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Matthew P. Reed and Michelle M. Lehto
University of Michigan Transportation Research Institute

Benoit Anctil
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ABSTRACT

As part of the Automotive Seat and Package Evaluation and Comparison Tools (ASPECT) program, UMTRI researchers developed a new H-point manikin that is intended to replace the current SAE J826 manikin. The original manikin is used in many automotive applications, including as a platform for a belt-fit test device (BTD). In the current project, components and procedures were developed to measure belt fit using the ASPECT manikin. Contoured lap and torso forms were constructed using anthropometric data from an earlier UMTRI study. Prototype forms were mounted on the ASPECT manikin for testing in a laboratory fixture and in vehicles. The testing demonstrated that the ASPECT-BTD produces consistent measures of belt fit that vary in expected ways with belt geometry.

INTRODUCTION

A test device for measuring seatbelt fit was developed in the early 1980s (Newman et al. 1984; Shewchenko 1997a). The Belt-Fit Test Device (BTD), shown in Figure 1, consists of contoured metal forms that simulate the lap and chest of an occupant, mounted to a modified version of the SAE J826 H-point machine. The torso and lap forms were constructed to be representative of a midsize occupant, nominally midway between average male and average female body sizes. The manikin is installed in a vehicle seat using a modified version of the SAE J826 H-point machine installation procedure, and the seatbelt is routed over the manikin. The positions of the belts on the chest and lap forms are recorded by reference to numerical scales at the thigh-abdominal junction, sternum, and clavicle areas.

In the last few years, Transport Canada and automobile industry representatives have participated in efforts to develop an electronic version of the BTD in a CAD environment. One objective of this effort is to assess the feasibility of a belt-fit standard that provides for compliance certification using electronic tools, rather than a physical device. This software-based BTD is known as the *e*BTD. Concurrent with this effort, a group of auto manufacturers and seat suppliers supported an effort led by UMTRI to develop a replacement for the SAE J826 H-point machine. The Automotive Seat and Package Evaluation and Comparison Tools (ASPECT) program developed a new manikin, shown in Figure 2 (Reed et al. 1999). The ASPECT manikin is based on midsize male anthropometry and has an articulated lumbar spine that allows it to conform to modern automobile seats better than the original H-point machine. The ASPECT manikin is currently undergoing final design changes prior to being adopted in SAE Recommended Practice J826.

The ASPECT manikin is expected to replace the current H-point machine as an international standard for auto seat measurement over the next few years. An important part of the transition process is developing ASPECT versions of tools that were originally developed for use with the H-point machine. Adding belt-fit measurement capability to the ASPECT manikin would provide a transition path for the applications of the current BTD.

This paper describes the development of belt-fit-assessment components for the ASPECT manikin. After an initial feasibility assessment and preliminary model development, a prototype design for the components was completed and tested. Minor modifications based on test results were integrated into the final design. Preliminary test procedures were developed based on experience using the new BTD in vehicles and laboratory mockups.

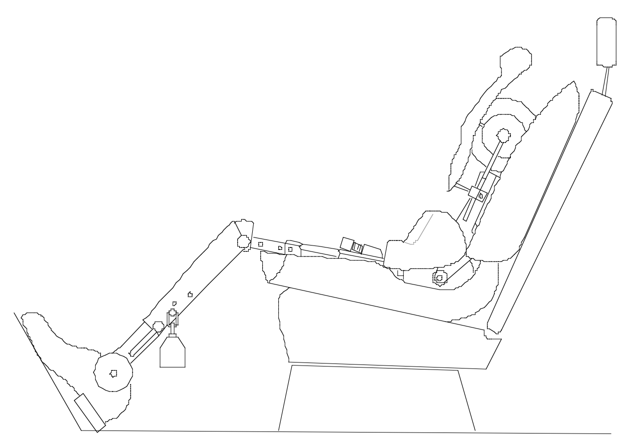

Figure 1. Current Belt-Fit Test Device (BTD) mounted on a modified SAE J826 H-point machine (Shewchenko 1997a).

Figure 2. The ASPECT manikin prototype.

