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Improving the Repeatability and Reproducibility of Belt Fit Measurement with 6YO and 10YO ATDs

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16. Abstract

In previous work, researchers at the University of Michigan Transportation Research Institute (UMTRI) developed a method for quantifying the belt fit provided by belt-positioning boosters by measuring the belt location relative to the six- and ten-year-old Hybrid-III dummies. In another study, the torso and lap belt scores obtained by this method were found to be closely related to the belt fit obtained by similar-size children across a wide range of booster and belt conditions. The Insurance Institute for Highway Safety (IIHS) adapted the UMTRI procedure to develop a rating system for booster belt fit, but adoption by other labs has been slowed by difficulty in obtaining repeatable results.

The current study was undertaken to improve the repeatability and reproducibility across operators of the procedure. The modifications made by IIHS were studied and most incorporated, and a number of other issues were examined through pilot testing. A revised version of the procedure was tested with repeated measurements by three operators in six boosters. The results were analyzed to quantify the variance associated with the operators, the installation of the booster and dummy, and the routing of the belt.

The results show that trained operators can perform the procedure with minimal systematic bias across boosters. The variability within booster varies considerably, with some boosters producing higher precision measurements due to the design of their belt-routing features. For any particular booster, the booster and dummy installation process accounts for about half the variability in the belt fit scores with the remainder due to variability in the belt routing and other measurement variability.

Based on these findings, multiple measurements of belt fit in each booster are recommended to establish the desired level of confidence in the true belt fit. Straightforward statistical methods involving confidence intervals are recommended for establishing objective test methods. More testing will be needed to determine the reproducibility of the method across laboratories.

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Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
In	inches	25.4	millimeters	mm
Ft	feet	0.305	meters	m
Yd	yards	0.914	meters	m
Mi	miles	1.61	kilometers	km
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
Ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square	6.89	kilopascals	kPa

	inch			
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
FORCE and PRESSURE or STRESS				
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CONTENTS

EXECUTIVE SUMMARY

In previous work, researchers at the University of Michigan Transportation Research Institute (UMTRI) developed a method for quantifying the belt fit provided by belt-positioning boosters by measuring the belt location relative to the six- and ten-year-old Hybrid-III dummies. In another study, the torso and lap belt scores obtained by this method were found to be closely related to the belt fit obtained by similar-size children across a wide range of booster and belt conditions. The Insurance Institute for Highway Safety (IIHS) adapted the UMTRI procedure to develop a rating system for booster belt fit, but adoption by other labs has been slowed by difficulty in obtaining repeatable results.

The current study was undertaken to improve the repeatability and reproducibility across operators of the procedure. The modifications made by IIHS were studied and most incorporated, and a number of other issues were examined through pilot testing. A revised version of the procedure was tested with repeated measurements by three operators in six boosters. The results were analyzed to quantify the variance associated with the operators, the installation of the booster and dummy, and the routing of the belt.

The results show that trained operators can perform the procedure with minimal systematic bias across boosters. The variability within booster varies considerably, with some boosters producing higher precision measurements due to the design of their belt-routing features. For any particular booster, the booster and dummy installation process accounts for about half the variability in the belt fit scores with the remainder due to variability in the belt routing and other measurement variability.

Based on these findings, multiple measurements of belt fit in each booster are recommended to establish the desired level of confidence in the true belt fit. Straightforward statistical methods involving confidence intervals are recommended for establishing objective test methods. More testing will be needed to determine the reproducibility of the method across laboratories. If multiple labs are to obtain similar test results, a uniform seat and belt configuration will need to be established.

INTRODUCTION

Belt-positioning boosters are intended to improve the fit of three-point belts for children who are too small to obtain good fit sitting on the vehicle seat. Laboratory research with children has shown that boosters are effective in improving belt fit in both the lap and shoulder areas, but substantial differences are observed across boosters (Reed et al. 2008). A belt-fit measurement procedure using a Hybrid-III six-year-old (6YO) anthropomorphic test device (ATD) was developed (Reed et al. 2009) to facilitate quantitative comparisons of belt fit for similar-size children. The procedure includes ATD positioning based on a statistical analysis of child postures (Reed et al. 2006). Strong relationships have been established between the lap and shoulder belt fit measured with the ATD and belt fit for similar size children (Reed et al. 2008). The Insurance Institute for Highway Safety (IIHS) adapted the procedures developed at the University of Michigan Transportation Research Institute (UMTRI) to rate the belt fit provided by a large number of boosters (IIHS 2009). A subsequent assessment demonstrated that manufacturers have improved the belt fit provided by their boosters since the first assessments (IIHS 2008, 2010).

Efforts to apply the procedures in other laboratories other than UMTRI and IIHS have been hampered by difficulties in obtaining repeatable and reproducible belt fit scores. The current study was conducted to identify sources of variability and to develop improvements to the belt-fit measurement procedures to improve repeatability and reproducibility. After extensive pilot testing, including several hundred belt fit measurements by multiple operators, a modified procedure was developed that includes a number of technical and procedural steps to improve performance. The new procedure can be used with both the 6YO and 10YO Hybrid-III ATDs. Using the new procedure, 90 belt fit measurements were conducted with the 6YO ATD by three operators with six boosters. The 10YO was used to make 54 measurements by three operators in two boosters.

This report documents the results of this testing, which quantifies the level of repeatability and reproducibility that can be obtained with the new procedure. Appropriate statistical techniques for analyzing and interpreting the belt fit results are documented. The complete belt-fit measurement procedure is provided in Appendix 2.

METHODS

Previous Testing with 6YO Hybrid-III ATD

Testing conducted during earlier UMTRI studies (Reed et al. 2008, 2009) provided substantial experience with the ATD-based belt-fit procedure and provided guidance on ways to improve performance. Table 1 is reproduced from Reed et al. (2009), showing belt fit measurements using the 6YO Hybrid-III ATD. The table shows results from three trials by two investigators in each of four booster conditions. In each trial, lap and shoulder belt scores were calculated in the manner depicted schematically in Figure 1. The lap belt score is the distance below and forward the ATD anterior-superior iliac spine (ASIS) landmark of the upper edge of the lap portion of the belt at the lateral position of the ASIS, measured along the ATD profile on that lateral section. The shoulder belt score is the lateral distance from the ATD centerline of the inboard edge of the shoulder portion of the belt measured at the height of the neck/chest-bib junction.

In the earlier study, the lap belt score range for three repeated tests was always less than 10 mm. This range was substantially less than the mean difference between boosters. The lap belt score ranges were generally smaller when the belt was repeatedly routed than when the full ATD installation was repeated, indicating that both ATD positioning and belt routing contribute to lap belt score variability. The differences between operators in lap belt score were smaller than the difference between boosters and similar to the range within operator and booster.

Shoulder belt score showed higher variability in both absolute and relative terms than lap belt score. The mean range for three repeated trials was 7 mm, about 27% of the mean difference between boosters B12 and B24. However, a larger variability in the range was observed than was the case with lap belt score, with some ranges as high as 14 mm. Overall, these results indicated good repeatability and reproducibility for this small set of conditions, with two operators.

Table 1
Previously reported repeatability and reproducibility of belt fit measurement procedure (Reed et al. 2009): mean and range values from three installations of booster and 6YO ATD followed by three trials with repeated belt donning (mm).

		Lap belt score*				Shoulder belt score*			
		Full install		Belt only		Full install		Belt only	
Booster**	Investigator	Mean	Range	Mean	Range	Mean	Range	Mean	Range
B12B†	1	39	8	36	1	4	8	2	11
B12B†	2	37	4	40	6	-1	5	-1	4
B12B	1	36	1	36	1	-19	5	-17	3
B12B	2	33	3	35	2	-11	8	-11	10
B12	1	31	6	29	1	-5	4	-5	8
B12	2	25	2	27	1	-1	2	-4	8
B24	1	4	2	4	2	-24	14	-27	3
B24	2	3	1	2	1	-34	7	-34	5

* The ideal 6YO ATD lap belt score is 15 mm or higher. The ideal 6YO ATD shoulder belt score is -8 mm. (See Reed et al. 2008.)

*B12 = Graco Turbobooster, B12B = Graco Turbobooster backless, B24 = Cosco (Dorel) Alpha Omega highback

† Tested with positioning clip for shoulder belt.

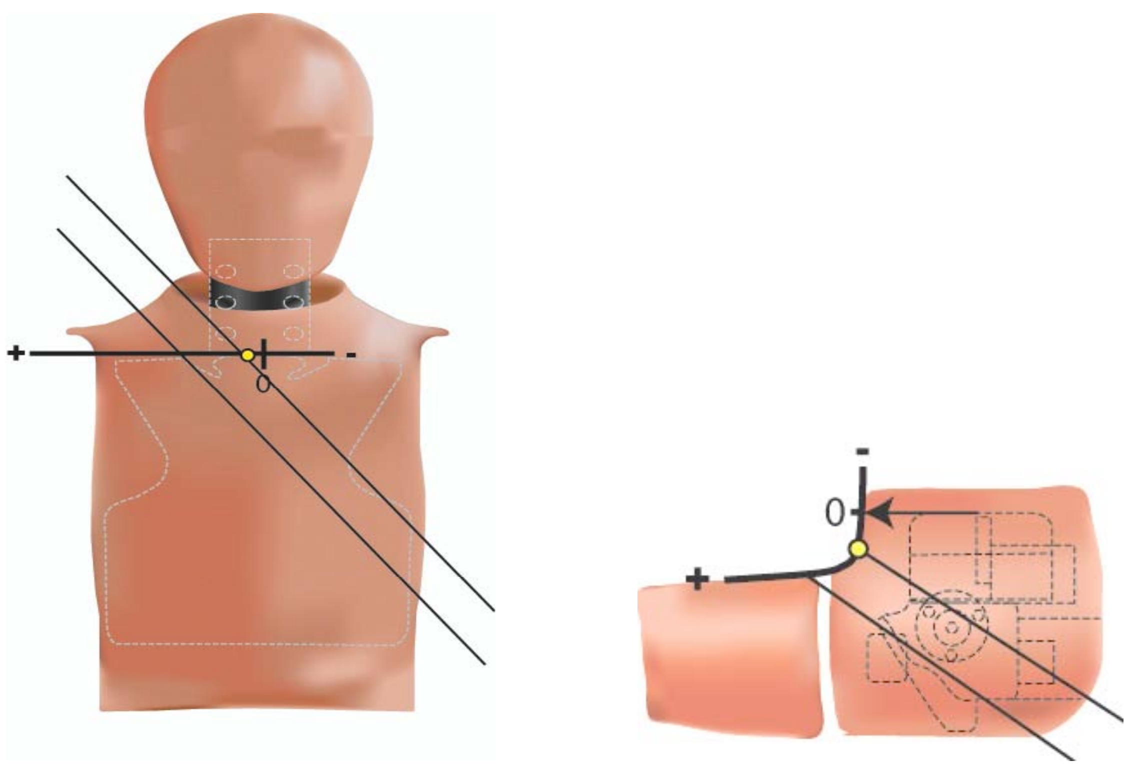

Figure 1. Diagrams showing calculation of scores for shoulder and lap belt fit. Small circles indicate digitized landmark used to compute scores; belt scores were defined as the distance (mm) along the indicated contour from the origin (marked with 0). The origin for the lap belt fit is the top of the ATD pelvis. The origin for the shoulder belt fit is the ATD centerline at the height of the neck/chest-bib junction.

IIHS Modifications to Procedure

IIHS adopted the UMTRI belt fit procedure for its booster rating program, but made several modifications to improve repeatability and to provide good consistency with UMTRI measurements. As described in IIHS (2009), the modifications included:

- A procedure for shimming the chest jacket and measuring its location to ensure consistent positioning of the jacket relative to the spine
- The addition of a Teflon bib to reduce friction between the belt and the chest jacket
- Use of Teflon under the ATD to reduce friction.

IIHS also developed a dedicated seat for booster testing, somewhat similar in construction to the FMVSS 213 bench with planar foam components for the cushion and back. As was the case at UMTRI, IIHS conducted testing with a production seat belt, including a retractor, sliding latchplate, and buckle.

Jacket Issues

In its developmental testing, IIHS identified two important potential sources of variability in the shoulder belt score. First, jackets for the 6YO Hybrid-III manufactured by Denton-ATD and First Technology Safety Systems differ in contour. IIHS uses an FTSS jacket, while UMTRI developed the procedure using a Denton jacket. Second, and more importantly, the jacket location relative to the ATD can vary substantially depending on how it is installed on the ATD and how the ATD is manipulated during positioning. The jacket issues were addressed in a recent study (see Ebert-Hamilton and Reed, 2011). The study concluded that (1) jacket positioning is a larger potential contributor to variability than the jacket design, and (2) the jacket can be positioned consistently by following a prescribed installation procedure and verifying the jacket location relative to the ATD spine at three points originally specified in the IIHS procedure. These recommendations from the jacket study have been incorporated into the new procedure.

Observations from Pilot Testing

Initial testing in the current project identified a number of potential sources of variability that could be controlled. Consistently centering the booster on the seating position and aligning it to grid in both front and top planes was found to be critical. Similarly, centering the ATD within the booster and ensuring that the booster did not move away from the centered position during ATD installation was important.

Operators differed in their interpretation of a number of steps in the procedure. Among the most important, some operators tended to guide the belt with their hands more than others during belt routing, leading to different results. Operators also differed in their interpretation of the booster manual. And as noted above, differences in jacket positioning due to ATD handling could strongly influence the shoulder belt scores.

A range of potential procedure modifications to reduce or eliminate these sources of variability were studied through a large number of belt-fit trials with multiple operators, boosters, and seat/belt configurations. The results were examined both qualitatively and quantitative to assess the success of candidate modifications, and feedback from operators was valuable to understand the limitations of the procedure documentation.

Overview of Procedure Modifications

Table 2 lists the substantive changes that have been made to the procedure as a result of the current investigation. The notes in the table provide some explanation as to why each change was made.

Table 2
Changes In Procedure

Item*	Change	Notes
6.2	Added Teflon bib over jacket on ATD	IIHS added Teflon bib over jacket to reduce friction between ATD and torso belt. IIHS also added Teflon sheet to top of booster seating surface to reduce friction between ATD and seat. At UMTRI the investigators had difficulty keeping the seat sheet from crumpling and wadding, so only the Teflon bib was incorporated. UMTRI added rounded inner corners to bib to reduce tearing and created a pattern for a bib for the 10YO ATD.
6.9	Added procedure for positioning the 6YO chest jacket, including checks for shoulder and chest reference points. The procedure includes positioning the clavicle and clavicle link components prior to jacket installation.	Jacket shape and position was identified by IIHS as an important contributor to shoulder belt score variability. In a separate report (Ebert-Hamilton and Reed, 2011), UMTRI studied the shape and positioning issues and recommended a specific positioning procedure for the 6YO jacket.
7	Telling user to find and read both booster and vehicle (if applicable) manuals.	Variability in the adjustment of the booster due to differing interpretations of the booster manual can substantially affect the reproducibility of belt fit scores. The booster manual must be followed explicitly, with any interpretation of unclear sections noted.
7.1	Additional reference points on booster for initial positioning the booster coplanar to the vehicle seat and for maintaining coplanar position during ATD and belt positioning	Pilot testing demonstrated that the booster might lean or rotate during positioning. This is particularly a problem when the procedure is used on the outboard seating position of the FMVSS 213 bench.
8.3	Illustration of booster position relative to vehicle seat center plane	Proper alignment is critical for repeatability and reproducibility. The additions convey to the operator that objects may not be coplanar even when points on the midlines of two objects are aligned.
9.2	Paper should be able to be pulled from	To improve the repeatability of the force with

	behind the ATD	which the ATD is pushed into the seat, a piece of paper is placed behind the ATD. The correct installation is achieved when the positioning pad is in contact with the seatback through the paper, but the paper can be removed without dislodging the ATD.
9.3	Check bilaterally symmetrical points on ATD	Proper alignment is critical for repeatability and reproducibility.
9.3	Illustration (Figure 12) of ATD pelvis relative to seat back	Added to emphasize the parallel planes described in the text
9.4	Check shoulder position and jacket after picking up and handling the ATD	Consistent jacket positioning is critical. Handling of the ATD during installation can easily move the jacket relative to the ATD spine.
9.4	Illustration of ATD and booster relative of vehicle seat	Proper alignment is critical for repeatability and reproducibility. The additions convey to the operator that objects may not be coplanar even when points on the midlines of two objects are aligned.
9.5	Instructions not to move the clavicle when rotating the arms out of the way	Based on UMTRI jacket comparison work, which showed that shoulder segment motions could affect jacket positioning.
9.7	Check shoulders and jacket	Based on UMTRI jacket comparison work
9.10	Do not visually align tape	The line on the jacket at bib/neck height must be horizontal. The curve of the jacket creates an optical illusion. – Especially on the 10YO's jacket. Visually leveled lines can be considerably misaligned.
10	Statement about not guiding the belt position	People who work in child passenger safety may have some idea of what "good" belt fit should look like, and booster manuals sometimes state that belts should be placed in positions other than what the guides actually produce. Both these factors can bias (in different ways) individuals using the procedure. Many people using the procedure will not know the background and may not read the introduction. This statement in this location is critical. The operator should not try to produce "good" belt fit or to match the pictures in the manual.
10.5	Let go of the lap belt after it clears the edge of the lap form. Statement: Do not guide the belt	The previous photos and wording had the hand under the lap belt closer to the abdomen. This position led some operators to guide the belt too much, rather than letting it move into place as the belt was pulled.
10.5	Do not let belt become twisted	Letting guides direct belt does not mean let the belt get tangled or twisted.

