



## **Booster Seat Belt Fit Evaluation Protocol Version IV**

**May 2018**

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## **DOCUMENT REVISION HISTORY**

### **Version IV**

May 2018: Revision to Version IV of the protocol compared with Version III.

Rewrote protocol to be consistent with Jasper.

### **Version III**

September 2014: Revision to Version III of the protocol compared with Version II.

Added the shoulder belt fore-aft distance into the measurement protocol.

### **Version II**

Revision to Version II of the protocol compared with Version I.

- Added information about the document revision history.
- Added more detail on creating the lap shield contour data in the Measurements section and in the Appendix.

## OVERVIEW

The objective of the Insurance Institute for Highway Safety's booster seat belt fit evaluation program is to quantify the ability of booster seats to provide proper seat belt positions on children, across a range of potential lap and shoulder belt anchorage locations.

The purpose of this protocol is to describe the method used to obtain lap and shoulder belt scores that represent the quality of seat belt locations on children. The protocol is based largely on research conducted by the University of Michigan Transportation Research Institute (Reed, Ebert, Sherwood, Klinich, & Manary, 2009), with some modifications made to standardize the procedure.

## BOOSTER TEST FIXTURE

The booster test fixture is the platform used to evaluate booster seats. The test fixture (Figure 1) consists of a representative test seat and a three-point lap/shoulder belt system with adjustable belt anchorage locations.

### Test Seat

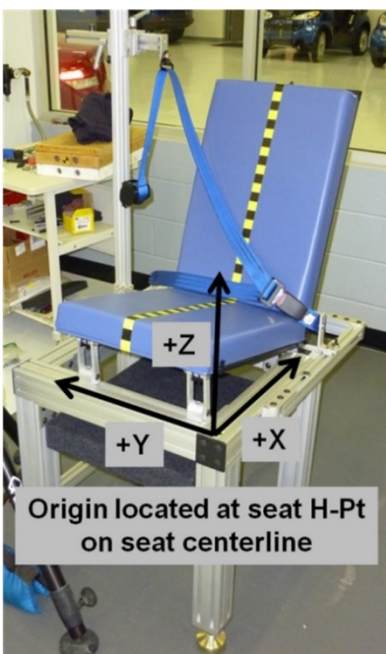
The test seat consists of a seat bottom and a seat back.

The seat bottom is  $51 \pm 1$  cm long (measured from the seat bight, defined as the intersection of the seat bottom and seat back) and is reclined  $15 \pm 1$  degrees from horizontal (Figure 2).

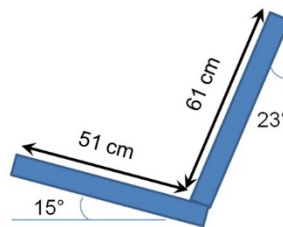
The seat back is  $61 \pm 1$  cm long (measured from the seat bight) and is reclined  $23 \pm 1$  degrees from vertical.

The total seat bottom length is greater, where it extends below the bottom surface of the seat back. Both the seat cushion and seat back are  $42 \pm 1$  cm wide.

**Figure 1. Test Fixture**



**Figure 2. Test Seat**



The seat bottom and seat back are both constructed from a 2-inch thick polyurethane foam (Wietholter, Echemendia, & Loudon, 2017) Sources for this foam, as well as other materials and supplies used in this protocol, are listed in Appendix A.

Both cushions are supported by a wood (plywood or medium-density fiberboard (MDF)) section with a minimum thickness of 1.3 cm. Each cushion then is covered in a marine vinyl (see Appendix A).

### Coordinate system and origin of the test fixture

The coordinate system for the test fixture is shown in Figure 1. The positive X axis points toward the rear of the seat, the positive Y axis points toward the right side of the seat, and the positive Z axis points upward vertically. The origin for this reference frame is located at the resulting H-point location for the seat (Society of Automotive Engineers, 2008), at the seat centerline.

After the H-point location was determined for the test seat during the design process, a simplified test device was created to locate this same origin. For the purposes of this official protocol, this simplified test device (Booster Seat H-Point Origin Device, or BPOD) is used to locate the origin. For images of this BPOD, see Appendix C.