METHODS

Initial Feasibility Assessment

A preliminary design for the ASPECT-BTD components was developed to provide a basis for a feasibility assessment. The ASPECT manikin has rigid external shells that form the seat interaction surfaces. The posterior torso surface is comprised of three articulating shells, while the buttock and thigh surfaces are represented by a single piece. The back contours were developed from a CAD model of a midsize male occupant that was based on data collected at UMTRI in the mid-1980s. As part of a study to develop anthropometric standards for a new family of crash dummies, detailed measurements were made on twenty-five midsize men as they sat in an automobile driving posture (Schneider et al. 1985). One of the outcomes of that study was a full-size, three-dimensional model of the midsize male driver. As part of the ASPECT program, the model was digitally scanned to create a CAD model of a midsize male driver, shown in Figure 3.

Figure 3. UMTRI midsize male CAD model.

The posterior torso surfaces of this model were used to create the back contour of the ASPECT manikin. As a consequence, there is an excellent fit between the back contours of the ASPECT manikin and the whole-body contour of the UMTRI midsize-male model. A preliminary design for the ASPECT-BTD was constructed by aligning the UMTRI midsize-male CAD model with a model of the ASPECT manikin and sectioning it in the torso and lap areas. Figure 4 shows the resulting model. The fore-aft position of the torso and lap forms is determined by landmark and external contour relationships from the ASPECT and UMTRI midsize-male datasets.

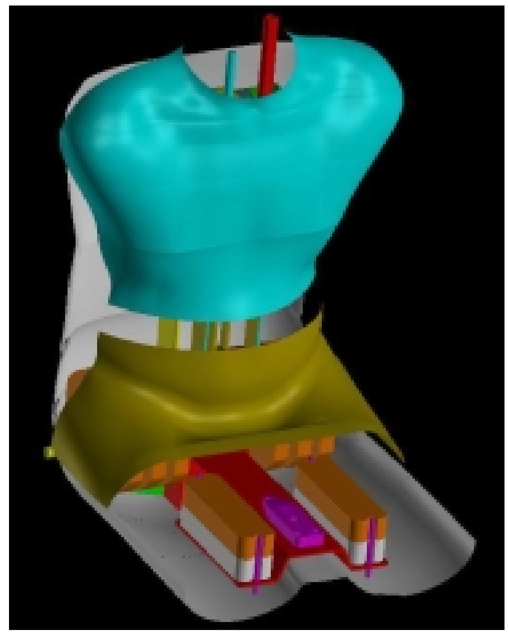

Figure 4. Preliminary concept for the ASPECT-BTD.

The ASPECT manikin is manufactured by Technosports, Inc. of Livonia, Michigan. Their engineers are also active in the design of the manikin, providing both engineering and CAD services. In conjunction with that work, Technosports provided CAD support to the current project and developed the ASPECT-BTD component hardware. After constructing the model shown in Figure 4, the clearances between the surface forms and the underlying hardware were examined.

Examination of this preliminary design concept suggested some issues that were addressed in the final implementation. The contour of the lap form in the anterior-superior iliac spine (ASIS) region of the pelvis needed to be smoothed to ensure accurate and consistent belt routing. The potential for interference between the side of the shells and buckles in certain belt configurations was investigated during prototype testing. The belt deployment procedure was also studied to ensure that the manikin thigh weights did not interfere with the belt deployment around the manikin.

Design of the First-Generation Torso and Lap Forms

The preliminary CAD model was modified in several ways to develop the first hardware prototype. The torso form was shortened at the lower end to eliminate the outward-curving portion of the upper abdomen. On human occupants, this portion of the body is soft tissue that is readily deformed by posture changes or contact with the belt. The thigh-abdominal junction area of the lap form was modified to simplify the geometry and to reduce the surface curvature in the area of the anterior superior iliac spines (ASIS) of the pelvis. The simplified geometry is intended to improve belt routing and the repeatability of the belt-fit measurements.

The first hardware prototype lap and torso forms were produced by stereolithography, a rapid-prototyping method. The resulting plastic shells, shown in Figure 5, were mounted to an UMTRI prototype of the ASPECT manikin. The UMTRI prototype is functionally equivalent to the ASPECT manikin manufactured by Technosports, although the hardware has cosmetic differences.