* See section numbers in Appendix 2.

Testing to Quantify Repeatability and Reproducibility

After finalizing the procedure, three operators who had participated in earlier testing and had detailed knowledge of the procedure performed belt-fit measurements in each of six boosters. Table 3 lists the test matrix. After each installation of the booster and ATD, the belt was routed and measured three times, so that the effects of belt routing variability could be separated from the effects of booster and ATD installation variability. In two boosters, selected to be the representative of the newest models, each investigator performed the entire measurement procedure three times. As in previous work, the right and left lap belt scores were averaged to obtain a single lap belt score.

All testing was conducted in an UMTRI seating mockup using the modified Grand Am second-row bench seat used in previous studies (Reed et al. 2008, Reed et al. 2009). The seat was set to a back angle (SAE A40) of 23 degrees and a seat cushion angle of 14.5 degrees. The lap belt angle was 52 degrees and the D-ring location was set to 260 mm aft, 310 mm outboard, and 600 mm above the H-point on seat centerline. Figure 2 shows the 6YO ATD installed in each of the boosters during the belt-fit measurement.

Table 3
Test Matrix for Revised Procedure

Booster*	ATD	Booster & ATD Installations	Belt Fit Measurement	Operators	Total Measurements
B12L	6YO	1	3	3	9
B12H	6YO	1	3	3	9
B32H	6YO	1	3	3	9
B34H	6YO	1	3	3	9
B35H	6YO	3	3	3	27
B36H	6YO	3	3	3	27
B35H	10YO	3	3	3	27
B36H	10YO	3	3	3	27
				Total	144

* See Figure 2 for booster names.

B12L: Graco Turbo Booster
Low-back configuration

B12H: Graco Turbo Booster
High-back configuration

B32H: Safety 1st Alpha Omega

B34H: Evenflo Generations

B35H: Recaro ProBooster

B36H: Britax Frontier

Figure 2. Boosters used for repeatability and reproducibility testing.

Analysis Methods

The test data were analyzed using linear mixed-effect model functions (*lmer* in package *lme4*) in the R statistical software package (r-project.org). The goal of the analysis was to estimate the variance in belt-fit scores attributable to operators, booster and ATD installation, and belt routing. These estimates provide an evaluation of the procedure and can guide future applications of the procedure to booster evaluation. Separate analyses were conducted with the data from the 6YO and 10YO ATDs.

Table 4 lists the primary categories of variance contributing to these measurements. Each booster is assumed to have some true belt fit score, which can be approximated by repeated measurements. For the current investigation, vehicle seat and belt factors are fixed. Note that these could be expected to interact with boosters, such that the belt fit scores in some boosters (both mean and variance) would be affected more by particular vehicle and belt factors than other boosters. To take one simple example, the shoulder belt scores in backless boosters are much more strongly affected by the upper belt anchorage location and seat back angle than are those in high-back boosters with shoulder belt routing features.

Several categories of variance are associated with operators. Individual operators may have a particular bias, such as consistently obtaining higher belt fit scores across boosters. The bias may interact with booster, so that a particular operator produces higher shoulder belt scores than the average operator, but only in boosters with a particular type of belt routing feature. Operators also can be expected to differ in the amount of variance in their measurements, with some operators producing very consistent scores and others less consistent. Within-operator variance may differ across boosters, with some operators more affected than others by booster features. The overall within-operator variance for a particular booster may also be partitioned differently among the booster/ATD installation and the belt routing.

Table 4
Factors Affecting Belt Scores

Variance Category	Notes
Vehicle Seat Configuration	The vehicle seat configuration can affect belt scores, particularly for backless boosters. This factor is not examined in the current study, but see Reed et al. (2008). Each vehicle seat configuration will have a mean effect and also may affect variance, with some seats producing more variable measurements than others (for example, due to friction between the seat and shoulder belt).
Vehicle Belt Configuration	The belt anchorage locations and some other belt features, such as buckle stalk length, affect both the mean and variance of belt fit scores. These factors were not examined in the current study, but see measurements across belt conditions in Reed et al. (2008).
Booster Mean	Each booster has some "true" belt fit score
Within-Booster Variance	Boosters appear to differ substantially in the variance of the belt fit scores they produce. For example, friction in the lap belt routing features can produce variance in the procedure. Backless boosters may have more variance in shoulder belt score because the D-ring is located farther from the shoulder than the routing features of a high-back booster.
Operator Mean	Operators may have biases, for example tending to route the shoulder belt more outboard.
Operator Variance	Operators may differ in the variability of their measurements, with some operators more precise than others.

Booster and ATD Installation	Each time the booster and ATD are installed, the booster and ATD end up in slightly different positions relative to the seat and each other, which can affect the belt fit scores.
Belt Routing	The routing of the belt over the ATD is variable.
Measurement Variance	Variance is introduced in the belt location measurement procedure.
Other Sources of Variance	These include chest jacket positioning, changes in ATD shape and posture due to handling, and other minor factors such as temperature and humidity affects on belt friction.

A very large dataset would be necessary to produce reasonable estimates of all of these potential sources of variance, and the practical values of those estimates would be minimal. Our goal is to determine how much one, two, or more measurements of belt scores in a particular booster by one or more operators tell us about the likely "true" score for that booster. In general, we can expect that the true score will differ from any individual measurement, but that the mean of multiple measurements will converge to the true score as the number of measurements increases. Hence, we want variance estimates that provide guidance on the number of measurements to take, whether those measurements should be distributed across some number of operators, and how much confidence we should have that the true score lies within some margin of the mean of the measurements.

Consequently, we have estimated three types of variance:

Operator Bias – Individual operators tend to produce higher or lower scores. We estimated the distribution of this bias by including a random effect for operator in the model.

Belt-Routing Variance – After each ATD installation, the belt was routed and the fit measured three times. The variance of these values within condition provides a good estimate of how reliably operators route the belt. We estimated this variance *across boosters, operators, and ATD installations*. This variance is estimated by the residual of the mixed model with operator and ATD installation as random effects. The result is identical to the value obtained by computing the sums of squares of belt scores, centered within ATD installation, and dividing by the number of degrees of freedom (90 trials – 30 within-installation means = 60 dof).

Operator and ATD Install Variance – We attributed all variance within booster *not* associated with belt routing to operator variability in installing the booster and ATD. We estimated this variance by estimating a random effect (variance) for a variable that coded each ATD installation as a unique instance.

The resulting model is:

Belt Score = Booster + (Operator) + (ATD Install) + (Belt Routing)

where Booster is a fixed effect and operator, ATD install, and belt routing are variable effects. Belt routing is not explicitly included in the model, but rather the residual from the model fit is taken as representing belt routing variance (as well as all other sources of measurement variance not accounted for by the model effects). All three random effects are assumed to be normally distributed and hence characterized by a variance estimate.

RESULTS

Repeatability and Reproducibility (R&R) Data Summary

The data from the 144 R&R trials are listed in Appendix 1. Tables 5 and 6 summarize the belt fit scores. Figures 3 and 4 show box plots of the scores for each booster. The mean shoulder belt scores ranged from -22.6 mm in B34H to 83.9 mm in B12L, the only backless booster configuration, for a total range of mean scores of 106.5 mm. Mean lap belt scores ranged from -0.1 mm with the 6YO in B32H to 22.3 mm with the 6YO in B12L. In previous work (Reed et al. 2008), the ideal lap and shoulder belt scores were estimated by comparing the belt fit obtained with the ATDs to belt fit obtained by similar-size children in the same test conditions. Based on those comparisons, the ideal lap belt score with the 6YO ATD is 15 mm or higher, and the ideal shoulder belt sore for the 6YO ATD is -8 mm. For the 10YO ATD, the ideal lap and shoulder belt scores are 20 mm and 5 mm. The shoulder belt scores obtained in the current study for the same boosters used in the earlier work are consistently higher, suggesting that changes in the test procedure to improve repeatability may also have shifted the mean values.

The standard deviation within booster, pooling across investigators and repeated installations, differed substantially across boosters. For shoulder belt score, the lowest standard deviation of 4.9 mm was observed in B34H and the highest (18 mm) was observed in B36H with the 10YO. The standard deviation of lap belt score ranged from 1.5 to 3.0 mm across boosters.

Table 5
Summary of **Shoulder Belt Scores** by Booster (mm)

Booster	ATD	N	Mean	Std. Dev.	Std. Error
B12H	6YO	9	18.6	8.5	2.8
B12L	6YO	9	83.9	10.6	3.5
B32H	6YO	9	90.4	15.2	5.1
B34H	6YO	9	-22.6	4.9	1.6
B35H	6YO	27	31.0	5.7	1.1
B36H	6YO	27	9.4	3.7	0.7
B35H	10YO	27	41.5	15.0	2.9
B36H	10YO	27	32.2	18.0	3.5

Table 6
Summary of **Lap Belt Scores** by Booster (mm)

Booster	ATD	N	Mean	Std. Dev.	Std. Error
B12H	6YO	9	12.0	3.0	1.0
B12L	6YO	9	22.3	2.6	0.9
B32H	6YO	9	-0.1	2.5	0.8
B34H	6YO	9	3.1	1.8	0.6
B35H	6YO	27	10.0	1.5	0.3
B36H	6YO	27	13.3	2.1	0.4
B35H	10YO	27	17.1	1.9	0.4

B36H	10YO	27	17.4	2.0	0.4

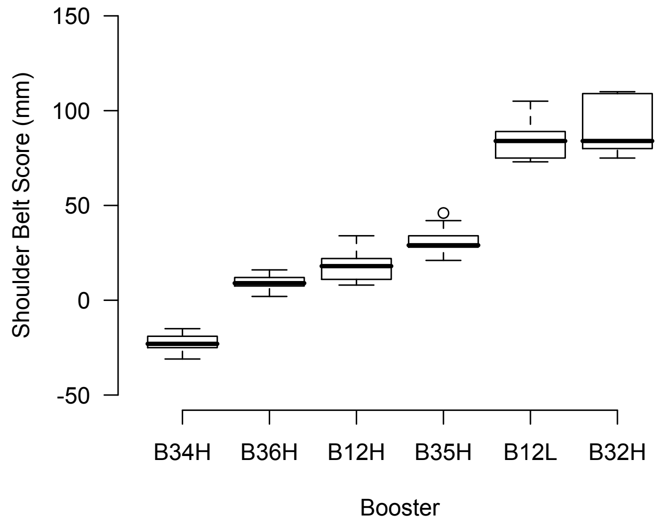

Figure 3. Box plot of shoulder belt scores by booster for 6YO, sorted left to right by median score.

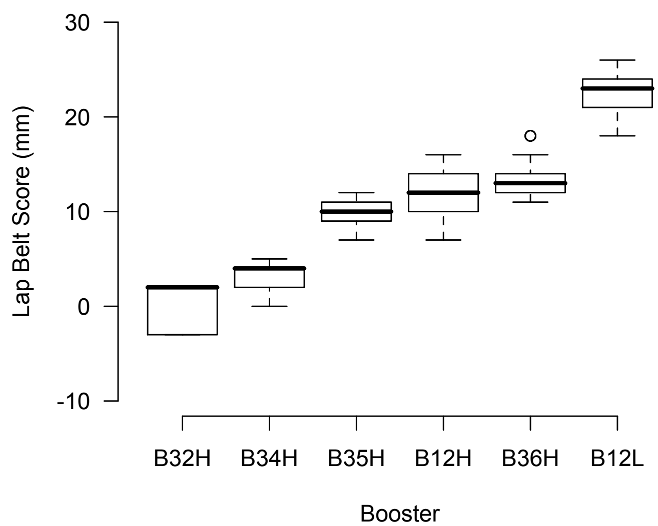

Figure 4. Box plot of lap belt scores by booster for 6YO, sorted left to right by median score.

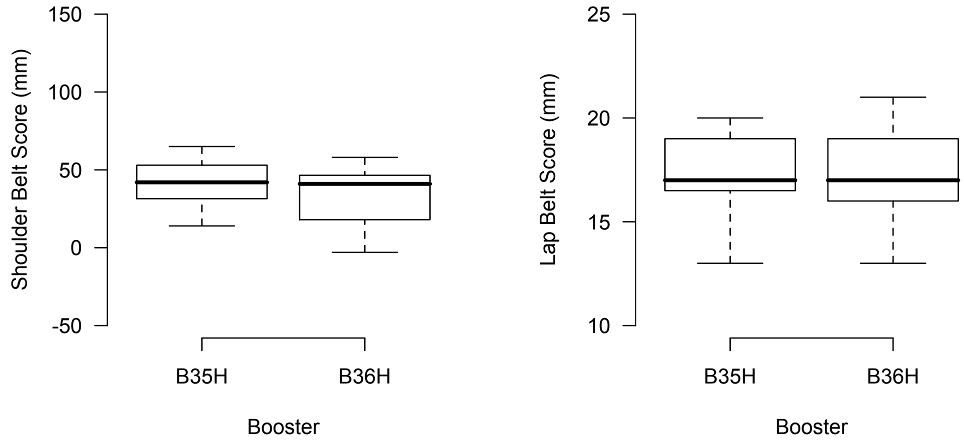

Figure 5. Box plots of shoulder and lap belt scores for 10YO.

Variance Estimates: 6YO

Table 7 shows the random effect estimates from the linear mixed model. The total variance for the belt fit measurement is taken as the sum of these three variances. The table shows that the shoulder belt score measurement has a standard deviation of about 7.8 mm and the lap belt score measurement has a standard deviation of about 2.3 mm, taking into account all sources of variability.

Note that these estimates of process variability are slightly different from those that are obtained directly from Tables 5 and 6. If the within-booster variances are converted to sums of squares, taking into account the differing numbers of observations across boosters, a root mean square error estimate within booster of 7.5 mm is obtained for shoulder belt score (2.1 mm for lap belt score). The difference is attributable to the way the linear mixed models algorithm fits this unbalanced design. Either set of estimates for the whole process variance is reasonable, but the LMM method provides a useful partitioning of variance among the various sources.

One useful way of assessing the importance of the belt-measurement process standard deviations is to compare them to the range across boosters. For shoulder belt score with the 6YO, the process standard deviation is 7 percent of the range of means. For lap belt score, the process standard deviation is 10 percent of the range of means.

Variance Estimates: 10YO

The lap belt fit scores with the 10YO had similar variance to those obtained with the 6YO. The contributions of operator, ATD install, and belt routing were similar. In contrast, the shoulder belt scores were more variable with the 10YO. Unlike with the 6YO, where differences between operators were negligible, operator variance contributed as much as ATD installation variance. The overall within-booster standard deviation estimate was slightly more than twice the estimate for the 6YO (7.8 vs. 18.4 mm).

