## PROSPECTS FOR ELECTRONIC COMPLIANCE WITH BELT FIT REQUIREMENTS

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# ABSTRACT

The effectiveness of seat belts depends largely on the extent to which their geometric design matches the occupants' anatomical characteristics. Transport Canada research into seat belt fit requirements culminated in the design of a Belt Fit Test Device (BTD), a full-scale model representing 50th percentile Canadian adult and based on the H-Point Machine. The purpose of this study was to determine the feasibility of developing an electronic representation of the BTD that could be used by manufacturers for restraint system design and certification. The project was not fully realized due to difficulties in obtaining suitable 3-D digital representations of automobile seats. However, the study demonstrated that seat belt design can be accurately assessed for proper fit using computer models.

### INTRODUCTION

The effectiveness of seat belts depends largely on the extent to which their geometric design matches the occupants' anatomical characteristics. The Belt-Fit Test Device (BTD) is a device used for the measurement and assessment of static seat belt geometry of automobile seat belts (Gibson et al., 1994, Tylko et al., 1993, Tylko et al., 1994). The device was conceived and developed to address abdominal and upper body injuries that may result from a mismatch between belt geometry and the occupants' anthropometric characteristics. In essence, the BTD comprises an SAE 3-dimensional H-Point Machine with the addition of special torso and lap forms that are designed to represent the 50th percentile Canadian adult male. The surfaces of the lap and torso forms are marked with scales to permit quantifying belt position. When positioned on an automobile seat, the device indicates whether the lap and shoulder belts fall within specified bounds relative to anatomical landmarks. Four criteria establish acceptable position limits with respect to the clavicle, sternum and lap scales. Belts which meet these criteria should adequately restrain the occupant in a crash, without causing serious injuries to soft tissue and organs from belt forces.

The BTD test was intended to complement other occupant protection requirements such as peak head acceleration and chest deflection. The current

requirements of the Canadian Motor Vehicle Safety Standard (CMVSS) 208, which specify the permissible angle of the lap belt and stipulate the location of the upper anchorage of the shoulder belt, do not ensure that the lap and shoulder belts are correctly positioned (Dalmotas and Welbourne, 1991). Although the original intention was to introduce new seat belt fit requirements as part of the 1997 CMVSS 208 amendment\*, the automotive industry requested that further research be conducted before its use was mandated. In response, a government-industry Joint Working Group on Abdominal Injury Reduction was formed to explore alternative approaches to minimizing the risk of belt-induced injury. The Joint Working Group was to make its recommendations by March 1998, but the research program was recently extended to explore the potential of developing a computer-based version of the BTD for electronic compliance, building on previous research to develop and validate the electronic BTD.

The development of an electronic version of the BTD was already underway at Transport Canada. Once the design of the BTD was finalized, research interests shifted to investigating the extent to which the BTD criteria accommodate the full range of the occupant sizes. The new focus was the development of an electronic representation of the BTD and the application of new computer human modeling techniques to extend the capabilities of the physical device.

Electronic compliance refers to the application of computer-based procedures to verify that hardware meets specified requirements. It promotes 'compliance by design' and, for certain standards, it may replace costly physical tests. The BTD test is an ideal first candidate for electronic compliance since the belt fit requirements relate to simple geometric properties of the restraint system and the test is static in nature.

This paper reviews the development of the electronic BTD and discusses its potential usefulness for electronic compliance with belt fit requirements.

<sup>\*</sup> A series of studies established the efficacy of the BTD as a reliable and accurate indicator of proper seat belt fit. According to the results of vehicle tests, the use of the BTD would require only minor changes to the current location of lap belt anchorages; however, it could impose greater restrictions on the location of shoulder belt anchorages.

### BACKGROUND

### **Development of the Belt Fit Test Device (BTD)**

The development of the BTD began in the midseventies in an effort to minimize the incidence of lacerations and rupture of vital organs due to lap belt intrusion (Gibson et al., 1994). A review of the literature and analysis of collision data identified geometric and anthropometric criteria for the correct positioning of the lap belt relative to the anterior superior iliac spines (ASIS). It was further determined that the shoulder belt should rest on the middle third of the collar bone, and that it should cross the sternum near the centre of the chest.

