class seat cushions (18).

One detail of the AS5276/1 test fixture that differs from the seats in the review, and most economy-class seats in general, is the shape and location of the front edge of the seat cushion and its support structure. For typical seats, the front of the supporting structure is cylindrical in shape and located about 1 to 2 in. behind the front of the seat cushion (Figs. 8 and 9). The location and shape of this support point can affect CRS forward excursion, as this point tends to act as a fulcrum for CRS rotation during forward translation. The location of the seat pan front edge (support-structure depth) on the AS5276/1 fixture is further aft than any of the seat frame support tubes measured in the review and somewhat further aft than was typical of economy class seats when the standard was written (18). To better emulate a typical modern aircraft seat frame and improve the realism of CRS behavior during dynamic testing, a 1-in. cylindrical extension could be added to the seat pan fixture, as shown in Figure 10.

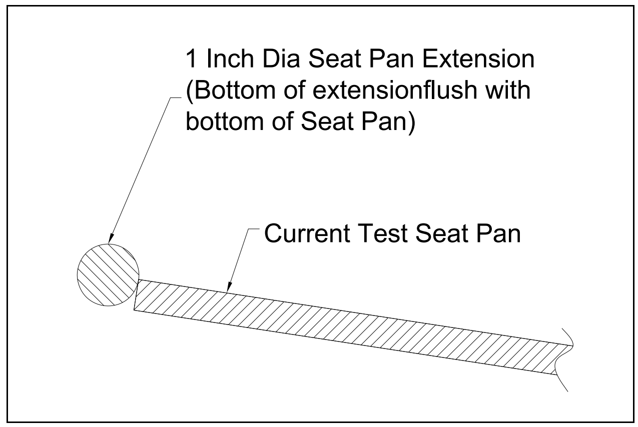

Figure 10 -Test Seat Pan Extension

INSTALLATION METHOD EVALUATION

The CRS installation test method cited in AS5276/1 calls for a 15-lb tensioning force to be applied to the free end of the lap belt, with no additional force applied to the CRS. Resulting belt tension is a function of the applied force, the friction of the belt path through the CRS, and the friction in the belt buckle adjuster mechanism. The ATD is installed after the belt is tightened. This method was intended to emulate the worst-case (least secure) installation condition that could occur in service. Thus, this test procedure results in a very loose fit if either the friction along the belt path prevents removal of all the slack when the specified force is applied or if the weight of the ATD compresses the seat cushion after the lap belt has been tensioned.

The installation method in FMVSS-213 calls for the lap belt to be tightened until a specific tension (12-15 lb) is achieved when installing the CRS onto the test fixture. The belt is tightened after the ATD has been placed in the CRS. In the absence of belt path friction, the AS5276/1 method would produce the same initial lap belt tightness as FMVSS-213 procedure if the belt were tightened after the ATD was set in place.

Installation instructions supplied by CRS manufacturers usually recommend that the installer push down hard on the CRS with his/her knee or hand as the belt is being tightened (19). This method requires application of much less adjustment force to the free end of the belt to achieve the same final tension force. Since the belt angle produced when a CRS is installed in an aircraft seat is often nearly vertical, as seen in Figure 11, the final tension in the belt after the child is seated can be directly related to the force required to compress the CRS into the bottom cushion, less the weight of the child. Application of this force in an actual CRS installation is, therefore, more analogous to the installation test method in FMVSS-213.

This means that the specified lap belt tension in an aircraft test installation modeled on FMVSS-213 can be achieved by applying a downward force on the CRS equal to the child's weight (35.65 lb for the 3-year-old ATD) plus a 30-lb tensioning force (15 lb in each side) while sufficient force is applied to the free end of the lap belt to overcome friction and remove all slack. The advantage of this procedure is that it provides better, more reproducible, test results using a tension level that can be achieved in actual practice by following the CRS manufacturer's installation instructions.

Figure 11 - Typical Lap Belt Angle

CONCLUSIONS

The review of AS5276/1, FMVSS-213, and TSO C-100b identified requirements in FMVSS-213 applicable to ACSD that are not addressed by TSO-C100b or SAE AS5276/1, as well as requirements that are addressed by all three documents but are handled differently. Incorporating the identified FMVSS-213 requirements into the aviation standards should improve the safety of ACSD. Utilizing applicable automotive requirements would also allow ACSD users to benefit from the extensive research supporting the development of those requirements.

The stated purpose of AS5276/1 is partly to "enable proper restraint of children in the aircraft environment." Evaluation of these test requirements indicated that changes to certain test parameters could enhance the tests to better reflect the current aircraft seat environment. An analysis of the currently installed economy-class aircraft seats indicated that most have the lap belt anchor location further aft than the location specified in the standard, which suggests that the standard is overly conservative with regard to CRS dynamic performance. The seat bottom cushion support surface required on the AS5276/1 test fixture needs to be lengthened at the forward edge to better model currently installed seats. In contrast, typical seat cushion dimensions and properties remain within the range specified by the standard. Potential variations in seat cushion stiffness identified between the specified seat cushion and typical production cushions are likely to have negligible effects. The CRS installation procedure was predisposed to result in a much looser fitment of the CRS in the test fixture than would be produced in actual aircraft installation if typical CRS manufacturer installation instructions were followed. Alternatively, the FMVSS-213 CRS installation procedure is more likely to produce a CRS initial position and belt tension analogous to that produced by following manufacturer's CRS installation instructions, suggesting that the AS5276/1 test would benefit from revision that includes FMVSS-213 methodology.

In summary, TSO-C100b is based on AS5276/1, which has been shown to need revision. Both the standard and the TSO would benefit if they were changed to reflect the results of this review. This would allow for better evaluation of candidate ACSD intended for the transport aviation environment, while maintaining or enhancing the current level of safety.

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