To determine the origin of the test fixture:

- a. Place the BPOD on the seat cushion forward of the seat bight.
- b. Slowly slide it rearward until contact is made with the seat back.
- c. Use a force gauge to push the BPOD into the seat, parallel to the seat cushion at a location approximately 6 cm above the base, at a force of 40 pounds (lbs).

The position of the BPOD reference point defines the location of the origin.

### Seat Belt System

The frame used to support the test seat also supports the anchorage locations for the seat belt system. Any rigid frame can be used to support the test seat and seat belt system. These anchorages must be adjustable, because they are moved to different positions during testing. Coordinates for the anchorage locations are listed in Table 1.

**Table 1.** Seat Belt System Anchor Coordinates

Anchorage	Location	X	Y	Z
Inboard	Maximum angle (83°)	15	-250	-125
	Minimum angle (41°)	144	-250	-125
Outboard	Maximum angle (68°)	57	330	-141
	Minimum angle (35°)	201	330	-141
D-ring	Fore/outboard/low	258	312	524
	Aft/inboard/high	560	214	668

The seat belt system includes an inboard female buckle, webbing extender, retractor, D-ring anchor with bolt, and outboard end fitting. For information on the materials for the seat belt system, see Appendix A.

When you set up a test fixture for the first time, a modification to the inboard female buckle is required. For more information, see Appendix B.

The test fixture is based on the geometry of a right, rear passenger seat.

The right side of the seat, with D-ring and retractor, is the outboard side, whereas the left side of the seat is the inboard side.

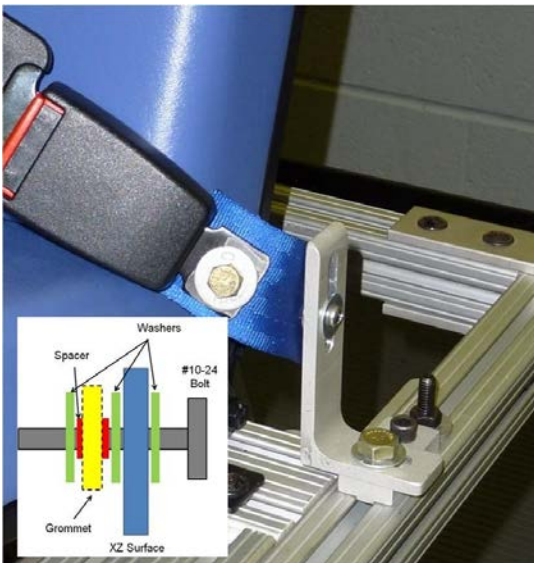
The coordinates for each position (lap belt maximum vs. minimum angles, D-ring fore/outboard/low vs. aft/inboard/high) are based on the range of positions found in recent model test vehicles, which approximates the full range allowed by federal standards. The angle of the lap belt is defined as the angle (with respect to horizontal) of a line from the seat H-point to the anchorage location.

The female buckle is attached to the webbing extender with a 3/8-inch bolt, tightened sufficiently to prevent rotation between these two pieces, with the long axis of the buckle in line with the two grommets. The other end of the webbing extender is attached to the test fixture at a vertically oriented surface in the X-Z plane (see Figure 3). A #10-24 bolt passes through the grommet and serves as the axis around which the webbing extender can rotate. A spacer is required inside the grommet to (a) prevent the nut from being tightened to the point of preventing the webbing from rotating and (b) reduce the amount of play between the grommet and the bolt. The spacer should have a length of  $0.22 \pm 0.02$  inch, an inner diameter (ID) of  $0.228 \pm 0.01$  inch, and an outer diameter (OD) of  $0.36 \pm 0.02$  inch. Washers are located on either side of the spacer.

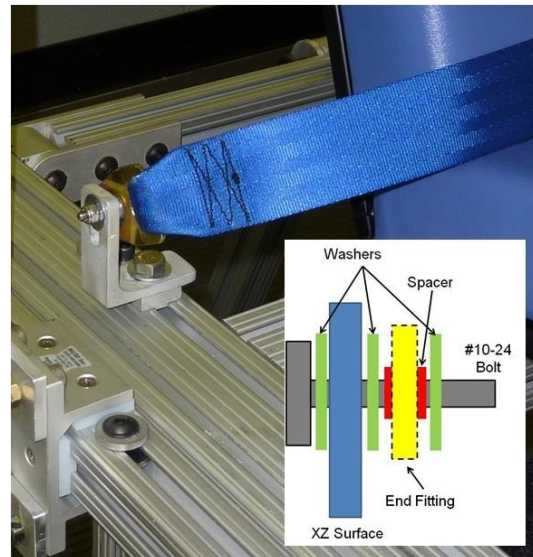
The outboard lap belt anchorage has a metal end fitting that is attached to the test fixture at a vertically oriented surface in the X-Z plane (Figure 4) with a #10-24 bolt. As on the inboard side, a spacer is required between the end fitting and the bolt.