A need was identified for a reliable test of pelvic and thoracic belt fit in any vehicle. To ensure compatibility with existing automotive engineering practices, it was decided that the device would be based on the standard SAE H-Point Machine. Threedimensional lap and torso forms were constructed from anthropometric data obtained from a sample of Canadian adults. Participants for this effort were selected on the basis of their height and weight to reflect the 50th percentile values reported in a 1981 Fitness Canada survey. The height and weight screening criteria were 164.9 cm and 66.7 kg respectively. Details of the development of the lap and torso forms can be found in (Gibson et al., 1994).

The proposed quality of fit requirements include four independent criteria which establish belt position limits with respect to the clavicle, sternum, and inboard and outboard lap scales. The minimum acceptable scores are outlined in Table 1. The clavicle and torso scores represent the intersection of the lower edge of the shoulder belt with the clavicle and torso scales, respectively. The inboard and outboard lap scores are taken with reference to the upper edge of the lap belt.

For further information about the development and use of the BTD, the reader is referred to Gibson et al. (1994) and Tylko et al. (1994).

### Table 1. BTD Criteria

Measurement Criteria

1. Lap Form: x > 1.5 on inboard and outboard scales

2. Clavicle: 7 < x < 13

3. Sternum: 12 < x < 22

4. Belt contact at each of the clavicle and lap scales

#### **Development Of The Electronic BTD**

The development of the electronic BTD is described in Noy et al. (1997). The main purpose of this effort was to determine the validity of BTD criteria in assessing the correct positioning of lap and shoulder belts for a wide range of occupant sizes. Additional advantages included improved repeatability and simplification of restraint testing and facilitation of compliance by design. The objectives of this program were to develop and validate an electronic version of the BTD and to determine the need to replace the BTD with computer-based human models representing a wider distribution of the occupant population.

In brief, the first stage involved creating an electronic version of the H-Point machine and adding the three-dimensional free-form surfaces representing the lap and torso shape of the 50th percentile Canadian adult male.

To simulate the seat belt, a computerized flexible seat belt model was created. As a first approximation, the position of the seat belt in three-dimensional space was defined as the shortest curve lying on the surface of the lap and torso forms and constrained by the anchor points\*. The belt was mathematically represented as a set of three spline curves lying on a surface with two tangent directionally constrained forces at each end. The three splines corresponded to the two edges and the middle of the belt. The shapes of these spline curves were defined by the two forces at each end, the shape of the surface and by various anchor points. Assuming no friction forces between the surface of the body and the belt, the true definition of spline curves was used for the part of the belt that lay over the body surface. The segment between the extreme contact points on the body and the anchor point was a straight line. The portion of the belt on the surface of the body was defined as the intersection between a plane containing the spline curve and the surface of the body.

### Validation Of Electronic BTD

Two validation studies were performed. The initial validation of the electronic BTD was performed by comparing coordinate values of specific landmarks generated electronically with the actual BTD coordinates. The physical BTD was installed on two different seats (one having a soft cushion and the other a firm cushion) and seat belt fit measurements were taken in accordance with the procedures outlined in the Operations Manual for the BTD (Transport Canada 1993).

<sup>\*</sup> The anchor point here is defined as the end of the flexible portion of the belt.

Since initial validation indicated good correspondence between computed and measured BTD coordinates of seat belt reference points, a more complete validation was undertaken. Actual BTD scores were obtained from ten vehicles. Seat belt anchor points and the H-point were digitized.

The electronic BTD was positioned in the seat by aligning its H-point with the corresponding digitized coordinate obtained with the actual BTD\*. While this procedure was necessitated by the lack of appropriate seating algorithms, it does not detract from the usefulness of the electronic BTD since the H-point\*\* can be readily obtained from vehicle manufacturers.

Electronic BTD scores were generated and compared with actual BTD scores. The results for the ten vehicles comparing the actual and the electronic BTD data are presented in Figures 1-4 for the inboard and outboard lap, clavicle and sternum scores, respectively. The horizontal reference lines on these figures represent the test pass/fail criteria levels.