The variance due to operator differences was considerably larger relative to the other sources of variance for the shoulder belt score measures with the 10YO. This difference is believed to arise due to the greater difficulty in handling the heavier, taller 10YO ATD. Systematic differences in the installed orientation of the ATD torso may arise due to differences in installer strength. Moreover, because the measuring point for shoulder belt score is higher on the 10YO than on the 6YO, variance in torso orientation is magnified relative to the 6YO.

Table 7a
Random Effect Estimates from Linear Mixed Models (6YO)

Factor	Shoulder Belt Score		Lap Belt Score	
	Variance	Std. Dev. (mm)	Variance	Std. Dev. (mm)
Operator	2.8	1.7	1.5	1.2
ATD Install	30.4	5.5	1.9	1.4
Belt Routing (Residual)	27.8	5.3	1.8	1.3
Total:	61	7.8*	5.2	2.3*

* Square root of total variance.

Table 7b
Random Effect Estimates from Linear Mixed Models (10YO)

Factor	Shoulder Belt Score		Lap Belt Score	
	Variance	Std. Dev. (mm)	Variance	Std. Dev. (mm)
Operator	162.3	12.7	1.6	1.3
ATD Install	108.7	10.4	1.6	1.3
Belt Routing (Residual)	68.9	8.3	1.6	1.3
Total:	339.9	18.4*	4.3	2.1*

* Square root of total variance.

Application

The measurement process variance estimates can be used to guide the development of a booster measurement methodology. For purposes of this discussion, we assume that a criterion value is applicable to each belt fit score. For example, the lap belt score criterion might be 0 mm, the value for which the upper edge of the belt lies at the ATD ASIS landmark. Using this criterion, an acceptable booster would be one in which the lap belt score was greater than zero.

The results above indicate that it may not be necessary to use multiple operators for the 6YO. The well-trained operators in the current testing showed little systematic bias with the 6YO, so repeated measurements by one operator may provide approximately the same precision as the same number of measurements by multiple operators. However, operator variance was considerably larger for shoulder belt score with the heavier 10YO ATD. Unless the causes of this variance can be addressed (difficulty in handling the 10YO seem to be at the root of the problem), multiple operators may be necessary with the 10YO.

For the 6YO, the results indicate that the ATD positioning and belt routing contribute approximately equally to the belt score variability. Because routing the belt takes less time than doing the full installation, we recommend that three belt routings and measurements be performed following each ATD install. The mean of these three measurements is then taken as one belt fit measurement.

We recommend that the full installation with three belt routings be performed three times for each booster to be measured. The resulting values are used to construct a confidence interval on the mean, using standard procedures. The confidence interval is:

$$(M - t_{a/2,n-1}\, SE, M + t_{a/2,n-1}\, SE)$$

where n is the number of samples, M is the sample mean, SE is the standard error of the mean (standard deviation divided by the square root of n) and t is the Student's t distribution with n -1 degrees of freedom. A typical value of a is 0.05 to obtain a 95% confidence interval.

Under the standard definition of the confidence interval, the true mean value is expected to lie within the confidence interval (1- a) 100 percent of the time that such intervals are constructed. In the present case, we can interpret a confidence bound that does not include the criterion value as strong evidence that the true mean belt fit does not lie beyond the criterion.

The number of measurements needed to determine whether mean belt fit for a booster exceeds a criterion depends on the difference between the criterion and the true mean for the booster, as well as the measurement variance. For n = 3 and alpha = 0.05, $t_{0.025,2} = 4.3$. If we assume the sample standard deviation is 5.8 (square root of the sum of the operator and ATD install variances for shoulder belt fit with the 6YO), the SE is 3.34. Hence, the confidence bound has a half-width of 4.3 (3.3) = 14 mm. If the sample mean lies more than 14 mm from the criterion, then we expect that the chance that the true mean exceeds the criterion is less than 5%. (In actual measurement situations, the SE could be larger or smaller.) For lap belt calculations, the equivalent SE is 1.8 mm and the 95% confidence interval half-width is 8 mm. That is, if the mean lap belt score after three measurements is more than 8 mm from the criterion, we have strong evidence that the true mean does not exceed the criterion.

(Note that since the criterion comparison will usually be one sided, testing the null hypothesis that the true mean is less than or equal to the criterion, the less conservative value of $t_{0.05,2} = 2.92$ could be used. This is equivalent to a one-sided t-test.)

If the criterion lies within the confidence interval (equivalent to failing to reject the null hypothesis), then more measurements can be taken. Increasing the number of measurements beyond 3 rapidly reduces the standard error of the mean and also decreases the t value, so that the confidence interval shrinks. However, when testing against a criterion belt fit, a reasonable limit to the number of measurements is probably necessary.

Further research is needed to determine if this calculation procedure will be adequate with the 10YO ATD for shoulder belt score, because of the relatively higher inter-operator variability.

DISCUSSION

Modifications to the Procedure

Hundreds of belt-fit measurements were made during the current project, testing a variety of different modifications to the procedure and the procedure documentation intended to improve repeatability and reproducibility. Careful attention to chest jacket positioning was found to be necessary following a quantitative study of chest jacket shape and location (Ebert-Hamilton and Reed, 2011). Aside from ensuring consistent jacket positioning, the most important modifications to the procedure were adapted from those instituted by IIHS as part of their booster belt-fit rating program. Among those, the Teflon chest bib has the greatest effect.

A comparison of the results from the current study with ATD measurements of the same boosters made in an earlier study (Reed et al. 2008) showed some differences in the mean scores, particularly in shoulder belt scores. Some of these differences may be attributed to differences in belt geometry, but it's also possible that the changes in the procedure to improve its repeatability may have shifted the mean values.

Comparison of 6YO and 10YO Results

The repeatability and reproducibility of lap belt fit scores with the 6YO and 10YO were very similar, with both showing low variability. However, the 6YO shoulder belt scores were substantially more repeatable and reproducible than were the scores with the 10YO. Most of the additional variance is due to variability in installing the ATD. Establishing consistent positioning of the 10YO is challenging for a number of reasons, but particularly:

1. The greater weight of the 10YO, compared with the 6YO, makes consistent positioning difficult for many operators.

2. The pelvis flesh of the 10YO is molded at a more open angle than the 6Y0. Although this allows more realistic pelvis positioning in some seating situations, it makes consistent positioning of the ATD pelvis more difficult in boosters.

3. The greater height of the 10YO causes it to be less stable both laterally and foreaft.

The 10YO provides the opportunity to assess the belt fit provided by boosters for relatively large children. Relatively few children the size of the 10YO ATD are seated in boosters, although previous research suggests most children that size would receive better belt fit using boosters than seated on vehicle seats without boosters.

Repeatability and Reproducibility

The final set of R&R data reported here demonstrated that the repeatability of the procedure is sufficient to reliably differentiate boosters with respect to lap belt fit with either ATD. Shoulder belt scores were reliable with the 6YO, but less so with the 10YO. The larger installation variability for the 10YO, particularly across operators, appears to be due to the greater mass and size of the ATD. Manipulating the 10YO requires more strength than handling the 6YO, and the height of the ATD, coupled with its torso mass, makes it less stable in absolute terms than the 6YO. That is, a lean of one degree with the 6YO has a smaller effect on shoulder belt score than the same lean on the 10YO, due to the greater height of the chest of the 10YO. Moreover, the greater mass makes the positioning variability more likely due to the difficulty in handling the ATD.

Considerably more work remains to determine the extent to which the procedure is reproducible across laboratories. Two major factors are the seat and the belt system. At UMTRI, most belt-fit testing, including the current work, has been conducted on a mockup of a typical second-row sedan seating environment. IIHS developed a generic seat mockup for booster belt-fit testing, using some design concepts from the FMVSS 213 buck, including planar seat surfaces.

At UMTRI, some belt-fit testing has been conducted on the FMVSS 213 buck, and many sled tests have been conducted using essentially identical ATD positioning and belt-routing procedures. This experience suggests that it would be feasible to use the FMVSS 213 bench as a standard environment for evaluating booster belt-fit, with attention to several issues:

- The FMVSS 213 bench is softer, on a range of measures, than typical second-row vehicle seats. Consequently, the 6YO Hybrid-III ATD seated on a booster penetrates into the seat more, and more variably, than on a typical vehicle rear seat.

- In part because of the relatively soft cushion, edge effects in the outboard seating position on the bench can lead to the booster and ATD tipping outboard during installation. Maintaining the booster and ATD level and centered on the seating position is more challenging on the FMVSS 213 bench than on typical vehicle seats.

- The FMVSS 213 bench lacks a standard belt system with a retractor, sliding latchplate, and webbing- or stalk-mounted buckle. A standardized belt-fit measurement procedure using the FMVSS 213 would need to specify a consistent procedure for attaching the belt webbing. The hardware approximating the buckle requires particular attention because it can often interact with the booster, altering the belt routing. The belt-routing procedures in the current procedure, which were developed for a belt system with a retractor and a sliding latchplate, may need to be adjusted for use with separate pieces of webbing for the lap and shoulder portions of the belt.

- The lower belt anchor locations on the FMVSS 213 bench are unusually high and rearward relative to anchorage locations in second-row outboard seating positions. For some boosters, this will tend to produce worse lap belt scores than more typical belt anchorage locations. This can be viewed as a positive factor, however, since it represents a challenge to the ability of the booster to improve lap belt fit.

Application

Like any measurement procedure, the belt-fit measurement procedure developed and evaluated in this work has variance, and the use of the procedure must keep that in mind. In addition to quantifying the performance of the procedure under essentially best-case conditions, we have recommended some straightforward statistical techniques for selecting the number of trials to perform and interpreting the results.

The evaluation criteria (for example, what constitutes "good" or "acceptable" belt fit) should be selected in tandem with the choice of key aspects of the measurement method, such as how many trials are to be used to estimate the true belt fit. If relatively few trials are permitted, a relatively lax criterion is necessary to avoid erroneously classifying boosters as poor performers. On the other hand, using a method that involves more trials, providing greater precision in estimating the mean, would allow more stringent criteria while maintaining a low probability of mistaken classification.

It is important to recognize that, because human operators are involved, the variance in repeated belt fit trials can be much larger than reported here. A sloppy or poorly trained operator can easily produce widely varying results. Even with these well-trained operators, the variance in shoulder belt score with the 10YO is considerably higher than with the 6YO. One approach to minimizing the effects of such variance would be to require that the 95% confidence interval on the mean be narrower than some criterion (say, 20 mm) prior to concluding a booster evaluation. That is, an operator producing highly variable numbers would need to perform more trials than one who produced values in a narrow band. Even with conscientious operators, some boosters produce more variable belt fit than others (see Tables 5 and 6), and so a greater number of measurements may be needed to achieve a target for confidence interval width.

A more difficult reproducibility problem to address is variability across labs in the seating position of the booster and ATD, potentially due to differences in seats. One way to track this problem is to carefully record reference points on the booster and ATD so that the causes of differences across labs can be assessed. The inter-operator is particularly acute for shoulder belt score, and particularly for the 10YO, because even subtle differences in the operators' interpretation of the procedure for installing the ATD and routing the belt can produce meaningful differences in belt score.

In previous testing with both children and ATD, varying the belt geometry over the range observed in vehicles has produced a wide range of belt fit. However, the ATD-measured belt fit in a mid-range belt geometry is a reasonable predictor of belt fit across the range of belt geometries. Testing belt fit at only one belt geometry does not evaluate the effectiveness of the booster in isolating the child from poor belt geometry. Using a range of belt anchorage locations injects additional variance into the study, so that more trials will typically be required to arrive at a desired confidence bound. An alternative approach is to perform separate evaluations at a range of belt configurations and require that the booster meet the criteria at all tested configurations, rather than on average across configurations.

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Appendix 1
Belt Fit Scores for Repeatability and Reproducibility Testing: 6YO

Trial	Booster	Operator	Booster/ATD Install	Belt Routing Rep.	Torso Belt Score (mm)	Lap Belt Score Left (mm)	Lap Belt Score Right (mm)	Mean Belt Score Mean (mm)
1	B12H	CU	1	1	11	8	5	7
2	B12H	CU	1	2	26	12	12	12
3	B12H	CU	1	3	8	11	10	11
4	B12H	LM	1	1	18	13	15	14
5	B12H	LM	1	2	17	15	17	16
6	B12H	LM	1	3	9	14	17	16
7	B12H	SE	1	1	22	11	9	10
8	B12H	SE	1	2	22	10	9	10
9	B12H	SE	1	3	34	12	11	12
10	B12L	CU	1	1	78	14	21	18
11	B12L	CU	1	2	75	20	24	22
12	B12L	CU	1	3	73	19	23	21
13	B12L	LM	1	1	73	23	26	25
14	B12L	LM	1	2	86	24	24	24
15	B12L	LM	1	3	89	25	27	26
16	B12L	SE	1	1	84	20	18	19
17	B12L	SE	1	2	105	20	25	23
18	B12L	SE	1	3	92	21	24	23
19	B32H	CU	1	1	109	-2	-4	-3
20	B32H	CU	1	2	110	-2	-4	-3
21	B32H	CU	1	3	110	-2	-4	-3
22	B32H	LM	1	1	75	4	0	2
23	B32H	LM	1	2	80	3	1	2
24	B32H	LM	1	3	80	2	1	2
25	B32H	SE	1	1	91	-3	0	-2
26	B32H	SE	1	2	75	0	3	2
27	B32H	SE	1	3	84	1	2	2
28	B34H	CU	1	1	-15	4	4	4
29	B34H	CU	1	2	-19	3	2	3
30	B34H	CU	1	3	-18	4	4	4
31	B34H	LM	1	1	-31	1	-1	0
32	B34H	LM	1	2	-24	2	1	2
33	B34H	LM	1	3	-23	1	1	1
34	B34H	SE	1	1	-27	2	5	4
35	B34H	SE	1	2	-25	3	6	5
36	B34H	SE	1	3	-21	3	7	5
37	B35H	CU	1	1	33	7	7	7
38	B35H	CU	1	2	36	10	10	10
39	B35H	CU	1	3	29	10	11	11
40	B35H	CU	2	1	28	7	7	7
41	B35H	CU	2	2	46	7	8	8
42	B35H	CU	2	3	27	8	8	8
43	B35H	CU	3	1	28	9	9	9

44	B35H	CU	3	2	34	11	11	11
45	B35H	CU	3	3	21	10	11	11
46	B35H	LM	1	1	23	12	11	12
47	B35H	LM	1	2	26	13	11	12
48	B35H	LM	1	3	28	12	10	11
49	B35H	LM	2	1	28	8	10	9
50	B35H	LM	2	2	24	9	11	10
51	B35H	LM	2	3	32	9	11	10
52	B35H	LM	3	1	29	10	8	9
53	B35H	LM	3	2	28	10	9	10
54	B35H	LM	3	3	29	10	10	10
55	B35H	SE	1	1	40	9	9	9
56	B35H	SE	1	2	29	10	11	11
57	B35H	SE	1	3	33	10	9	10
58	B35H	SE	2	1	42	10	13	12
59	B35H	SE	2	2	32	9	13	11
60	B35H	SE	2	3	29	10	13	12
61	B35H	SE	3	1	35	10	8	9
62	B35H	SE	3	2	34	12	10	11
63	B35H	SE	3	3	35	13	9	11
64	B36H	CU	1	1	9	10	11	11
65	B36H	CU	1	2	2	10	12	11
66	B36H	CU	1	3	9	10	13	12
67	B36H	CU	2	1	8	9	13	11
68	B36H	CU	2	2	3	10	12	11
69	B36H	CU	2	3	4	11	15	13
70	B36H	CU	3	1	13	10	11	11
71	B36H	CU	3	2	11	12	12	12
72	B36H	CU	3	3	12	12	11	12
73	B36H	LM	1	1	15	20	15	18
74	B36H	LM	1	2	4	19	17	18
75	B36H	LM	1	3	6	15	16	16
76	B36H	LM	2	1	14	13	12	13
77	B36H	LM	2	2	7	13	12	13
78	B36H	LM	2	3	8	13	13	13
79	B36H	LM	3	1	16	11	13	12
80	B36H	LM	3	2	11	12	13	13
81	B36H	LM	3	3	10	20	15	18
82	B36H	SE	1	1	8	14	9	12
83	B36H	SE	1	2	12	14	11	13
84	B36H	SE	1	3	8	14	9	12
85	B36H	SE	2	1	10	13	14	14
86	B36H	SE	2	2	14	14	13	14
87	B36H	SE	2	3	12	15	15	15
88	B36H	SE	3	1	7	13	11	12
89	B36H	SE	3	2	8	16	12	14
90	B36H	SE	3	3	13	15	14	15