The spacer should have a length of  $0.22 \pm 0.02$  inch, an ID of  $0.228 \pm 0.01$  inch, and an OD of  $0.5 \pm 0.02$  inch. Washers are located on either side of the spacer.

**Figure 3. Inboard Belt Anchor**  
(diagram not to scale)



**Figure 4. Outboard Belt Anchor**  
(diagram not to scale)



The D-ring assembly is mounted so that the attached mounting bolt (included in assembly) is attached to a vertically oriented surface in the X-Z plane, with the measured coordinates referring to the center of the head of the mounting bolt (Figure 5). The bolt, which is included in the seat belt assembly, requires a 7/16 inch × 20 nut to be attached to the mounting plate.

**Figure 5: D-Ring Anchor**



The actual inboard and outboard lap belt anchor locations cannot be directly measured. The X and Z coordinates are identical to the X and Z coordinates of the centerline of the bolt about which the hardware rotates. The Y coordinates of the inboard anchor (webbing extender grommet) and outboard anchor (end fitting) must be measured separately. The Y coordinate should be measured at the edge of the spacer closest to the seat centerline (also the face of the washer that contacts the spacer on this edge). The coordinates for the D-ring anchorage refer to the center of the mounting bolt.

After purchase of the system, a punch (or other method) should be used to create a permanent location at the center face of the bolt for measurement (Figure 5).

Each booster is tested in four combinations of lap and shoulder belt anchor locations. The test matrix is shown in Table 2.

**Table 2. Test Matrix: Combinations of Lap and Shoulder Belt Anchor Locations**

Condition	Description (Lap/Shoulder)	Lap–Inboard		Lap–Outboard		Shoulder
		Minimum angle	41°	Minimum angle	35°	Fore/outboard/low
1	Minimum/Fore	Minimum angle	41°	Minimum angle	35°	Fore/outboard/low
2	Maximum/Fore	Maximum angle	83°	Maximum angle	68°	Fore/outboard/low
3	Minimum/Aft	Minimum angle	41°	Minimum angle	35°	Aft/inboard/high
4	Maximum/Aft	Maximum angle	83°	Maximum angle	68°	Aft/inboard/high

## BELT FIT DEVICE

The device used in this protocol is a Juvenile Anthropomorphic Seat belt Position Evaluation Rig (Jasper). Jasper represents a booster-age child. No instrumentation is required.

### Prepare Jasper

To prepare Jasper for testing, complete the following steps.

- 1.1. On each side of Jasper's head, locate the center of gravity locations, and mark each with a test sticker.
- 1.2. Attach a pelvis-positioning pad to the rear surface of the pelvis (Figure 6). Using double sided tape, position the pad in a centered location on the posterior of Jasper's pelvis, with the top edge of the foam aligned with the superior edge of the pelvis (Figure 6).

Attaching the pelvis-positioning pad helps to better mimic how real children sit in vehicle seats (Reed, Ebert-Hamilton, Manary, Klinich, & Schneider, 2006).

- 1.3. To help the belt -positioning clip to remain stationary during testing, attach the 3 mm-thick shoulder pads using double-sided tape (Figure 7)

See Appendix A for details about the pelvis-positioning pad.

**Figure 6.** Pelvis-Positioning Pad



**Figure 7.** Shoulder Pads





## MEASUREMENT PROTOCOL

To prepare the booster and Jasper for testing, complete the following steps (in the order listed):

- Before positioning the booster
- Position the booster
- Position Jasper
- Apply the seat belt
- Position Jasper – Final check

### Before Positioning the Booster

- 2.1 Place booster reference target stickers on the booster, in easily accessible positions. Reference point 1 should be on the front of the booster, point 2 should be closer to the rear, and point 3 should be on the adjustable headrest.