The lap and torso forms together weigh only 2.6 kg (5.75 lb), or about three percent of the manikin weight. This small addition to the manikin weight does not change the manikin position in the seat significantly, and hence no reduction of the manikin weight is needed.

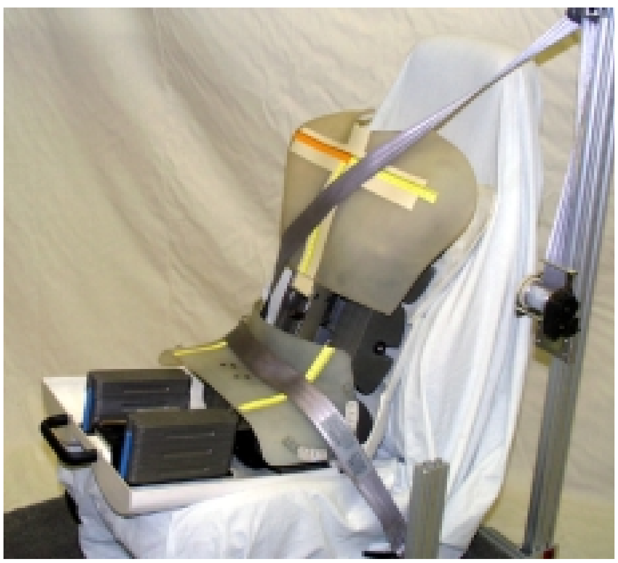

Figure 5. First-generation prototype lap and torso forms applied to a prototype ASPECT manikin.

An important consideration in the development of the BTD forms was the manner in which the forms are mounted to the manikin. The torso form has four points of attachment to the torso of the manikin. A fork at the base of the form slides into two grooves in the H-point saddle of the manikin (see Figures 5 and 8). Two rods in the chest area connect the torso form to a weight-hanger bar in the torso of the manikin to provide lateral stability. Initially, the mounting hardware for the torso form was designed so that the torso form angle could be set independent of the manikin back angle. However, further analysis of vehicle occupant posture data demonstrated that acceptable accuracy in chest position could be obtained with a direct linkage between the manikin back angle and the BTD torso form.

Two options were considered for mounting the lap form. One option was to allow the lap form to pivot at the hips, to simulate a range of pelvis orientations. The second option, the one used in the final design, was to attach the lap form rigidly to the buttock/thigh pan of the manikin. Because of concerns that the first option would introduce unwanted variability in the belt fit readings, the rigid attachment was chosen. One concern, however, is that the rigid attachment to the buttock/thigh pan means that the belt-fit scale readings are potentially dependent on the cushion angle of the seat. This issue is addressed below.

Prototype Testing

The prototype testing was intended to detect any problems that would affect the use of the ASPECT-BTD for in-vehicle testing, to develop appropriate belt fit scales, and to create a preliminary installation procedure. A laboratory fixture was constructed that allowed belt anchorage locations to be moved over a wide range, as shown in Figure 6. Initial testing focused on belt routing procedures and positions for the belt fit scales. Testing was conducted at a range of seat back recline angles. Testing was also conducted in the front and rear seats of several vehicles, as shown in Figure 7. Multiple trials were conducted in some conditions to assess the repeatability of the measures.

The belt is deployed using the procedures developed for the original BTD (Shewchenko 1997b). Points where the belt crosses the scales on the lap and torso forms are recorded to quantify the belt fit, as shown in Figure 8. The lap form scales are parallel to the midline at the locations of the ASIS (234 mm apart). The scales read in centimeters from a reference point that is 10 cm forward of the ASIS along the contour of the lap form. Hence, a reading of 10 cm indicates that the belt edge passes directly over the ASIS reference point on the lap form. On the torso form, the scales measure with respect to a reference point on the midline that is 450 mm above the H-point along the manikin torso line. Symmetrical scales extend to the left and right, and a vertical scale extends down from the reference point. The torso belt fit is quantified by the vertical and lateral scale readings where the lower edge of the torso belt crosses the scales.