Belt Fit Scores for Repeatability and Reproducibility Testing: 10YO

Trial	Booster	Operator	Booster/ATD Install	Belt Routing Rep.	Torso Belt Score (mm)	Lap Belt Score Left (mm)	Lap Belt Score Right (mm)	Mean Belt Score Mean (mm)
1	B35H	CU	1	1	33	13	13	13
2	B35H	CU	1	2	42	13	14	14
3	B35H	CU	1	3	39	12	15	14
4	B35H	CU	2	1	61	17	17	17
5	B35H	CU	2	2	65	16	15	16
6	B35H	CU	2	3	61	17	19	18
7	B35H	CU	3	1	21	21	18	20
8	B35H	CU	3	2	28	15	12	13
9	B35H	CU	3	3	14	17	16	17
10	B35H	LM	1	1	16	16	19	18
11	B35H	LM	1	2	30	17	20	19
12	B35H	LM	1	3	38	17	20	19
13	B35H	LM	2	1	45	17	18	18
14	B35H	LM	2	2	23	17	17	17
15	B35H	LM	2	3	38	17	17	17
16	B35H	LM	3	1	37	14	17	16
17	B35H	LM	3	2	33	15	18	17
18	B35H	LM	3	3	21	15	19	17
19	B35H	SE	1	1	53	15	16	15
20	B35H	SE	1	2	61	18	20	19
21	B35H	SE	1	3	61	18	19	19
22	B35H	SE	2	1	43	15	18	17
23	B35H	SE	2	2	48	17	19	18
24	B35H	SE	2	3	55	19	19	19
25	B35H	SE	3	1	53	18	18	18
26	B35H	SE	3	2	52	21	17	19
27	B35H	SE	3	3	51	20	18	19
28	B36H	CU	1	1	56	11	14	13
29	B36H	CU	1	2	58	14	16	15
30	B36H	CU	1	3	46	15	17	16
31	B36H	CU	2	1	18	18	15	17
32	B36H	CU	2	2	11	19	15	17
33	B36H	CU	2	3	23	18	14	16
34	B36H	CU	3	1	44	16	18	17
35	B36H	CU	3	2	42	18	18	18
36	B36H	CU	3	3	41	18	20	19
37	B36H	LM	1	1	13	18	16	17
38	B36H	LM	1	2	-3	19	17	18
39	B36H	LM	1	3	27	19	17	18
40	B36H	LM	2	1	10	14	19	17
41	B36H	LM	2	2	20	16	20	18
42	B36H	LM	2	3	-2	17	20	19
43	B36H	LM	3	1	37	15	13	14
44	B36H	LM	3	2	1	15	15	15
45	B36H	LM	3	3	18	15	16	16

46	B36H	SE	1	1	40	15	17	16
47	B36H	SE	1	2	44	16	17	17
48	B36H	SE	1	3	49	16	18	17
49	B36H	SE	2	1	44	19	19	19
50	B36H	SE	2	2	48	20	19	20
51	B36H	SE	2	3	47	20	21	21
52	B36H	SE	3	1	47	18	19	19
53	B36H	SE	3	2	48	19	20	20
54	B36H	SE	3	3	42	20	21	21

Appendix 2
Child ATD Belt Fit Measurement procedure

Child ATD Belt Fit Measurement procedure
April 2011
Editorial Revisions 2011-11

Foreword

Child passengers who have outgrown harness restraints but are too small to be properly restrained by vehicle belts alone should be seated in belt-positioning booster seats (hereafter referred to as boosters). Boosters are designed to improve the position of the child relative to the vehicle belt restraint system and to alter the routing of the belt with respect to the child's body. The intent of the procedure is to compare belt fit across different boosters, vehicle seats, and belt configurations.

This procedure measures belt fit provided by boosters using a six-year-old and ten-year-old Hybrid-III ATDs. Points along the belt relative to the ATD are digitized in a coordinate measurement system, which requires a FARO Arm or similar coordinate measurement device.

1. OBJECTIVE

Describe a method for measuring the static belt fit using a six-year-old and ten-year-old Hybrid-III ATDs.

2. SCOPE

The procedure described in this document provides a method to reliably measure the belt fit produced by booster seats. Instructions are provided for positioning and adjusting the booster, installing and posturing the dummy, applying the belt and recording the belt fit using a FARO Arm coordinate measurement machine. The procedure is designed to produce repeatable and reproducible results using ATD positions that match the expected locations for similar-size children. Belt routing and belt tensions are intended to be typical of those produced by children who don the belt themselves. This procedure is intended for use on a seating buck (mockup), but can also be used in a vehicle.

3. TABLE OF CONTENTS

4. DEFINITIONS AND EQUIPMENT

ATD – Anthropomorphic Test Device. In this document, ATD refers to six-year-old or ten-year-old Hybrid-III.

Pelvis Positioning Pad- 125 x 95 x 20 mm piece of foam or rubber centered on the posterior of ATD pelvis with the top edge of the foam aligned with the superior edge of the ATD pelvis skin and adhered to the ATD with double sided tape. The material must have a compression resistance between 13 to 17 pounds per square inch (psi) in a compression deflection test specified in ASTM D–1056–07, a maximum compression set of 25 percent after a 24 hour recovery time in a compression set test for a Type 2—Grade 4 material specified in ASTM D–1056–07, and with a density of 9.5 to 12.5 lb/ft3.18. Example material: Ensolite IE4 (Armacell Inc.)

Lap Form – A piece of translucent silicone rubber 1/8 in thick (50A Durometer) cut to the pattern in Appendix A attached to the ATD during the procedure. The purpose of the lap form is to keep the lap belt from becoming caught in the pelvis-thigh gap of the ATD.

Hip-offsets - Hip-offsets are tools used to track the pelvis location and are inserted into the H-point gauging holes of the ATD. Appendix B gives specifications and illustrations.

Teflon Chest Bib- Teflon Film (0.003 inches thick), cut to the pattern in Appendix C and applied to ATD jacket.

ATD Jacket Pads- Spacers used to adjust the position of the jacket on the ATD. Made of the same material as the pelvis pad. Shoulder spacer dimension 2 x 1-3/4 in with varying thickness.

ATD Anatomical Terms of Location - The standardized terms of anatomical location are used when describing the ATD.

Vehicle Seat - Refers to the seat in a vehicle or the seat acting as the vehicle seat in the test buck.

Latch plate – Must be a sliding latchplate.

Retractor – As per FMVSS 209, the retractor shall exert a retractive force of not less than 1 N (0.23 lb) and not more than 7 N (1.6 lb) under zero acceleration when attached to a strap or webbing that restrains both the upper torso and the pelvis.

Vehicle Terms of Location – Terms used within follow those in SAE standards.

Centerplane - A plane that passes through the centerline of an object such as a vehicle seat or booster that bisects the object into two symmetrical halves.

Seat Centerline - A line coplanar with the vehicle's longitudinal center plane (unless specified by the manufacturer) that bisects the head restraint of the seat. If there is no head restraint, it is the geometric centerline as indicated by the contouring of the seat surface.

Booster Centerline – A line coplanar with the booster's longitudinal center plane that bisects the booster.

Inclinometer - An instrument for measuring angles of slope with respect to gravity.

Force gauge – The force gauge must be able to read forces of 133 N (30 lb) and 178 N (40 lb) and have a flat square surface with an area of 2580 square millimeters (4 square inches) with which to apply the force.

Test Buck – The buck consists of a configurable vehicle seat and seatbelt system. The vehicle seat has an adjustable seat back angle (BA), cushion angle (CA), and seat pan length. The seatbelt system allows for motion in three dimensions of the upper (D-ring) and lower (outboard and inboard) belt anchorages. Figure1 shows an example of a test buck. Configuring the buck requires a J826 H-point manikin for setting the BA, CA and measuring the H-point. The locations of the belt anchorage are measured relative to the H-point of the vehicle seat at each combination of BA and CA.

Figure 1. Example of a test buck at UMTRI

Metal Seat Back Plate - 400 mm (15.75") x 125 mm (4.9") plate of 1/8", 6061-T6 Aluminum

Cushion Length Tool – A tool used to measure seat cushion length and position the ATD pelvis.

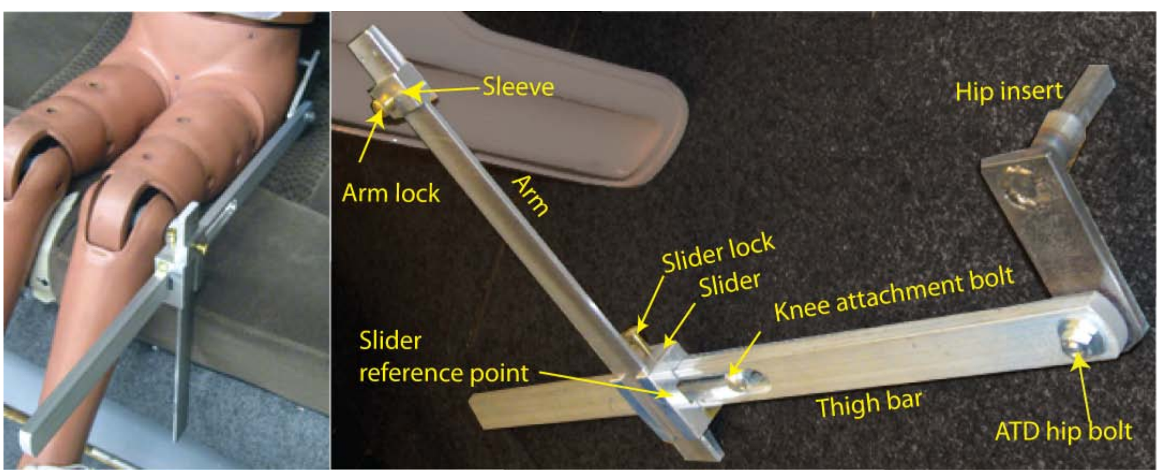


Figure 2. Example of cushion a length tool for six year-old ATD.

5. PREPARE THE VEHICLE SEAT

5.1. Adjust the vehicle seat to the required back and cushion angle. Adjust the seatbelt anchorages to the required position.

5.2. Prior to the installation of the booster the vehicle seat should remain unloaded for 30 minutes. This is to allow the seat and seat materials (e.g., foam) to recover from compression.

5.3. The vehicle seat should be located such that the centerplane of the vehicle seat is parallel to the X-Z plane of a right-handed coordinate system.

5.4. Mark the centerline of the vehicle seat with one piece of tape on the top of the head restraint or the highest point on the seat back and one piece of tape on the front edge of the seat cushion.

5.5. Record the coordinates of the vehicle seat centerline at two points on the back and cushion. Take the average Y coordinate; this will be the "vehicle seat centerline Y".

5.6. For installations of the ATD directly onto the vehicle seat (i.e. no booster), place the metal seat back plate against seat back and rest bottom on seat cushion. Ensure that the top edge of the plate remains in contact with the seat back; slide the bottom of the plate as far rearward as possible as shown in Figure 3.

Figure 3. Examples of good (left) and bad (right) seat back plate position

6. PREPARE THE ATD

6.1. Head. Draw a line on the side of the ATD head that is a projection of the plane of the accelerometer-mounting surface. This line will be used as the ATD's Frankfort plane. The line should extend between the front centerline of the head to the side of the head where the skull skin ends before the skull cap as shown in Figure 4

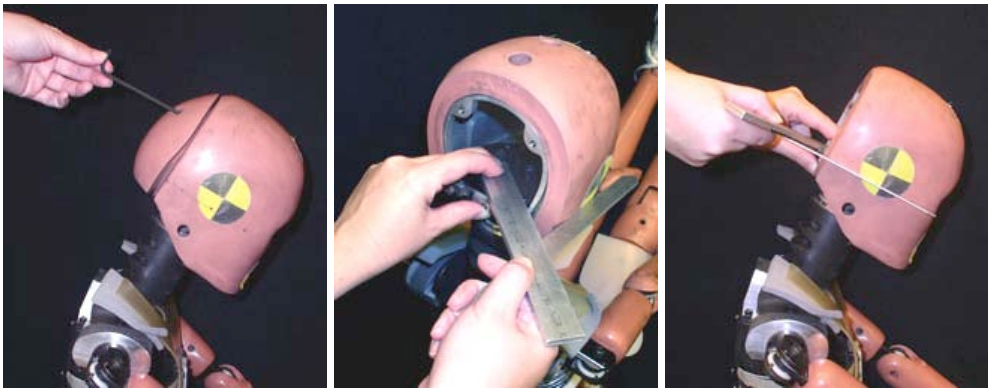


Figure 4. Marking Frankfort Plane of ATD head.

6.2. Ten-year-old ATD neck and spine. Set the adjustable neck and lumbar spine to their nominal positions.

6.3. Pelvis coordinate system, angle, PS and ASIS locations. Remove the ATD abdomen insert and set the ATD on a hard level surface such that neither the pelvis nor the torso of the ATD will move. Insert the hip-offsets in pelvis H-point gauging holes.

6.3.1. Construct the pelvis coordinate system- Orient the ATD such that the front and side of the lumbar load cell are parallel to the Y and X axes respectively as shown in Figure 5. The pelvis plane (the top surface of the pelvis) is parallel to the X-Y plane. To find the centerline of the ATD digitize the corners of the lumbar load cell as shown in Figure 5. The X and Z values should have the same values, and the centerline should be the average of the Y values. To ensure the pelvis plane is parallel to the X-Y plane, take an additional point on this surface. All three points should have the same Z value.

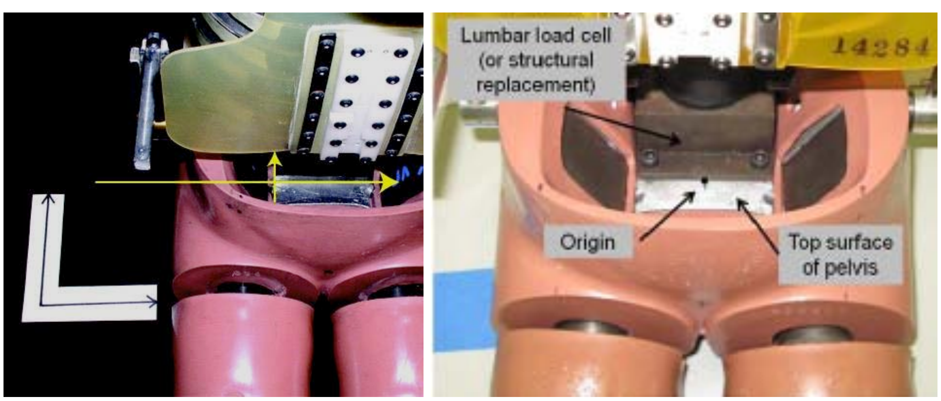


Figure 5. Creating the ATD pelvis coordinate system and landmarks by first aligning the pelvis with an external coordinate system.