If the seat is a backless booster, only 2 reference points are required.

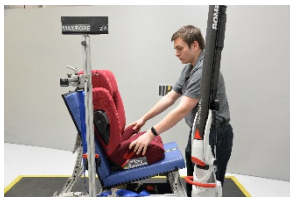
- 2.2. Position the D-ring and inboard and outboard anchors in the correct positions.

### Position the Booster

Read and follow the booster manual instructions for proper use. Make any booster adjustments (if applicable).

If after the final measurements are taken, it is determined that additional modifications to the booster (as allowed and instructed by the booster manual) would improve belt fit, make these adjustments and begin this *Position the Booster* section again. Verify and note all booster adjustment positions.

- 3.1. Place the adjusted booster on the test seat, such that the center plane of the booster is aligned with the center plane of the test seat and the base of the booster is flat on the test seat cushion.
- 3.2. Move the booster rearward on the test seat until some part of the booster touches the seat back, keeping the booster centered and vertical.



Steps 3.1–3.2

- 3.3. If the booster has a back with belt-positioning guides, route the shoulder belt through the appropriate guide at this time so that the final position of Jasper will not be disturbed.



Step 3.3

- 3.4. Apply 133 N (30 lbs) of force to the front of the booster seat cushion in a direction parallel to the test seat cushion, moving the booster rearward into the vehicle seat.

**Important:** All forces in this protocol should be applied with a force gauge having a flat, square contact surface with a surface area of 2,580 square mm (4 square inches).



Step 3.4

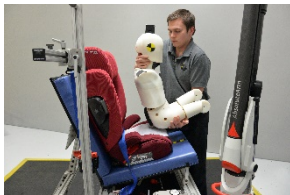
- 3.5. To reduce the effects of friction during positioning of Jasper, place a Teflon sheet on the booster seat cushion (between Jasper and the booster seat). The sheet (see Appendix A) should be placed in the center of the seat, with approximately 5 cm of the sheet extending past the booster seat bight (intersection of the seat bottom and seat back).



Step 3.5

## Position Jasper

- 4.1. Hold Jasper above the booster seat cushion, such that the plane of the posterior pelvis is parallel to the plane of the booster seat back (or test seat back for backless boosters), but not touching.
  - 4.1.1 When positioning Jasper in a backless booster, assistance might be needed when positioning the webbing-mounted shoulder belt clips, to prevent artificial interactions with the pelvis-positioning pad.



Step 4.1

- 4.2. Move Jasper rearward, maintaining the parallel planes, until the pelvis-positioning pad and booster seat back (or test seat back for backless boosters) are in minimal contact.

At the end of this step, the pelvis-positioning pad should not be pressed firmly against the seat back, but rather should only touch the seat back.

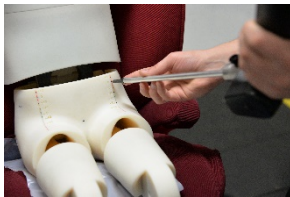
- 4.3. Set Jasper down in the seat. If during the process, some part of the booster seat back moves the pelvis away from being parallel to the booster seat back (e.g., the structure of the seat back forces the torso forward before the pelvis touches the seat back, thereby tilting the pelvis relative to the seat back), move Jasper 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.



Steps 4.2–4.3

- 4.4. Center Jasper's pelvis and align Jasper with the centerline of the booster and test seat.

A coordinate measuring machine (CMM) can be used to digitize the reference points on the booster and Jasper to verify correct positioning. Identical left/right locations on the anterior superior iliac spine (ASIS) points are particularly useful when performing this step.



Step 4.4

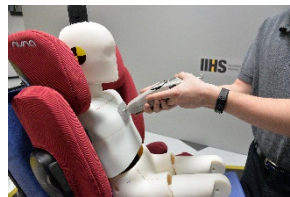


Step 4.4

- 4.5. For highback boosters, verify the seat back is vertical and centered. If it is not, and the seat back can be adjusted slightly left or right, stabilize Jasper and make the adjustment. If the seat back is not able to be corrected, remove Jasper and repeat the positioning of the booster (step 3.1).
- 4.6. Apply a force of 177 N (40 lbs) perpendicular to the back of the booster (or seat back for backless boosters), first against Jasper's lower pelvis and then at the thorax on the centerline of Jasper.