In total, 40 BTD scores were computed using the electronic BTD and compared with actual BTD values. In 30 of the 40 comparisons, the discrepancy between measured and computed values was less than one centimetre. When BTD scores were expressed in terms of test performance using the pass/fail criteria indicated in Table 1, 36 of the 40 comparisons were in agreement. The four instances for which computed and measured performance differed, were associated mostly with the torso form.

In terms of overall belt system performance, the electronic and actual BTD results were in agreement for seven out of the ten vehicles tested. One vehicle, the 1989 Toyota Tercel, failed the electronic BTD evaluation (both on clavicle and sternum scales) but passed with the actual device. It should be noted, however, that the clavicle and sternum scores were extremely close to criteria levels. The second vehicle, a 1985 Chevrolet Jimmy, failed the electronic BTD (outboard lap score) but passed when using the actual device. The third vehicle, a 1995 Ford Windstar, failed on the electronic sternum score.

\*\* The H-point is equivalent to the seating reference point (SRP).



Figure 1. Lap Inboard.



Figure 2. Lap Outboard.





Figure 4. Sternum.

<sup>\*</sup> The resting position of a mannequin when placed on a seat depends upon numerous factors including seat cushion and seat back angles, the distribution of weight on regions of the buttocks and back, the deformation properties of the cushion, the shape of the cushion, the type of upholstery material used, belt contact points, etc. There are no algorithms available, at present, that can be used to determine the position of the H-point as a function of known seat and mannequin characteristics.

This study indicated the need to refine the seat belt algorithm to address more complex seat and restraint systems (double retractors, various types of belt hardware, seat squab angles, different seat designs, etc.).

### PURPOSE OF THE PRESENT STUDY

The present study was undertaken to explore further the feasibility of developing an electronic BTD that would be suitable to verify compliance with belt fit requirements. Two specific objectives were established; (1) to refine the electronic BTD and seat belt algorithm, and (2) to demonstrate test feasibility by assessing a small sample of actual production vehicles using digital data provided by vehicle manufacturers. These two objectives are elaborated further below.

Due to the unavailability of seat data necessary to address the second objective, as explained below, the scope of this study was limited to refining and validating the model and seat belt algorithm.

# Improvements to the Electronic BTD and the Seat Belt Algorithm

A number of improvements were made to both the electronic BTD and the seat belt algorithm. For example, the number of cross-sections representing the geometry of the torso and the lap forms was increased by a factor of ten. This was considered essential for the lap form due to its highly variable contours. With the improved algorithm, the number of cross-sections was about 100 for each form, resulting in substantial improvement in the accuracy of the collision detection algorithm, used to locate the belt on the form in three-dimensional space.

The simple spline equation which was used in the earlier version to define the belt routing was modified by inclusion of tensile force calculations at each end of the belt. This modification was implemented to ensure that the part of the belt lying on the torso is deformed according to the geometrical shape of the form. Assuming no friction between the form and the belt, a mathematical model of the belt can be represented as series parallel splines lying on a surface with two tangent directional constrained forces at each end. Again, three splines were created to represent the belt, one at the middle and one at each edge of the belt. The belt routing was defined by the intersection of the three cutting plane with the cross-section of the form. Each intersection point between the plane and cross-section represented a point on the belt in contact with the form. The belt was constructed from the intersection points using interconnectivity algorithms.

The electronic BTD was modified to allow users to input the seat pan angle as a user-defined variable. In

previous studies, seat squab angle was found to affect belt fit scores but was not adequately accounted for in the model. The ability to input manufacturer-specified or empirically-derived seat squab angle was expected to reduce potential errors due to variations in seat design.

The electronic BTD was also modified to allow users to input certain seat geometric data such as seat height, seat width, physical length of the buckle hardware, SRP and H-point location.

As implemented within *Safework*<sup>TM \*</sup>, the electronic BTD has an improved graphical user interface, permitting users to assess the effects of changing anchor points and other seat properties on belt fit.

### Feasibility Electronic Compliance

The second objective of the study was to demonstrate the procedure for assessing restraint systems using the electronic BTD (and improved seat belt algorithm) completely within a computer-aided-design environment. In order to accomplish this, it was necessary to obtain from manufacturers digital 3-D surface drawings of seats that could be imported into the CAD environment and manipulated as objects. The only other data required to assess belt fit were the coordinates of the seat belt anchor points, the SRP and a seat squab reference point.