The results of preliminary laboratory and vehicle testing of the BTD prototype are found in Reed and Lehto (2001). The BTD scale readings are sensitive to changes in belt angle, and the repeatability of belt deployment is excellent. Most of the variability in belt fit readings results from variability in manikin installation. Because the installation repeatability of the ASPECT manikin is better than that of the current H-point machine, the ASPECT-BTD is expected to provide more reliable measurements than its predecessor.

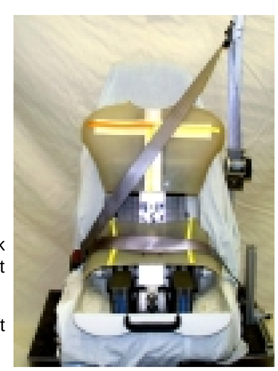

Figure 6. Laboratory fixture for testing prototype BTD forms.

Figure 7. ASPECT-BTD installed in a vehicle seat.

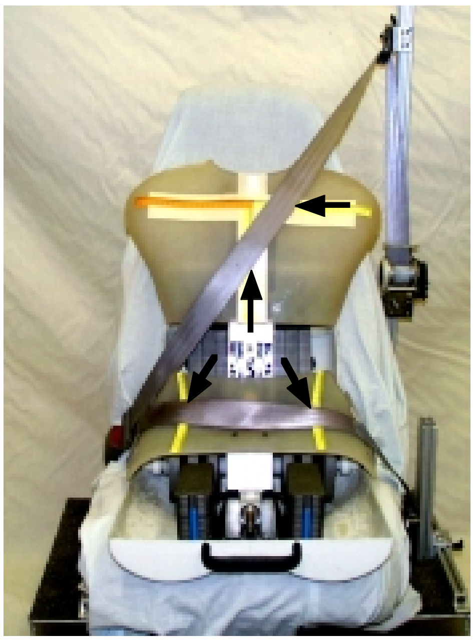

Figure 8. Reading belt fit from the lap and torso scales. Arrows indicate locations where the scales are read.

Final Prototype Features

Figure 9 shows the final prototype constructed by Technosports. The surface is coated with a smooth finish to facilitate repeatable belt installation. The scales are decals applied with reference to marks molded into the surface. The lap form is mounted using two quick-release fasteners. The torso form is mounted to the H-point pivot and to the upper torso weight hangers. The components can be installed and removed from the manikin in less than a minute.

Figure 9. Final prototype forms constructed by Technosports.

DISCUSSION

ASPECT-BTD Design

The ASPECT-BTD components were developed in a short-duration, small-scale research and development program. Although the anthropometric basis for the lap and torso forms is well established, no validation of the measures obtained from the ASPECT-BTD has been performed. In particular, the relationship between ASPECT-BTD measures and occupant belt fit has not been established. Considerably more work will be necessary to complete the development of the installation procedures and to provide meaningful interpretation of the scale readings. Detailed study of the repeatability of the scale readings across a wide range of seat and vehicle configurations is needed. Plans are underway for more extensive testing of the ASPECT-BTD in vehicles, as well as validation studies comparing the ASPECT-BTD measures to the belt fit of vehicle occupants.

Pelvis Angle in Rear Seats

The ASPECT-BTD responds to vehicle and seat geometry in a manner that is different from the original BTD. In rear seats with limited legroom, the legs of the original BTD would elevate the front of the manikin buttock/thigh pan, simultaneously changing the orientation of the lap form and the ASIS-scale readings. The original BTD was not affected by seat cushion angle, except when the fore-aft positions of the manikin's feet were unrestricted.

In contrast, the ASPECT-BTD measurements are independent of legroom, seat height, or other package dimensions. By design, the ASPECT manikin measures the seat geometry independent of the package. As in the original BTD, the ASPECT-BTD lap form moves with the buttock/thigh pan. However, the ASPECT buttock/thigh pan orientation is determined by interaction with the seat cushion.

The angle of the manikin thigh line is termed seat cushion angle and is a measure of seat geometry.

During the development of the ASPECT-BTD, some people familiar with the behavior of the original BTD expressed concern that the lack of response of the ASPECT-BTD to restricted legroom would lead to unrealistic belt fit assessments in rear seats. The assumption is that elevated thighs lead to more reclined pelvis orientations, as reflected by the change in the orientation of the lap form on the original BTD.