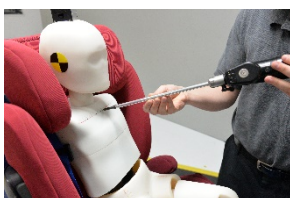


Step 4.6



Step 4.6

- 4.7. Verify that Jasper's torso is vertical (Y coordinate of the center of the chest is  $\pm 2$  mm).



Step 4.7

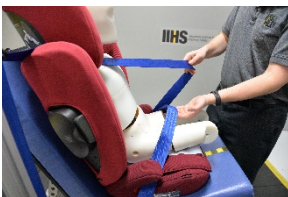
## Apply the Seat Belt

- 5.1. Stabilize Jasper and the booster, and pull the belt out of the retractor in a direction across the front of Jasper and the booster so that the latch plate ends up above Jasper's inboard leg.



Step 5.1

- 5.2. If there is a belt-positioning attachment guide/clip on a backless booster, route the shoulder belt through the attachment as instructed in the booster manual.
- 5.3. If Jasper must be moved (minor bending of the torso is acceptable, but the pelvis cannot be moved) to position the belt in the guide/clip, adjust the guide/clip to the shoulder as instructed in the booster manual, then remove Jasper and repeat the positioning of the booster (step 3.1)
- 5.4. Route the lap belt as instructed by the booster manual on the outboard side.
- 5.5. Leaving enough slack in the lap belt to hold the lap belt approximately 15 cm from the front edge of the pelvis, route the lap and shoulder belts as instructed by the booster manual on the buckle side of the booster and buckle the belt.
- 5.6. With one hand, pull the slack portion of the lap belt between the lower belt guides forward along the midsagittal plane of the pelvis, so that the belt is approximately 2 cm above the top surface of the thighs. This can be accomplished by grasping the belt with the palm up, such that the back of the hand is resting lightly on top of Jasper's thighs.
- 5.7. With the other hand, grasp the torso portion of the belt approximately 15 cm 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 with minimal resistance, keeping the lower edge of the lap belt just clear of the thighs.
  - 5.7.1 If the angle of the lower thigh joints causes a large gap where the belt becomes caught, it is acceptable to place tape over the joints to allow the belt to slide over the joints.



Steps 5.4–5.7

- 5.8. When the leading edge of the lap portion of the belt is within 10 cm of the pelvis, release the lap belt and pull on the shoulder belt until the lap belt has no slack. (This is only the preliminary step for positioning the lap belt.)



Step 5.8

- 5.9. Stabilizing Jasper and booster with one hand, grasp the torso portion of the belt 15 cm above the latch plate and slowly pull upward in the direction of the shoulder belt path with a force no greater than approximately 44 N (10 lbs). Continue repeated pulls on the belt until there is no additional visually-apparent movement of the lap belt.



Step 5.9

- 5.10. If Jasper is observed to move during this step (minor bending of the torso is acceptable, but the pelvis cannot be moved) repeat the positioning of the booster (step 3.1).
- 5.11. Feed any excess shoulder belt slack into the D-ring retractor.
- 5.12. Position the section of the shoulder belt between the buckle/lower guide and the upper guide or D-ring so that the belt routes through the shortest (or most natural) path between the two locations. (This is only the preliminary step for positioning the shoulder belt).



Step 5.12

- 5.12.1 For backless boosters with a shoulder belt guide/clip, keep the clip in position at the shoulder as instructed by the booster manual during preliminary positioning.

- 5.13. Feed any excess belt into the retractor. Attach a clamping device onto the webbing section between the D-ring and the retractor (see Appendix A). Stabilizing Jasper and the booster with one hand, slowly pull this device downward in the direction of the webbing, at a force of 22 N (5 lbs). Only pull the webbing once.



Step 5.13

- 5.14. Check the shoulder belt routing and determine if it is in the location specified by the booster instruction manual or in the desired location for the test. If the adjustments are not correct, make these adjustments and then repeat the positioning of the booster (step 3.1).

### **Position Jasper: Final Check**

- 6.1. Verify that the lap and shoulder belt routings are correct.
- 6.2. On Jasper's chest, verify that the Y value of the center of the chest is still  $\pm 2$  mm. If this tolerance is not met, adjust Jasper and re-apply the belt (step 5.1).