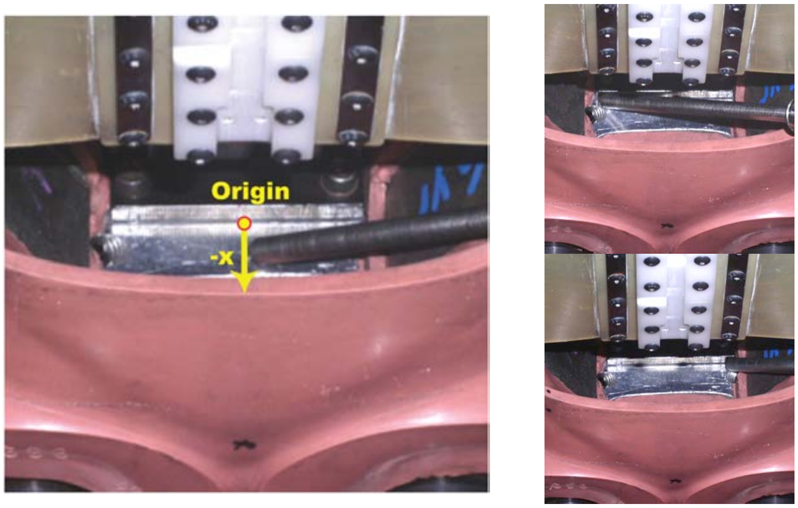


Figure 6. Aligning the lateral axis of the pelvis with the Y-axis and the pelvis plane to the X-Y plane.

6.3.2. Pubic symphysis (PS). Mark the point on the front surface of the ATD's pelvis skin with a Z value of the pelvis plane and the Y value of the centerline.

6.3.3. Anterior superior iliac spines (ASIS). Start with the right side of the pelvis. Digitize three points along the superior/medial margin of the right ASIS load cell or blank. Because the ATD is aligned to the external coordinate system, the Y and Z values of these points should be very similar; take the average Y and Z values, and find the point on the exterior flesh of the ATD with the average Y and Z and mark it. This is the external right ASIS landmark. Repeat this process for the left side.

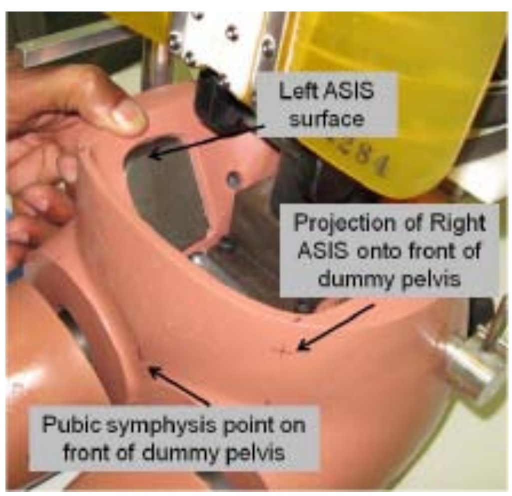


Figure 7. Anterior superior iliac spines and pubic symphysis marks on pelvis flesh

6.3.4. Mark the lateral locations of the ASIS on the superior edge of the pelvis skin (just anterior to the location of the abdomen when inserted) and the anterior edge of the pelvis just before the pelvis-thigh gap. These marks will assist in digitizing the belt location.

6.3.5. Digitize the location of the two reference points on each hip-offset tool with the upright attachment in place. Take the upright attachments off and digitize the location of the two reference points on the part that is inserted into the ATD (Figure 8).

Figure 8. Digitizing the reference marks on the hip offset tools with the upright attachment on and off.

6.4. Limbs. Limb joints are set at between 1 and 2 g's.

6.5. Clothing. The ATD will be used without clothing for belt fit measurement.

6.6. Cover pelvis-thigh gap. Set the ATD on a flat surface with the legs straight forward from the pelvis and the torso upright. Apply double sided tape to the surface of the lap form that will be in contact with the pelvis as shown in Figure 9. Place the lap form on the ATD as shown in Figure 10. The top of the lap form is aligned with the superior anterior edge of the ATD pelvis skin.

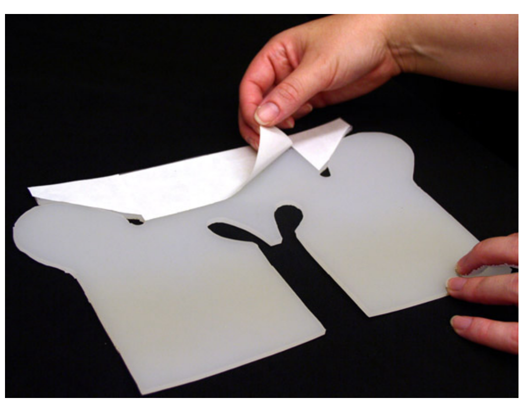


Figure 9. Applying double sided tape to the upper portion of the lap form

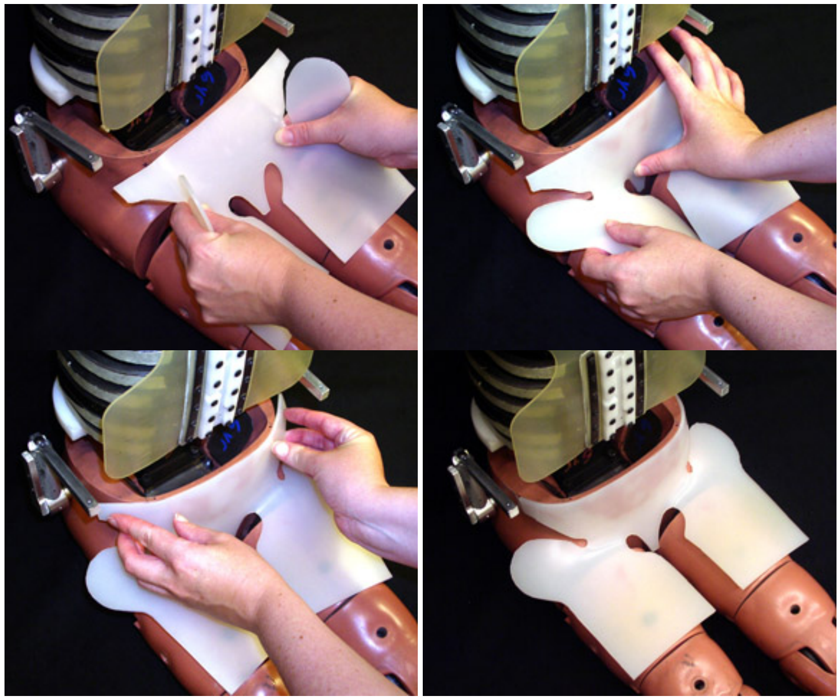


Figure 10. Attaching the lap form to the ATD

6.7. Attach pelvis-positioning pad. Cover one side of the pad with double sided tape, and center the long axis of the pad on the posterior of the ATD pelvis with the top edge of the foam aligned with the superior edge of the ATD pelvis skin as shown in Figure 11.

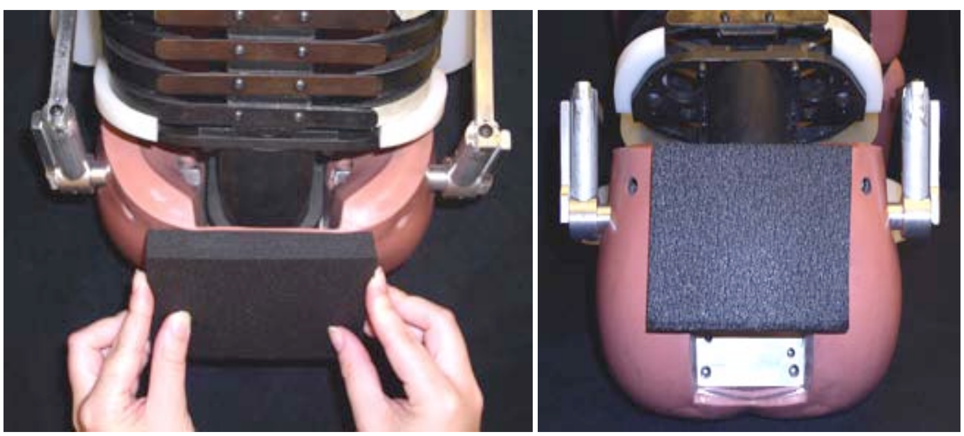


Figure 11. Attaching the pelvis-positioning pad.

6.8. Identify landmarks for digitizing. The tables in section 11 illustrate and describe the location of the landmarks and reference points that will be digitized with the FARO Arm.
6.9. Apply Teflon Bib. To reduce friction between the shoulder belt and the ATD chest jacket during the procedure, a thin Teflon sheet (see Appendix C) is taped to the front of the ATD chest jacket as shown in Figure 12. Double-sided tape should be place in the approximate location of the chest reference point to adhere the bib to the jacket.

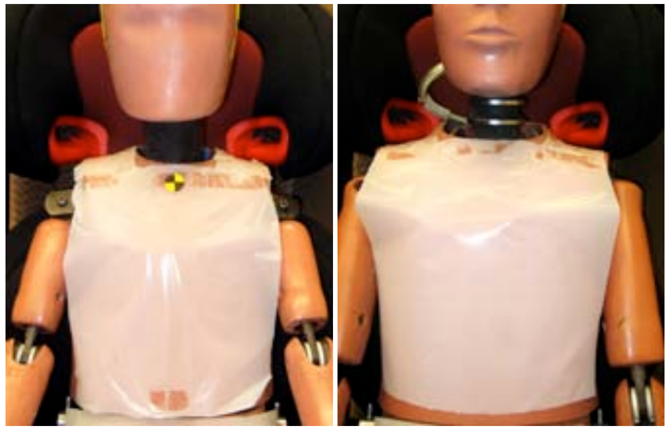


Figure 12. Teflon bibs for six-year-old (left) and ten-year-old ATDs.

6.10. For the six-year-old ATD: Check the location of the jacket relative to ATD at reference points on the chest and shoulder. The position of these points is based on the location of the ATD spine box. Place the ATD torso in an upright position, defined as the superior face of the lower neck load cell (or structural replacement) being horizontal as shown in Figure 13.

6.10.1. The orientation of the reference frame is identical to that for the test buck (X-Y plane parallel to the superior face of the load cell), and the origin is the posterior superior edge of the load cell, at the midline of the ATD (Figure 11). (Note that when using a CMM, the torso position does not need to be exactly vertical because the reference frame is determined by the orientation of the lower neck load cell. If a CMM is not used, the ATD spine may need to be more precisely positioned to accurately position the chest reference point).

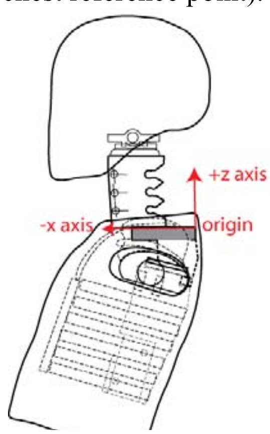


Figure 13. Coordinate system for locating jacket reference points

6.10.2. Preposition ATD shoulders and jacket as shown in Figure 14. First position clavicle link full down (push down firmly on shoulder/arm joint) and clavicle full rear (push rearward firmly on shoulder/arm joint). Then pull the jacket downward as much as possible.

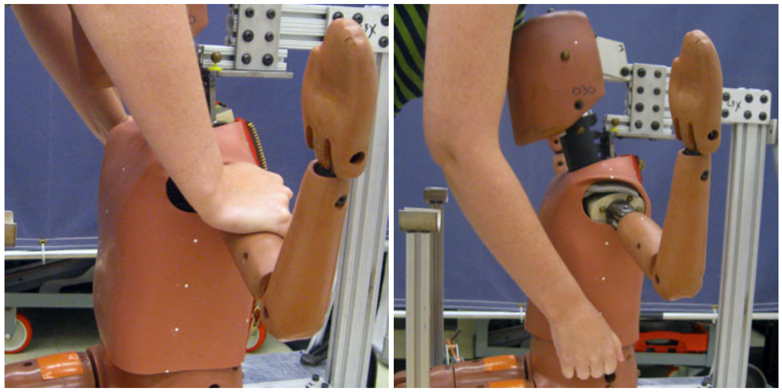


Figure 14. Positioning the shoulders and jacket on the six-year-old ATD

6.10.3. The chest reference point is defined as the location on the anterior surface of the chest jacket, at the ATD centerline, which has a Z coordinate of 0 (same plane as the load cell surface). The coordinate of this point should be (-110 ± 5, 0, 0 mm).

6.10.4. The shoulder reference point is defined as the location on the superior surface of the jacket at the midline of the ATD neck (approximate X value of 53 mm), 40 mm out from the edge of the neck. The coordinate of this point should be (-53, 72, 10 ± 5 mm). The reference points are illustrated in Figure 15.

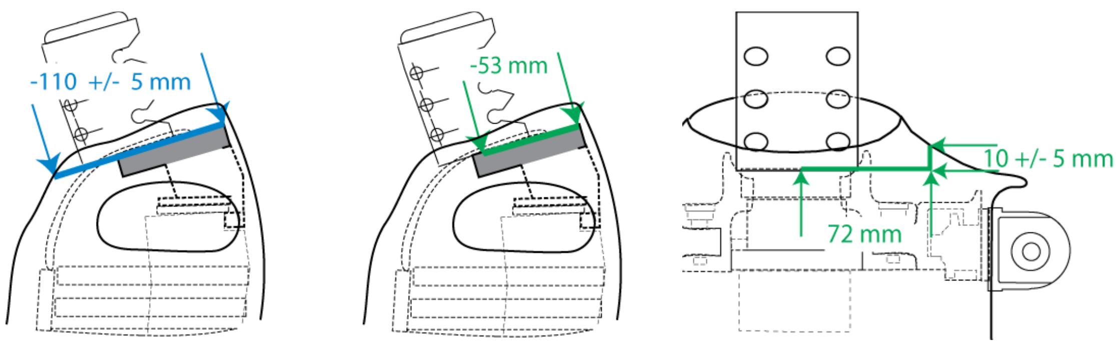


Figure 15. Chest reference point (left) and shoulder (middle and right) reference points on ATD jacket

6.10.5. If the ATD chest jacket does not meet these requirements, spacers must be placed on top of the clavicle (below the chest jacket). The spacers should be the same material as that designated for the pelvis-positioning pad but in the necessary thickness required to properly position the jacket. A first attempt at spacers should include the two shoulder spacers with a thickness of 1/2 inch, and the front chest spacer with a thickness of 3/8 inch. An example is shown in Figure 16.

Figure 16. Example of ½ inch thick shoulder spacer

6.11. If using the cushion length tool, remove hip offset tool and replace with hip insert part of cushion length tool and attach the thigh bar to the knee joint of the ATD. Leave the slider off until after the ATD is placed on the vehicle seat.

7. PREPARE THE BOOSTER

IMPORTANT: Find and read the manual for the booster being installed. If installation is being done in a vehicle, find and read the vehicle manual sections on child restraints.

7.1. Mark the centerline of the booster on the front edge of the booster seat pan. If the booster has a back, mark the centerline on the top edge of the booster back. Also place two bilaterally symmetrical points on the either side of the booster as shown in Figure 17. These lines and points will be used in aligning the booster with the vehicle seat.

Figure 17. Example bilaterally symmetrical points on booster seat

7.2. Check booster settings:

7.2.1. Install the booster on the vehicle seat using the instructions in Section 8.

7.2.2. Place the ATD in the booster and adjust the booster components such as belt guide heights, headrest heights, and cushion dimensions as instructed by the **booster manual** for a child the size of the ATD. Remove the ATD and booster from the vehicle seat.

8. POSITION THE BOOSTER

8.1. Place the booster on the vehicle seat so that the centerplane of the booster is aligned with the centerplane of the vehicle seat and the bottom of the booster is flat on the vehicle seat. Move the booster seat rearward into the vehicle seat until some part of the booster touches the vehicle seat back as shown in Figure 18.

Figure 18. Placing the booster on the vehicle seat and applying force

8.2. Apply 133 N (30 lb) of force to the front of the booster seat cushion, in a direction parallel to the vehicle seat cushion, moving the booster rearward into the vehicle seat (Figure 18). If there is any additional information in the booster seat manual about how the booster should sit in the vehicle seat, such as points of contact, follow the manufacturer's instructions. See Appendix D for information on dealing with different booster – vehicle seat interactions.