UMTRI data on occupant posture and position do not support the assumption that pelvis angles in rear seats are substantially different from those in front seats, or that restricted legroom causes more reclined pelvis postures. ASIS-to-eye distances and orientations for rear-seat passengers are not changed significantly when legroom is restricted, suggesting that the torso posture remains unchanged. Elevated thigh angles caused by restricted leg room may even produce more upright pelvis angles, rather than more reclined, because more body weight is concentrated under the buttocks, pushing the ischial tuberosities into the seat and allowing the lumbar support to provide greater stability to the pelvis. A study of passenger postures now underway at UMTRI will definitively address the question of how pelvis postures are affected by restricted legroom.

What the ASPECT-BTD Measures

The ASPECT-BTD represents a single, midsize male body size in one or a few seat positions. The resulting belt-fit measures are intended to be typical of the belt fit that a similarly sized person would experience, but an occupant population would experience a wide range of belt fit in the measured vehicle seat. Differences in belt fit across individuals are due to anthropometric and postural variability as well as differences in belt donning behavior and belt routing. The ASPECT-BTD is intended to provide measures that are consistently related to the distribution of the belt fit that an occupant population would experience, while not necessarily representing any individual's belt fit.

In a basic sense, the ASPECT-BTD measures belt anchorage locations. The linear scales on the manikin are sensitive to the angles at which the belt traverses the lap and torso forms. Anchorage locations at any distance from the manikin, but producing the same belt angles, will produce the same belt fit scores. Testing in multiple seat positions would provide some measure of the anchorage distance as well as angle, thereby providing a better assessment of population belt fit distributions for front seats. The purpose of the ASPECT-BTD is to detect belt anchorage locations and routing that would produce poor belt fit in an unacceptably large number of occupants. Poor belt fit could be defined in many ways, but one way to define belt fit is with respect to the angles with which the belt traverses a person's body. For the side-view angle of the lap belt, an angle that is too shallow (anchorage too high and/or too far rearward) is undesirable because of the risk of submarining. Angles that are too vertical are undesirable because the effective stiffness of the belt is reduced, allowing excessive occupant translation during a crash. For the torso portion of the belt, front-view angles that are too vertical can lead to discomfort for shorter occupants. Front-view angles too far from vertical may not provide adequate torso restraint for tall, thin occupants.

It is important to stress that the ASPECT-BTD does not measure where the belt will contact any particular person's body. For example, the positioning of the belt relative to the lap form of the ASPECT-BTD is not intended to be directly predictive of the average lap belt positioning for a midsize male occupant. Rather, the ASPECT-BTD measures are intended to be sensitive to changes in belt geometry that would change the distribution of belt fit for the occupant population.

*e*BTD

The Joint Working Group on Abdominal Injury Reduction is overseeing development of a software tool for belt fit assessment. The *e*BTD simulates the original BTD in an interactive computer graphics environment. The objective of the working group is to develop a tool that would allow manufacturers to demonstrate compliance with belt fit design guidelines using a software tool rather than a physical test.

The ASPECT-BTD can readily be integrated into this approach. In fact, the process should be easier with the ASPECT-BTD. A complete, standard CAD description of the ASPECT manikin and the BTD forms is available, whereas a reverse-engineering approach was required with the original BTD. The ASPECT-BTD is also used without legs, substantially simplifying the installation procedure, both physically and in software. The belt routing algorithms that have been developed for the current *e*BTD should be applicable without modification to a simulation of the ASPECT-BTD.

CONCLUSIONS

This program has completed development of torso and lap forms that attach to the ASPECT manikin. When the ASPECT-BTD is installed according to the specified procedures, scales on the torso and lap forms provide quantitative information about the seat belt geometry. Preliminary test results suggest that the ASPECT-BTD measures are consistent and vary with belt geometry in a manner that should be related to distributions of human belt fit. However, a substantial testing and validation effort will be required to establish test procedures for the ASPECT-BTD and belt assessment criteria based on ASPECT-BTD measures.

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