## MEASUREMENTS

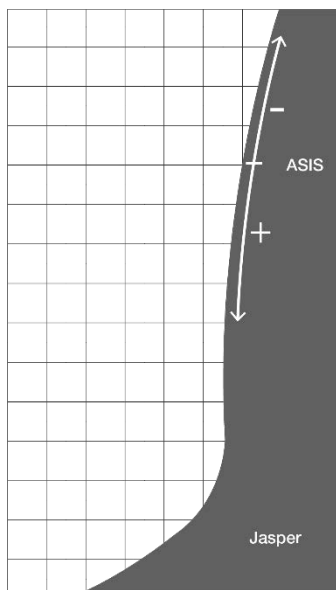
### Lap Belt Score

The Lap Belt Score (LBS) is defined as the distance from the ASIS to the top edge of the lap belt (Figure 8). The distance is measured along the surface of Jasper's pelvis to the top edge of the lap belt, at the lateral location of the ASIS. Values are positive when the belt is positioned below the ASIS and negative when the belt is positioned above the ASIS.

On some boosters, the bottom edge of the lap belt is in greater tension than the top edge, and the top edge may not actually be in contact with the lap. This tends to happen in cases with large (good) belt scores. When this occurs, lightly press on the lap belt to flatten it out against Jasper's pelvis prior to taking measurements.

The official LBS will be determined by measurements taken by hand using the ruler inscribed on Jasper's pelvis.

**Figure 8.** Lap Belt Score (illustration shown with Jasper's pelvis)



### Shoulder Belt Score

The Shoulder Belt Score (SBS) is the distance from the chest reference point to the inboard edge of the shoulder belt (where it crosses the chest reference line), with only the lateral component of this distance (Y axis) being included.

If a CMM is not used, an approximation can be made by measuring this distance using the ruler inscribed on Jasper's chest.

### Shoulder Belt Fore-Aft Distance

The shoulder belt fore-aft distance is the longitudinal distance (X axis) from the chest reference point to the inboard edge of the shoulder belt, where it crosses the chest reference tape (Figure 9).

If a CMM is not used, an approximation can be made by measuring this distance from the chest surface with a ruler.

**Figure 9.** Shoulder Belt Fore-Aft Distance





## Record Measurements

Record coordinates of the following booster, Jasper, test fixture, and seatbelt landmarks.

- 7.1. Head angle – negative angles are inclined forward; positive angles are reclined rearward.



- 7.2. Lap and shoulder belt hand measurements.



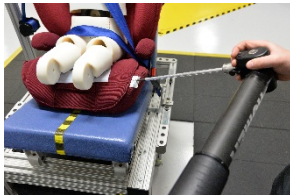
Lap belt hand measurement



Shoulder belt hand measurement

- 7.3 **Booster reference points:** The following reference points are measured in the test fixture reference frame.

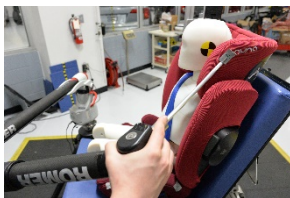
- 7.3.1 Left reference point #1



- 7.3.2 Left reference point #2

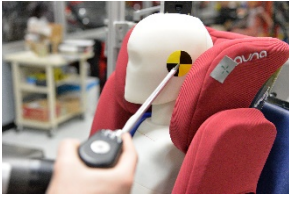


- 7.3.3 Left reference point #3



7.4. **Jasper landmarks:** The following reference points are measured in the test fixture reference frame.

7.4.1 Left head center of gravity



7.4.2. Chest reference point



7.4.3. Left ASIS-Jasper



7.4.4 Right ASIS-Jasper

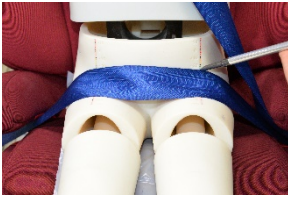


7.4.5 Pubic Symphysis (PS-Jasper)



**7.5 Test fixture and seatbelt reference points:** The following reference points are measured in the test fixture reference frame.