8.3. Keep the booster and vehicle seat centerplanes aligned as much as possible. Check the seat centerline against the vehicle seat centerline Y value, and check the X and Z values of two bilaterally symmetrical points against each other (Figure 19 and Figure 20).

Figure 19. Aligning center planes of booster and vehicle seat

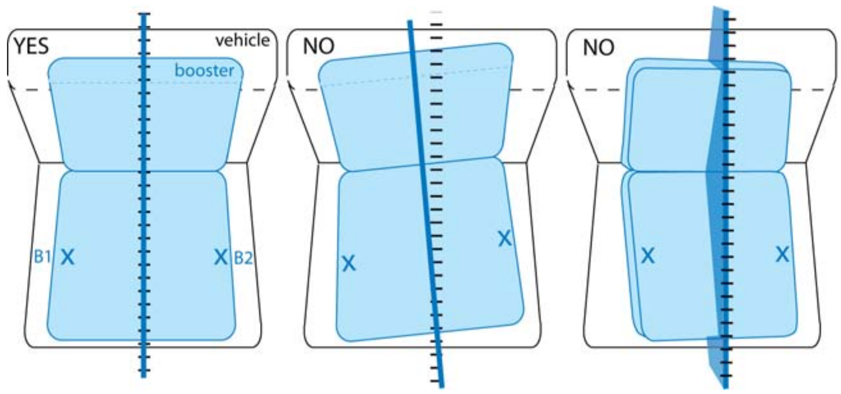


Figure 20. Proper alignment of the centerplanes of the booster and vehicle seat (left) and two examples of unaligned centerplanes (middle and right), in which the bilaterally symmetrical points (B1 and B3) are not aligned.

8.4. If the booster covers the location where the buckle comes through the seat

AND the buckle is mounted so that it cannot be tilted away from the booster to be routed around the booster, move the booster away from the buckle until the buckle can be used. (Figure 21)

AND the buckle is mounted on a flexible piece of webbing move the booster outboard until the buckle is out from under the booster, though the webbing may still be under the booster.

AND the buckle is mounted on a somewhat flexible piece of plastic so that it can be tilted away from the booster, move the booster away from the buckle until the buckle can be bent enough to be used.

8.5. If after installing the booster, the latchplate cannot be inserted into the buckle due to the interaction of the booster and the buckle, move the booster laterally away from the buckle until the latchplate can be inserted. Keep the centerplanes of the booster and vehicle seat parallel.

8.6. If 8.4 the booster is moved laterally, start Section 8 over with the booster centerplane parallel to the vehicle seat centerplane, but moved laterally the required amount.

Important: Keep the centerplanes of the booster and vehicle seat parallel to each other as much as possible while positioning the seat relative to the buckle.

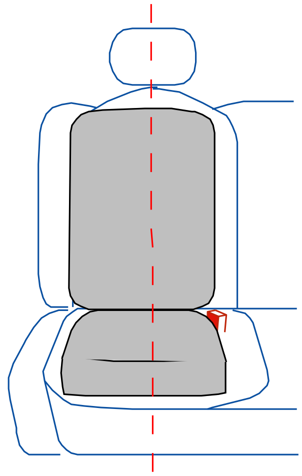


Figure 21. If the buckle is inaccessible due to the location of inboard anchor or the width of the booster, move the booster outboard the minimum distance needed to access the buckle.

9. POSITION THE ATD

9.1. *Six-year-old ATD*. As shown in Figure 22, place the ATD on the booster seat cushion such that the plane of the posterior pelvis is parallel to the plane of the booster seat back or metal plate, but not touching. Pick up and move the ATD rearward maintaining the parallel planes until the pelvis-positioning pad and booster seat back (or vehicle seat backrest, for a backless booster) are in minimal contact as illustrated in Figure 23. At the conclusion of this step, the pelvis-positioning pad should not be pressed firmly against the seat back, but rather should only touch the seat back. One should be able to remove a 125 x 95 mm piece of copy paper from between the pad and seatback. The friction produced between the pad and seatback should be the similar at the top and the bottom of the pad. Set the ATD down in the seat.

Figure 22. Moving the ATD rearward in the seat

9.2. *Ten-year-old ATD*. Place the ATD on the booster seat cushion such that the inferior surface of the pelvis is parallel to the seat cushion. Pick up and move the ATD rearward maintaining the parallel planes until pelvis-positioning pad and booster seat back (or vehicle seat backrest, for a backless booster) or metal plate are in minimal contact as illustrated in Figure 24. Due to the angle of the pelvis flesh on the ten-year-old ATD, the bottom of the pelvis-positioning pad might not be in contact with the seat back. However, the pelvis-positioning pad should not be pressed firmly against the seat back, but rather should only touch the seat back. One should be able to remove a 125 x 95 mm piece of copy paper from between the pad and seatback.

Figure 23. Six-year-old ATD pelvis-positioning pad parallel and in minimal contact

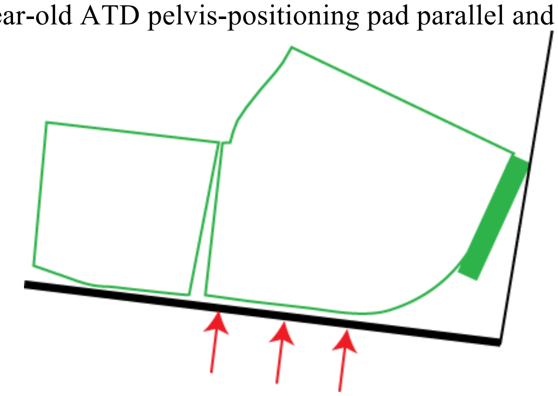


Figure 24. Ten-year-old ATD with bottom of pelvis parallel to the seat cushion

9.3. If during this process with the six-year-old ATD, some part of the seat back moves the pelvis from parallel to the seat back (e.g. the structure of the seat back forces the torso forward before the pelvis touches the seat back, thereby tilting the pelvis relative to the seat back), move the ATD rearward keeping the pelvis as parallel as possible to the seat back until some part of the pelvis pad is in light contact with the seat back. Digitize the location of midsagittal plane of the ATD at the neck-bib assembly point and at the middle of the pelvis, both should be within 5 mm of the centerplanes of the booster and vehicle seat.

9.3.1. Check that the booster seat is still aligned with vehicle seat. If it is not and the booster can be adjusted slightly, stabilize the ATD and make the adjustment. If the booster position cannot be corrected, remove the ATD and repeat the installation of the booster.

9.3.2. Check that the pelvis vertical and centered. The Y and Z values of two bilaterally symmetrical points on the pelvis should be within 5 mm of each other in each direction (Figure 25and Figure 26).

9.4. Check that the clavicle is down and rearward, and that the jacket is pulled downward.

Figure 25 Checking that the X and Z values of the symmetrical points

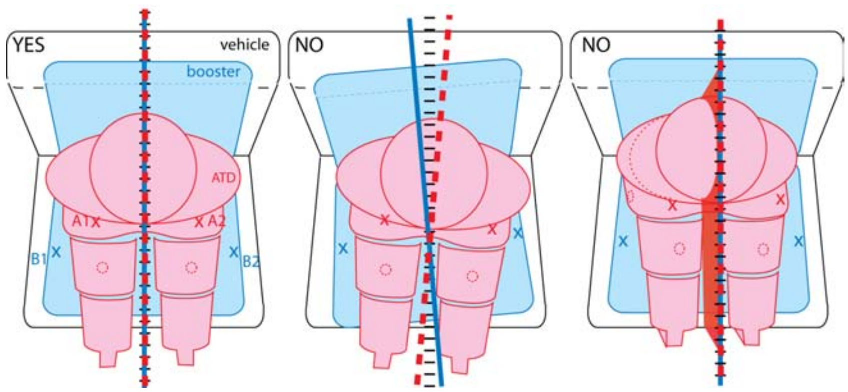


Figure 26. Proper alignment of the centerplanes of the ATD, booster and vehicle seat (left) and two examples of unaligned centerplanes (middle and right).

Figure 27. Pushing clavicles down and rearward at shoulder with arms out and then pulling jacket down

9.5. Straighten and align the arm segments so that the forearms and hands are in the neutral position. Without moving the clavicle, rotate the arms of the test dummy upward at the shoulder as far as possible without contacting the booster seat. Straighten and align the legs of the ATD and extend the lower legs as far as possible in the forward horizontal direction, with the ATD feet perpendicular to the centerline of the lower legs.

9.6. Using the flat square surface of the force gauge apply a force of 177 N (40 lbs), perpendicular to the back of the booster (or seat back if it is a backless booster) first against the ATD lower pelvis and then at the ATD thorax in the midsagittal plane of the ATD.

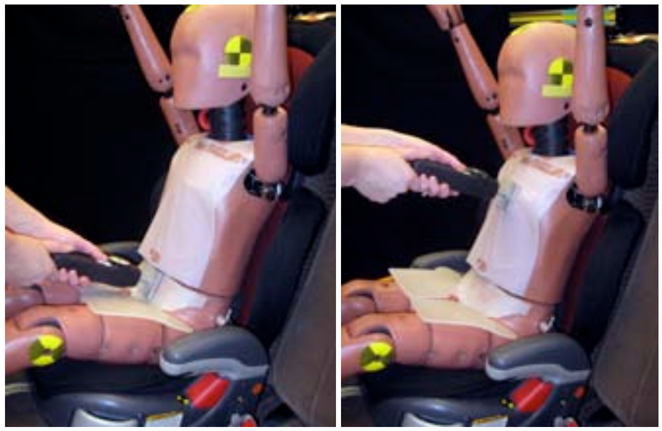


Figure 28. Applying 177 N of force to the pelvis and thorax of the ATD.

9.7. Measuring cushion length and adjusting ATD pelvis location [This step is performed only when a booster is not used.]

9.7.1. Rotate the ATD lower legs up to keep them from compressing the front edge of the seat cushion and lock in place with the knee bolt. Check that the thighs are in contact with the seat cushion and that the thigh bar is parallel to the centerline of the seat. Attach the slider to the thigh bar and move rearward to mid thigh. Insert slider arm into sleeve and and slider. Leave slider arm unlocked.

9.7.2. Slowly move slider forward (toward the knees) until the arm drops down at the front of the cushion as shown in Figure 29. Lock slider and slider arm.

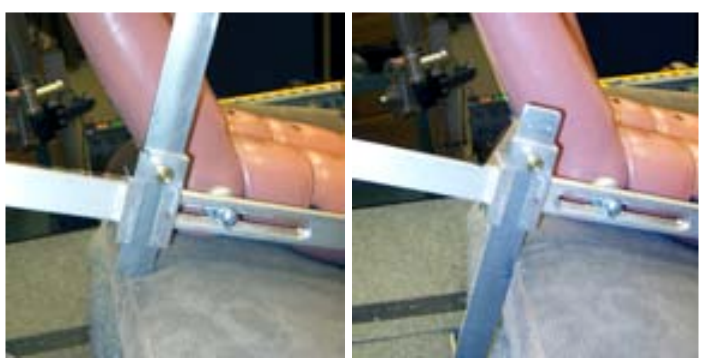
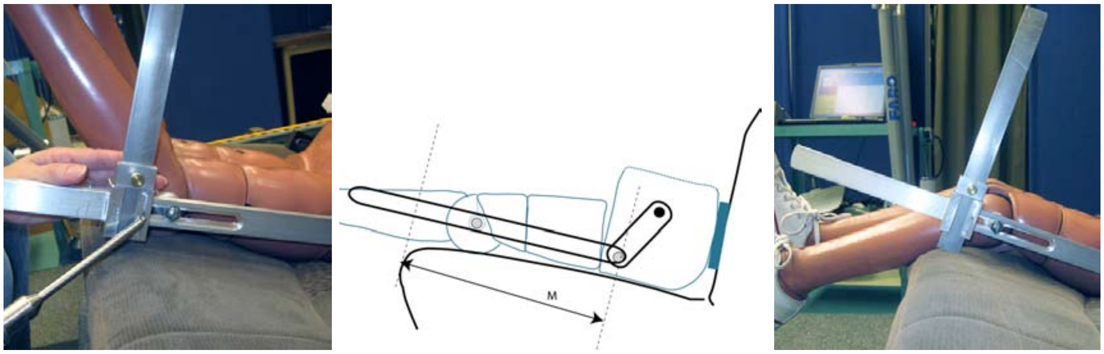


Figure 29. Moving the slider forward until the arm drops.

9.7.3. Measure the distance between the hip point bolt center and slider reference point. This is "M," the measured length of the cushion forward of the ATD hip. Calculate "Hp" using the formulas in Figure 30. If M > Hp, move the slider rearward until the distance between the hip bolt and the slider reference point is equal to Hp. Lock slider and loosen arm lock.



Six year-old ATD Hp =75 + 0.643 M
Ten year-old ATD Hp =107 + 0.643 M

Figure 30. Measuring M, calculating Hp, and moving horizontal slider until M=Hp.

9.7.4. Measure the pelvis XZ angle (eg. inclinometer on H-point tool). Pick up and move the pelvis forward maintaining the initial pelvis angle (Figure 31) until the vertical arm drops over the front edge of the seat, then set the pelvis down. While moving the pelvis keep the ATD aligned with the centerplane of the seat.


Figure 31. Moving the pelvis forward

9.7.5. Pull the vertical arm up again and let drop. If the arm does not clear the front of the seat, pick up the pelvis (keeping original pelvis angle) and move it forward. Check arm again. Repeat until the ATD is seated with the backs of the thighs contacting the seat surface and the vertical arm just clears the front of the seat. Once the pelvis is resting on the seat let the torso rest on the seat back; do not try to control the pelvis XZ angle. Lock vertical arm adjustment.

9.7.6. Digitize ASIS, PS and neck. Adjust to meet co-planar critera explained in previous sections.

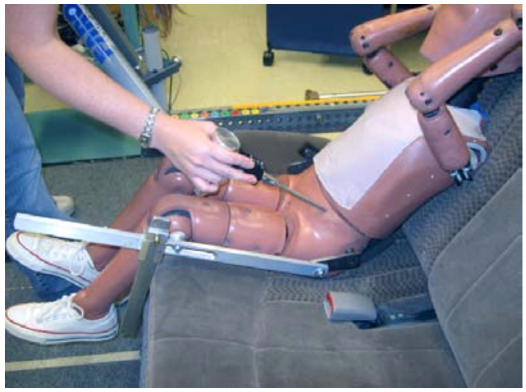


Figure 32. Checking ATD pelvis position

9.7.7. Remove the seat back plate, being careful not to move the ATD.

9.7.8. Unlock knees and loosen until the legs move freely. Let legs drop to seat.

If the head of the ATD is resting on the seat back, insert a foam wedge behind the back of the the back of the ATD and prop the ATD until the head is just off the seat back as shown in shown in

9.7.9. Figure 33.

9.7.10. Remove the positioning tool.

9.7.11. Rotate the arms of the ATD down so that they are perpendicular to the torso (i.e., upper extremities horizontal, elbows and wrists straight). Check that the clavicle is down and back, and that the jacket is pulled down as far as possible. Bend the knees until the back of the lower legs are in minimal contact with the booster or vehicle seat. Position the legs such that the outer edges of the knees are 180 mm apart for the six-year-old and 220 mm apart for the ten-year-old. Position the feet such that the soles are perpendicular to the centerline of the lower legs.

Figure 33. Propping ATD head off the seat back

Figure 34. Keeping clavicles down and back while rotating arm downward.

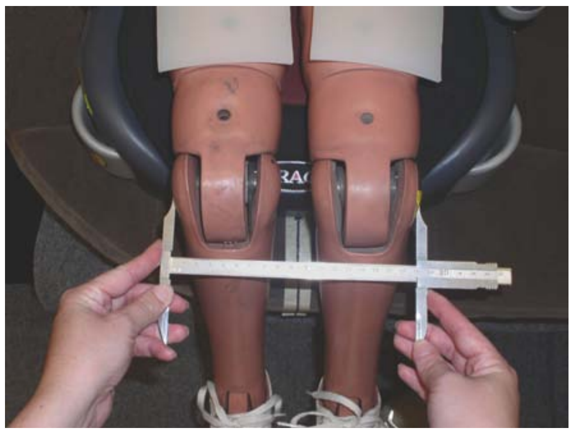


Figure 35. Setting the distance between the outer edges of the knees to 180 mm for the six-year-old and 220 mm for the ten-year-old.