Despite best efforts, it was not possible to obtain the necessary data to accomplish this objective. For a variety of reasons, manufacturers were unable to provide digital representations of seats that can be used in the way envisioned. Few manufacturers require digital definition of seat surfaces. Seat manufacturers, on the other hand, may have such data, but they are not necessarily available to vehicle manufacturers.

The feasibility of electronic compliance relies on the availability of appropriate digital data. Further efforts in this area will require a concerted effort on the part of the industry to obtain and provide the requisite data.

Ideally, the input variables to the seat belt algorithm should include only characteristics that can be readily obtained from the manufacturers, such as seat belt type, specifications for associated hardware (belt buckle, plastic sleeves, etc.) and coordinates of anchorage locations. The seat belt algorithm would use these characteristics to determine the natural routing of the belt, taking into account the buckle characteristics and the interaction between webbing and mannequin as well as seat contact points.

<sup>\*</sup> Safework<sup>™</sup> is a computer application developed by Genicom Consultants for human modeling applications such as the design, evaluation and re-design of workstations from a human engineering point of view.

### METHODOLOGY

Two vehicles were selected for the study, a 1998 GM Cavalier and a 1998 Dodge Caravan. The BTD was placed in each vehicle, and coordinates of the seat belt anchor points and H-point were digitized using a Faro Arm. In addition, the seat geometry and surface elements were digitized so that a digital representation could be imported into the CAD environment.

# RESULTS

Figure 5 shows the electronic BTD as it was implemented within *Safework*<sup>TM</sup>. The snapshot illustrates the dialogue box used for entering the coordinates of belt anchor points, the SRP and seat squab angle.



Figure 5. The Electronic BTD as implemented in Safework<sup>TM</sup>

Figure 6 is a computer screen snapshot showing the electronic representation of the BTD in the GM Cavalier. The spline curves representing the lap and torso forms are clearly visible in this view; the seat details, unfortunately, cannot be seen. Figure 7 is a snapshot showing a close-up of the shoulder belt of the Cavalier over part of the torso form. The belt fit scores can be read directly from the clavicle and sternum scales and they can be generated electronically .

The data comparing actual and electronic BTD scores are presented in Tables 2 and 3 for the GM Cavalier and the Dodge Caravan, respectively. Test failure is indicated in the table by the underlined scores.



Figure 6. The GM Cavalier



Figure 7. Close-up of the Cavalier Shoulder Belt

Table 2. Validation 1998 Cavalier

Scale	Actual BTD	Electronic BTD
Clavicle	12.6	12.4
Sternum	17.5	17.1
Lap Inboard	2.2	<u>1.3</u>
Lap Outboard	3.9	3.8

Table 3.Validation 1998 Dodge Caravan

Scale	Actual BTD	Electronic BTD
Clavicle	11.2	11.1
Sternum	13.8	13.9
Lap Inboard	4.8	4.0
Lap Outboard	4.2	4.2

### DISCUSSION

The data presented in Tables 2 and 3 indicate that the differences between the electronic and actual BTD scores were all within one centimetre. In one instance, there was disagreement between predicted and observed pass/fail outcomes. The 1998 Cavalier failed the inboard lap criterion using the electronic BTD but passed using the actual device. It should be noted, however, that the electronic score was within 2 mm of the criterion value of 1.5 cm. The actual score was 2.2 cm, within 7 mm of being acceptable.

The results confirm the potential for the electronic BTD to replace the actual device. There was good correspondence between electronic and actual scores for a popular model passenger car and a minivan.

### CONCLUSIONS

The computer-based model of the BTD was refined and validated. The results of the validation study demonstrated good concordance with scores obtained with the actual device. However, as a result of the difficulties in obtaining digital 3-D seat data, it was not possible to adequately test the concept of electronic compliance. The feasibility of electronic compliance relies on the availability of appropriate digital data. Further collaborative efforts in this area will explore the potential for industry to acquire and provide the requisite data.

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