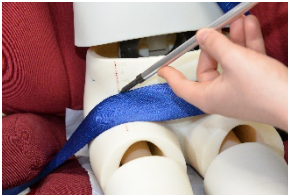
7.5.1. Left upper edge of lap belt at lateral location of ASIS



7.5.2. Left lower edge of lap belt at lateral location of ASIS



7.5.3. Right upper edge of lap belt at lateral location of ASIS



7.5.4. Right lower edge of lap belt at lateral location of ASIS



**Note:** The following four lap belt points (7.5.5–7.5.8) are for **reference only** and are not used to determine the lap belt score.

7.5.5. Inboard edge of shoulder belt where it crosses chest reference line (reference only).



7.5.6. Outboard edge of shoulder belt where it crosses chest reference line (reference only).



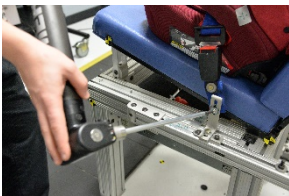
7.5.7. Upper edge of shoulder belt where it crosses Jasper centerline (reference only).



7.5.8. Lower edge of shoulder belt where it crosses Jasper centerline (reference only).



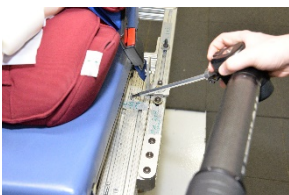
7.5.9 Lower inboard anchorage point XZ (centerline of bolt, correct X and Z).



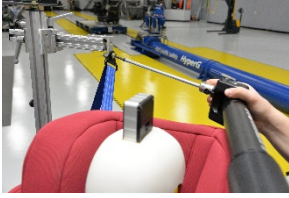
7.5.10 Buckle reference point.



7.5.11 Test fixture reference point.



7.5.12 D-ring (center of bolt face).



7.5.13 Lower outboard anchorage point XZ (centerline of bolt, correct X and Z).



### **Photograph Booster and Jasper**

Photograph the final booster and Jasper setup from both sides and the front, at a height approximately equal to the chest reference point, in perpendicular planes. Take additional photographs if necessary.

## REFERENCES

- Reed, M.P., Ebert, S.M., Sherwood, C.P., Klinich, K.D., & Manary, M.A. (2009). Evaluation of the static belt fit provided by belt-positioning booster seats. *Accident Analysis & Prevention*, *41*(3), 598–607.
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- Society of Automotive Engineers. (2008). *Surface vehicle standard: devices for use in defining and measuring vehicle seating accommodation* (Report No. J826). Warrendale, PA.
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## **APPENDIX A: MATERIALS AND SUPPLIES**

### **Seat Foam**

Polyurethane foam

Source: Foam Factory, Inc.

<https://www.foambymail.com/LHQ/lux-high-quality-foam.html>

Product name: Lux High Quality Foam

Thickness: 2 in

Sheet size: Third sheet, 82 in x 24 in

### **Seat Vinyl**

Source: Joann Fabrics

<http://www.joann.com/marine-vinyl/prd23669.html#start=1>

Product name: Marine Vinyl

Color: Mediterranean

Item #: PRD23669

### **Seat Belt System**

Three-point belt system (retractor, D-ring, sliding latch plate, lower outboard anchor), inboard female buckle, and webbing extender. This is a custom-made seat belt system.

Source: Shield Restraint Systems, Inc.

[www.trustshield.com](http://www.trustshield.com)

Part #I2476-001, Item # DSCH14154

Contact: Wade Johnson, Sales Manager

[wjohnson@trustshield.com](mailto:wjohnson@trustshield.com)

Phone: 405-213-9110

Fax: 574-970-3805

### **Grommets**

Source: McMaster Carr

<http://www.mcmaster.com/#87995k52/=3ad4t2>

Rolled-rim grommets with spur/extended neck, nickel-plated, Trade Size 1, 13/32 inch hole size

Part # 87995K52

## Pelvis-Positioning Pad for Jasper

Source: McMaster-Carr

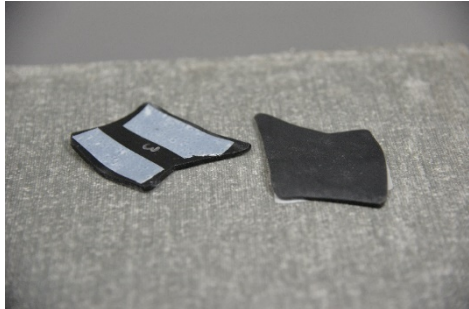
<http://www.mcmaster.com/#85175k95/=3cggw0>