9.8. In the case of high back boosters, adjust the ATD so that the shoulders are parallel to a line connecting the shoulder guides. This can be accomplished by leaning the torso such that the ATD head and neck are centered on the backrest components of the booster.

9.9. In the case of backless boosters or on vehicle seats, adjust the ATD torso so that the head is laterally level, or as close to level as possible.

9.10. Locate the intersection of the neck and the torso bib assembly in the midsagittal plane and project it out onto the ATD jacket. Place a piece of tape on the jacket extending from this point towards the shoulder that is on the D-ring side of the vehicle seat. The top edge of the tape should be at the same height as the point with the length of the tape parallel to the floor. The process of applying the tape is illustrated in Figure 36. Use a level or a measurement arm. **Do not estimate the position of this line by eye.** As shown in Figure 37, the curvature of the jackets may make a level line appear angled.

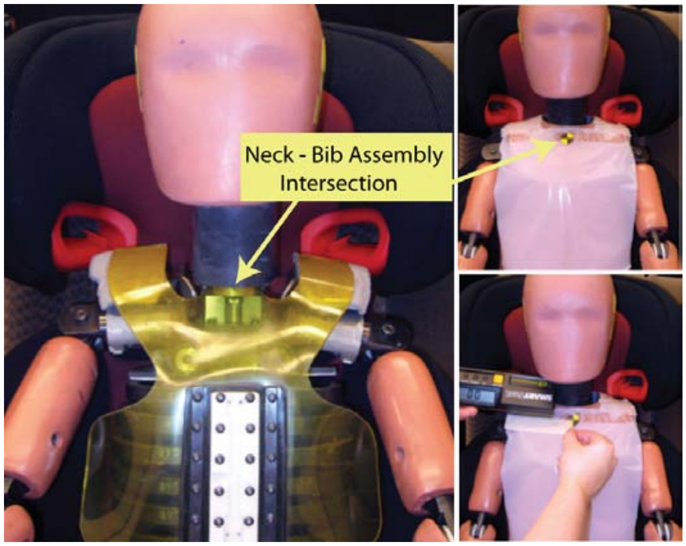


Figure 36. Applying tape used to measure the fit of the shoulder belt

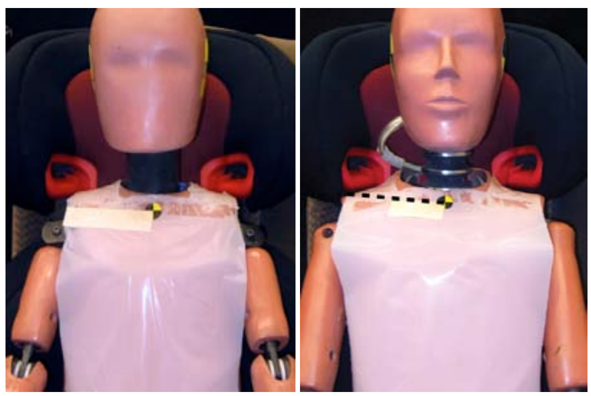


Figure 37. Tape on six-year-old and ten-year-old ATDs. The dashed line drawn past the tape on the ten-year-old ATD is not on the jacket surface.

10. APPLY THE BELT

IMPORTANT: The purpose of this section is to allow the geometry of the booster and vehicle seat to position the lap and shoulder belt on the ATD. Do not try to guide the belt to be in contact with any particular point on the ATD.

10.1. Initial Deployment. Pull the belt out of the retractor in a motion across the front of the ATD and booster so that the latch plate ends up above the foot of the ATD located on the buckle side of the booster as shown in Figure 38.

10.2. Shoulder Belt *Part 1*. If the booster has a back with belt positioning guides, first route the shoulder belt through the guide as instructed in the booster manual. If there is a belt positioning attachment to a backless booster, route the shoulder belt through the attachment. If there is no guide or attachment go to the next step.

10.3. Lap Belt *Part 1*. If using a booster, position the lap belt as indicated by the booster manual on the side away from the buckle. Leave enough slack in the belt between the inboard and outboard lower belt guides to hold the lap belt eight inches out from the midsagittal line of the ATD pelvis. Position the lap belt as indicated by the booster manual on the *buckle side* of the booster and buckle the belt.

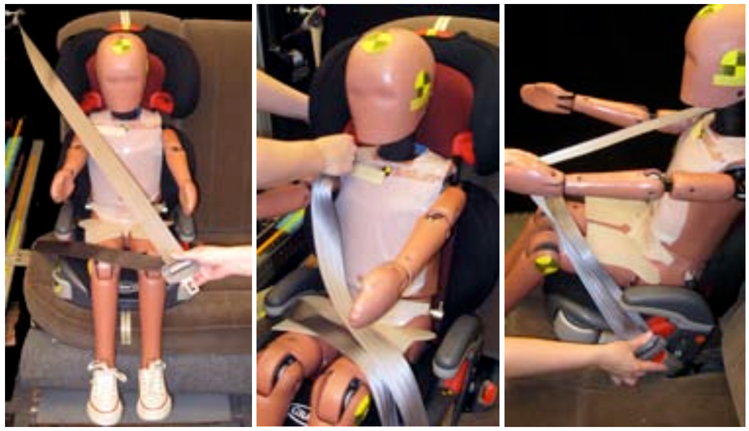


Figure 38. Initial deployment of the belt, routing the shoulder belt through the guide and buckling the belt

10.4. Shoulder Belt *Part 2.* If there is a lower guide for the shoulder belt on the buckle side of the booster, make sure that it is routed properly. If there is an attached guide on a backless booster, make use it is set to the proper height, as specified by the booster manufacturer.

10.5. Lap Belt *Part 2*. With one hand, pull the slack portion of the lap belt that was created between the lower belt guides forward along the midsagittal plane of the pelvis so that the belt is approximately 20 mm above the top surface of the thighs. This can be accomplished by grasping the belt with the palm up, as shown in such that the back of the hand is resting lightly on the tops of the ATD thighs. With the other hand, grasp the torso portion of the belt 150 mm above the latch plate and slowly pull upward in the direction of the shoulder belt path. Allow the hand holding the lap belt to be pulled toward the pelvis, taking the slack out of the lap belt while keeping the lap belt just clear of the thighs (Figure 39). When the leading edge of the lap portion of the belt reaches the thigh area covered by the lap form, release the lap belt and continue pulling slowly but firmly on the shoulder belt until the lap belt has no slack. Do not guide the belt (Figure 40), but do not let it become twisted.

Figure 39. Holding the lap belt off the thighs while removing slack.

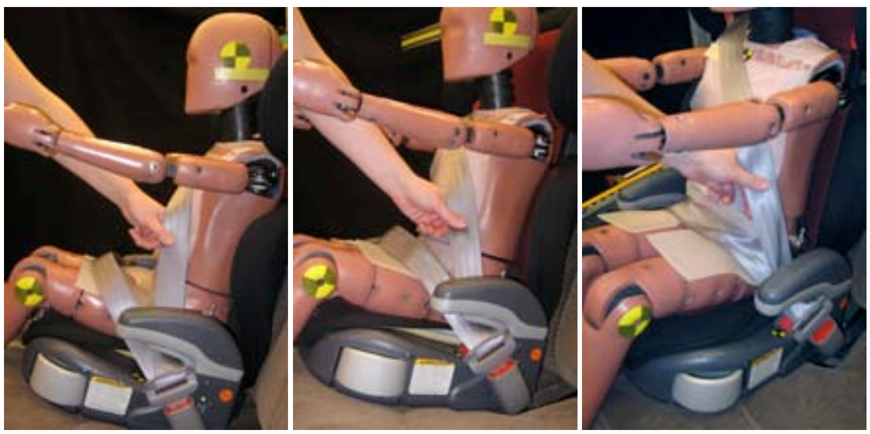


Figure 40. Point at which the lap belt is released (left) while pulling on the shoulder belt in the direction of the belt path until slack is removed from lap belt.

10.6. Routing Check. Rotate the ATD arm located nearest the D-ring down to the seat surface until the 5th metacarpal side contacts the booster surface and the palm contacts the outside of the thigh. Check the shoulder belt guide and determine if it is in the setting specified by the booster instruction manual or in the desired location for the test. If not and adjustments can be made without moving the pelvis or torso of the ATD, rotate the arm back up, make the adjustments and start Section 10 over. If not and adjustments cannot be made without moving the pelvis or torso of the ATD, start the installation procedure over. Otherwise, continue to the next step.

10.7. Lap Belt *Part 3* - Tightening. Grasp the torso portion of the belt 150 mm above the latch plate and slowly pull upward in the direction of the shoulder belt path. Stop pulling on the belt when visually apparent movement of the lap portion of the belt stops. If the ATD is observed to move during this step, return to Section 9 (reposition the ATD). Feed the excess belt into the D-ring retractor. Do not let the belt become twisted.

10.8. Shoulder Belt *Part 3*- Position the section of the shoulder belt between the buckle/lower guide and the upper guide or the D-ring (if no upper guide) so that the belt routes through the shortest path between the two locations. Feed any excess belt into the retractor as shown in Figure 41. The goal is to find the position of the belt across the ATD chest that involves the minimal amount of webbing length. The belt tension applied during this process should not cause visible movement of the ATD.

Figure 41. Feeding the shoulder belt into the retractor

10.9. If during the process changes must be made to the configuration of the booster seat and this disturbs the installation, start over, returning to Section 8.

10.10. ATD Final Positioning

10.10.1. Legs. Check leg and feet position and make adjustments to achieve the described positions in section 9.6.

10.10.2. Arm on the side nearest the buckle. Keep the arm straightened at the elbows and rotate arms at shoulder down towards seat surface until the 5th metacarpal (pinky) side contacts the booster surface and the palms are in contact with the outsides of the thighs. If the shoulder belt interferes with this motion, stop the rotation 1 cm short of contacting the belt.

10.10.3. Thorax and head. Same as 9.8 - 9.9.

10.10.4. Recheck shoulder belt path 10.8

Figure 42. Examples of final positioning

11. RECORD BOOSTER, ATD AND BELT LOCATIONS

1. Record belt tensions
2. Digitize:
   - Booster reference points on each movable part such as
     - Seat pan
     - Seat back and headrest
     - Adjustable belt guides
   - ATD landmarks
   - Belt contact with
     - Vehicle seat, booster and booster belt guides
     - ATD at shoulder, centerline, and lap
     - Lower belt anchorages and Dring
3. Photograph installation from front and inboard side.

Table 1
Points Digitized to Measure Shoulder Belt Fit

Digitized Point	Description
 	*Torso Belt – ATD Shoulder* Inboard and outboard points on the torso belt where it crosses the ATD shoulder height (vertical height determined by the location of the Bib Assembly Centerline, marked on the chest jacket with tape). The belt might not be in contact with the ATD at this point – always digitize the point on the belt. It is a good idea to digitize and check the bib-neck assembly point lateral position and height just before digitizing the belt point.
 	*ATD Centerline* Upper and lower points of the torso belt where it crosses the ATD centerline.

Table 2
Points Digitized to Measure Lap Belt Fit

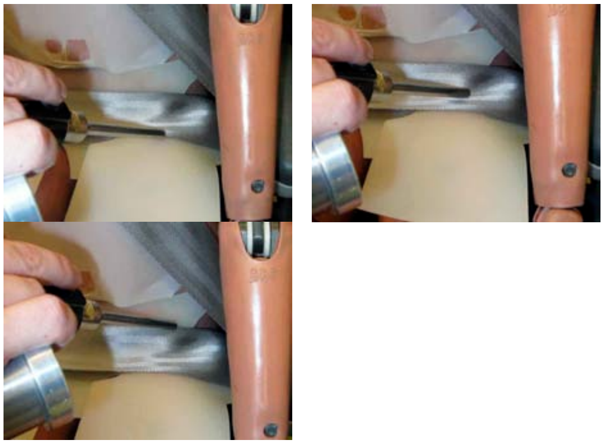
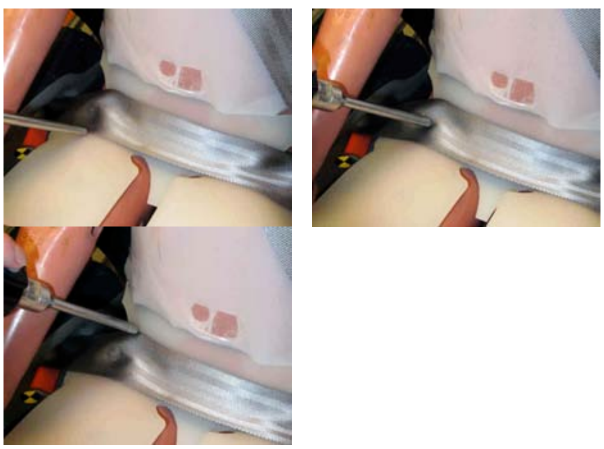
Digitized Point	Description
	ASIS (inboard) Fore, mid, and aft points of the lap belt where it crosses the ATD ASIS on the inboard side. Digitized the lateral position of the ASIS first and the belt point to the Y-values. If the belt covers the ASIS marks, use the reference lines on the superior edge of the pelvis flesh.
	ASIS (outboard) Fore, mid, and aft points of the lap belt where it crosses the ATD ASIS on the outboard side. Digitized the lateral position of the ASIS first and the belt point to the Y-values. If the belt covers the ASIS marks, use the reference lines on the superior edge of the pelvis flesh.

Table 3
Points Digitized to Measure the Position of ATD Head and Thorax

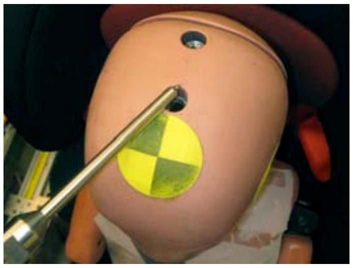
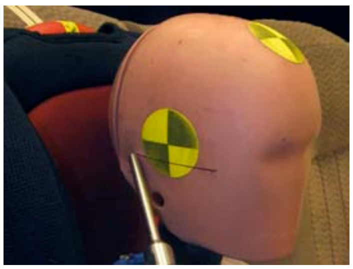
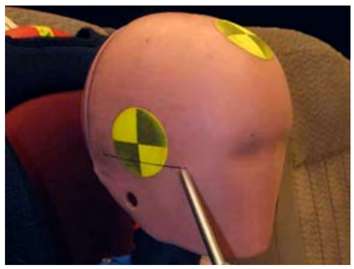
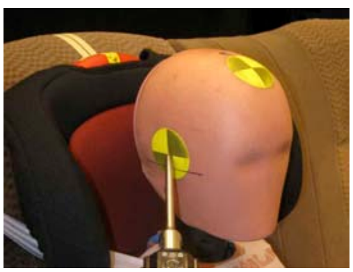
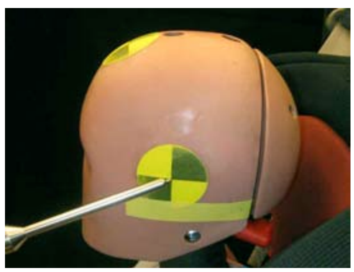
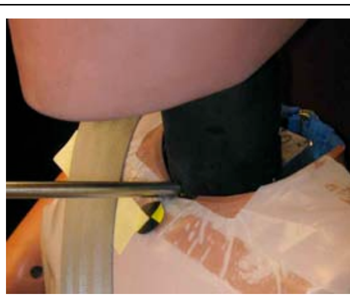
Digitized Point	Description
	Top of Head Reference point located at the top of the ATD head.
 	Frankfort Plane Two points on a line projected from the plane of the accelerometer mounting surface inside the ATD head.
 	Center of Mass Two points on forming a line whose midpoint represents the center of mass of the ATD head.
 	Neck Bracket Inboard point on the rear corner of the ATD neck bracket.
 	Centerline Bib Assembly - A point on the centerline of the ATD at the top edge of the bib assembly where it meets the molded neck. Lower Torso-Reference point on the chest deflection assembly beneath the chest jacket.