Buna-N Foam, 3/4-inch thick oil-resistant (125 × 90 mm) neoprene/vinyl, firm

Part #85175K95

## Jasper Shoulder Pads

3 mm-thick shoulder pads



## Teflon Sheet for Booster Seat

Source: McMaster-Carr

<https://www.mcmaster.com/>

Teflon film, 0.005-inch thick, 15 × 8-1/2 inch (length × width)

Part #8569K38

## Clamp for Loading Shoulder Belt

Older model belt guide from Combi Dakota.

Modified by adding a short bolt for application of the force gauge.

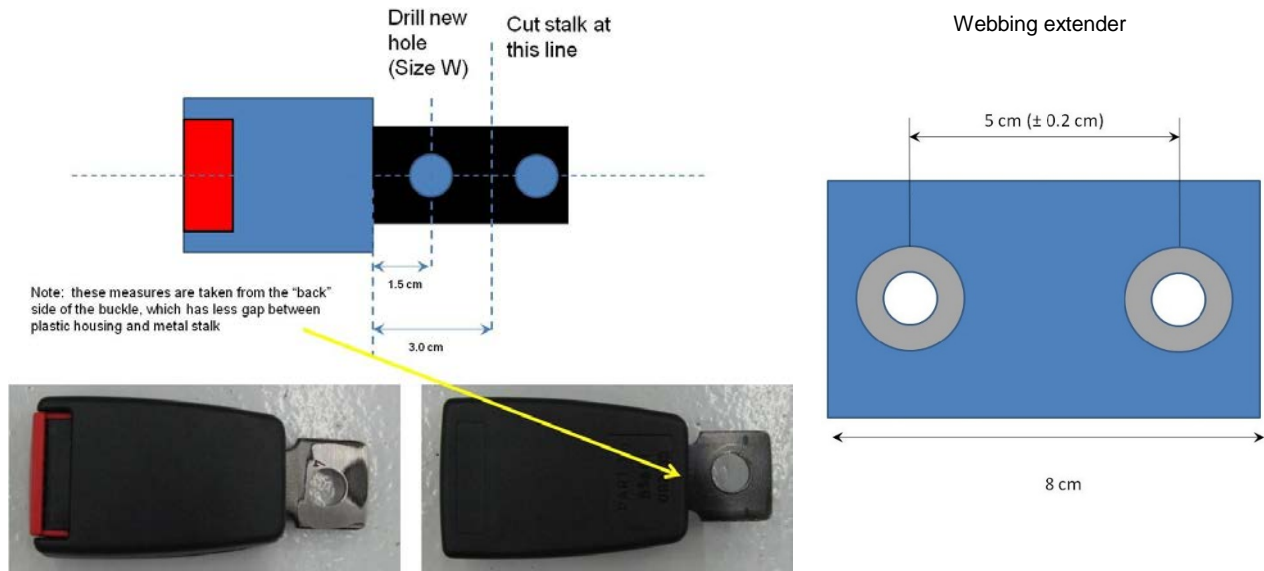




## APPENDIX B: INBOARD FEMALE BUCKLE MODIFICATION

When you set up a booster test fixture for the first time, the inboard female buckle requires a minor modification prior to installation. An additional mounting hole must be drilled, and the end of the stalk (with the existing hole) must be cut off.

The new hole is 0.386 inch (size W, clearance hole for a 3/8 inch  $\times$  16 bolt). The hole is centered on the stalk at a distance of 1.5 cm from the bottom edge of the plastic housing. The excess stalk is removed at a distance of 3.0 cm from the bottom edge of the housing.



The webbing extender is included in the part number. The following information below is included for reference purposes only.

A piece of seatbelt webbing (same material as the three-point belt system) is used to link the female buckle to the anchor location on the test fixture. The webbing is 8 cm long and has two grommets added with centers  $5.0 \pm 0.2$  cm apart, centered on the webbing. The grommets are rolled-rim grommets with a spur/extended neck, Trade Size 1 (13/32 inch hole size).

**APPENDIX C: BOOSTER SEAT H-POINT ORIGIN DEVICE (BPOD)**