Table 4
Points Digitized to Measure the Position of the ATD Pelvis

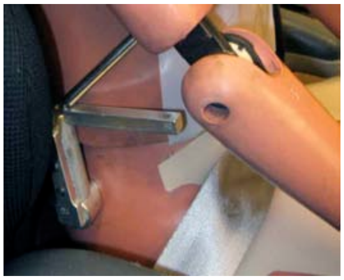
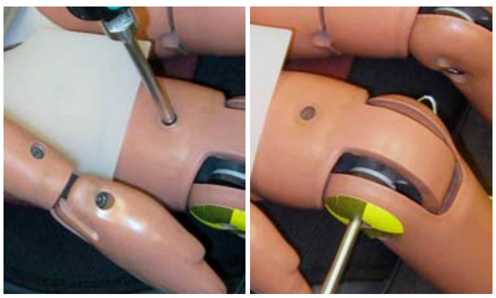
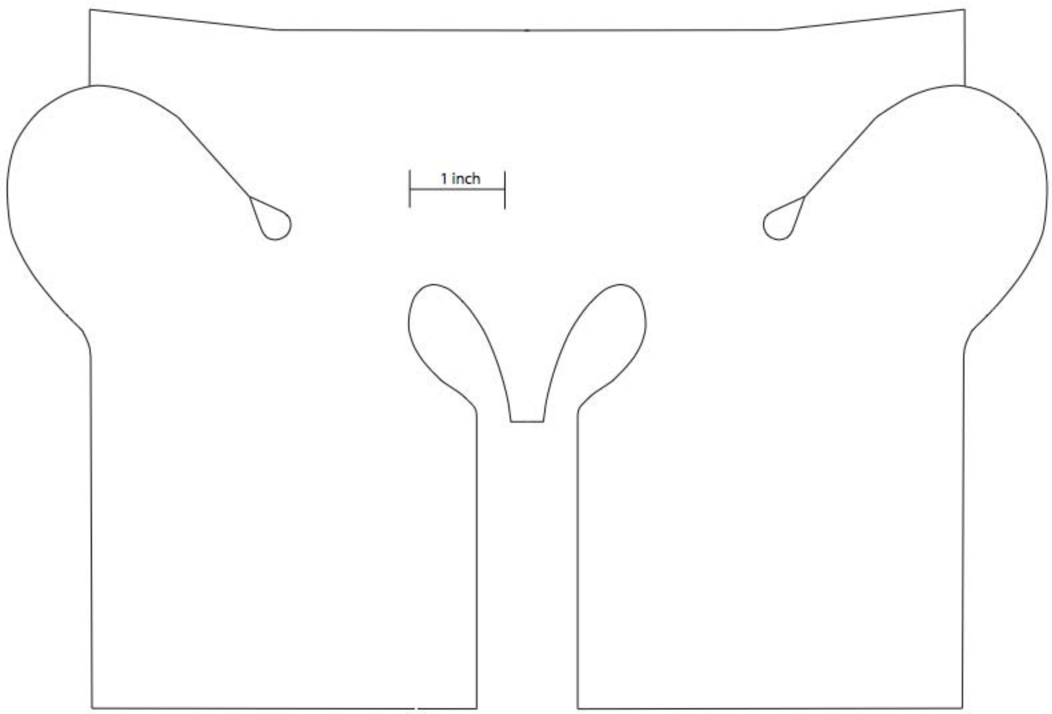
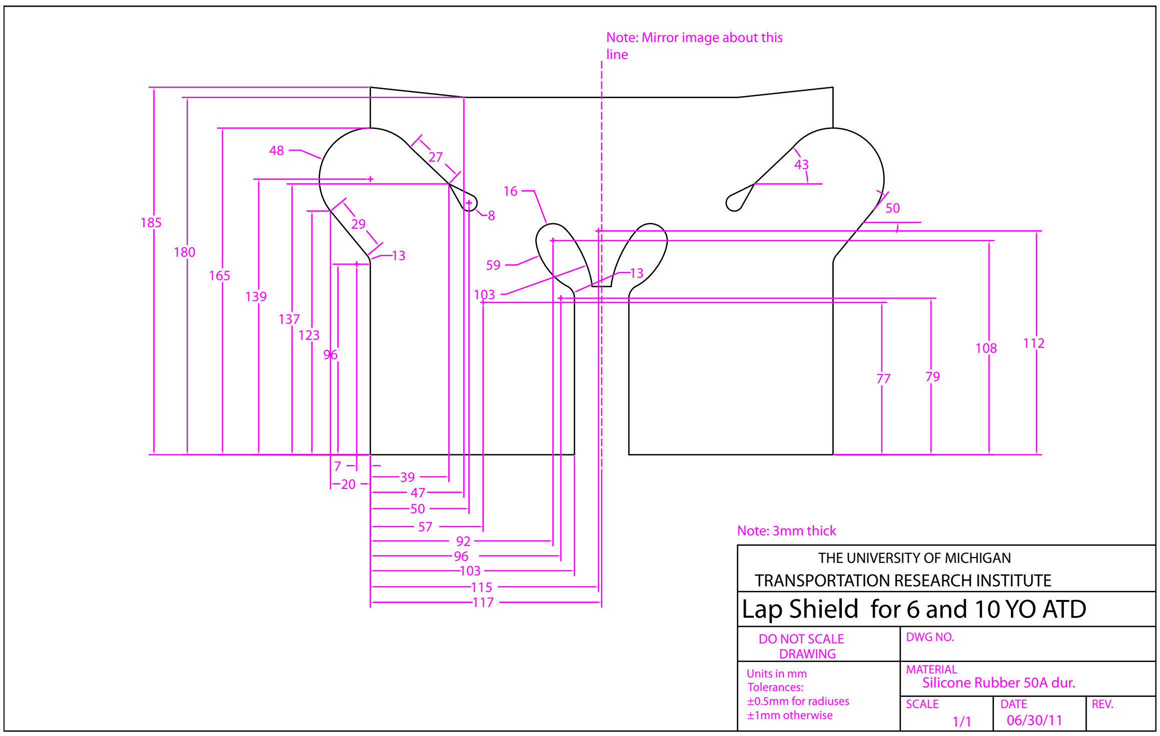
Digitized Point	Description
 	Outboard Hip Offset Fore and aft reference points on the hip offset tool. (The tool consists of two pieces; the upright piece can be removed if it interferes with the belt path.)
 	Inboard Hip Offset Upper and lower reference points on hip offset tool. (The tool consists of two pieces; the upright piece can be removed if it interferes with the belt path.)
    	Pelvis References ASIS -Reference point representing the location of the ASIS on the flesh and on the lap form. PS- Reference point representing the location of the PS on the flesh.

Table 5
Points Digitized to Measure the Position of the ATD Limbs

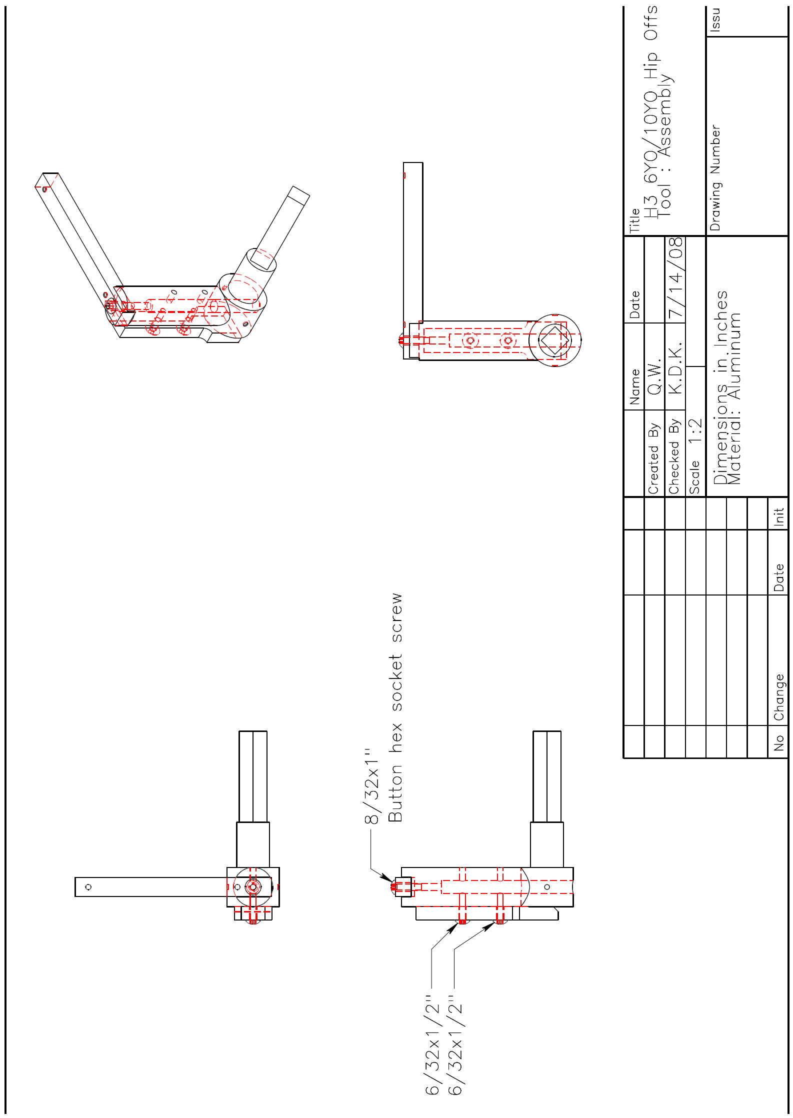
Digitized Point	Description
	*Shoulder Joint* - located on the shoulder pivot bolt. *Elbow Joint* - located on the elbow pivot bolt. *Wrist Joint* - located on the wrist pivot bolt.
	*Suprapatella* - located on the bolt positioned above the knee. *Knee Joint* - located on the knee pivot bolt.
	*Ankle Joint* - located on the ankle ball joint set screw. *Ball of Foot* - located on the shoe where the ball of the foot is.

Appendix A. Lap Form

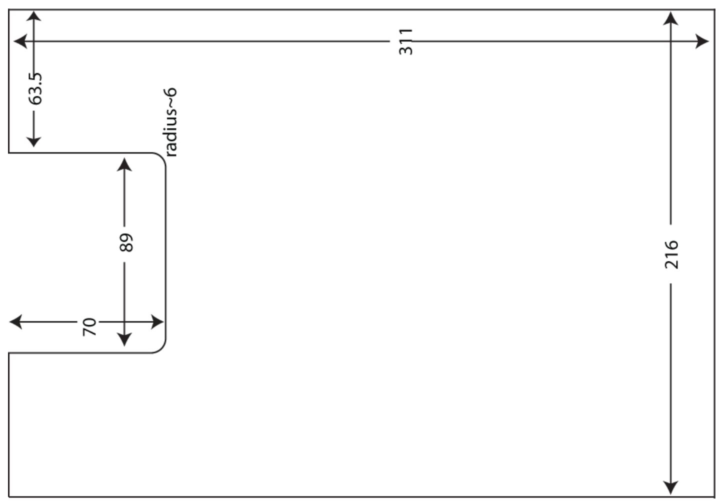


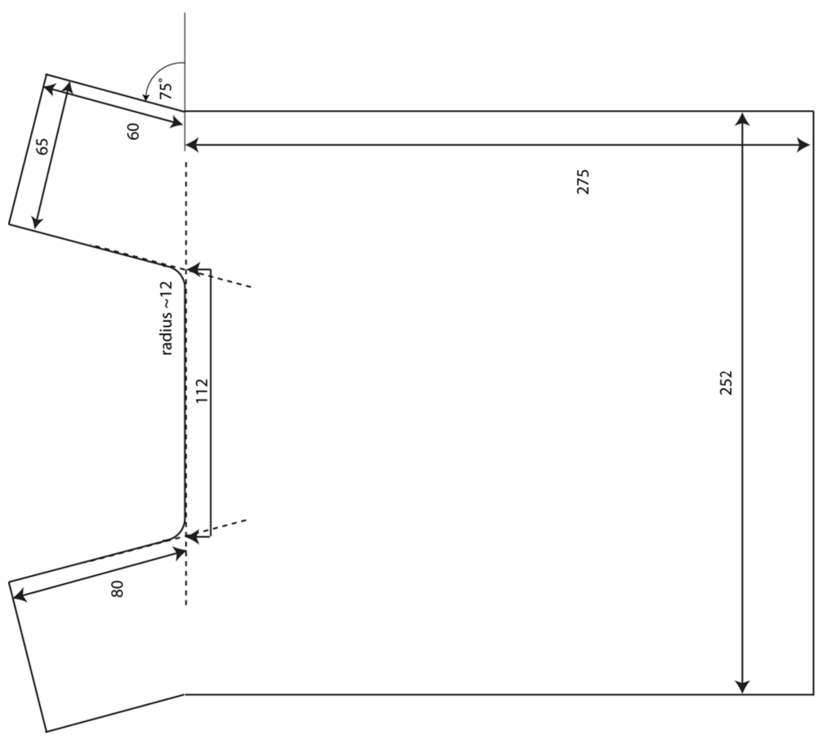

Note: Mirror image about this line
Note: 3mm thick
THE UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE
Lap Shield for 6 and 10 YO ATD
DO NOT SCALE DRAWING
DWG NO.
Units in mm
Tolerances:
±0.5mm for radiuses
±1mm otherwise
MATERIAL
Silicone Rubber 50A dur.
SCALE
1/1
DATE
06/30/11
REV.

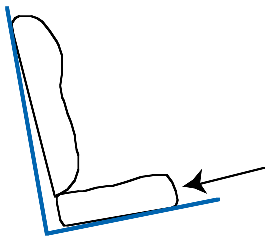
Appendix B. Hip Offset

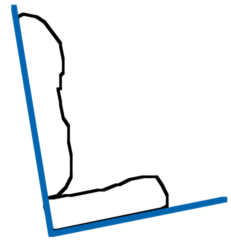


Appendix C. Teflon Bibs for 6YO (above) and 10 YO(below) ATDs

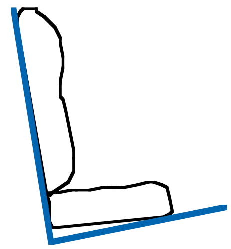






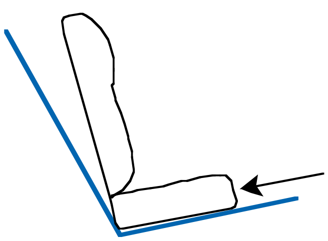


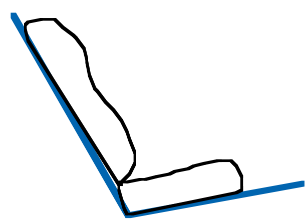
When the booster seat has a seat back that reclines, the booster may have good contact with the vehicle seat back and cushion.



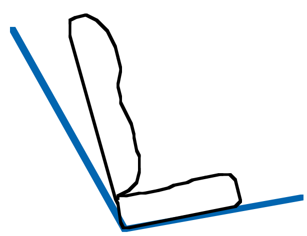
When the booster seat a fixed back position, the contact between the booster and the vehicle seat is whatever results from the pressure applied.

Figure D1. Apply 30 lb force to the front of the booster seat cushion. When the vehicle seat back is very upright and/or the vehicle cushion very angled, boosters with a fixed back angle may not conform to the vehicle seat as much as boosters with seat backs that recline.





When the booster seat has a seat back that reclines, the booster may have good contact with the vehicle seat back and cushion.



When the booster seat has a fixed back position, the contact between the booster and the vehicle seat is whatever results from the pressure applied **without** tipping the booster rearward.

Figure D2. Apply 30 lb force to the front of the booster seat cushion. When the vehicle seat back is very reclined and/or the vehicle cushion very flat, boosters with a fixed back angle may not conform to the vehicle seat as much as boosters with seat backs that recline.