THE ELECTRONIC BELT-FIT TEST DEVICE (*e*BTD): A METHOD FOR CERTIFYING SAFE SEAT BELT FIT

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ABSTRACT

The belt-fit test device (BTD) measures and assesses static seat belt geometry of automobile seat belts. It was conceived and developed by Transport Canada throughout the 1970s, 1980s and 1990s to address abdominal and upper body injuries that resulted from a mismatch between seat belt geometry and occupants' anthropometric characteristics. When positioned on an automobile seat, the BTD indicates whether the lap and shoulder belts fall within specified bounds that have been established to minimize the risk of serious injuries to soft tissue and organs from belt intrusion.

Recently, work has focused on the development of an electronic version of the BTD using computer-human modeling techniques and computer-aided design (CAD). tecmath AG, creators of the RAMSIS™ 3D human modeling system, are currently developing an electronic BTD (or *e*BTD). In addition to providing a convenient tool with which to certify seat belt fit of current vehicle models, the *e*BTD will help designers assess seat belt geometry before a vehicle reaches production.

INTRODUCTION

With the introduction of seat belt legislation in Canada in the mid-1970s, government and industry found a need to evaluate seat belt fit. Analyses of collisions involving fully restrained occupants had found that serious belt-related abdominal injuries were attributed to lap belt intrusion, which occurred when the belt lay over the soft tissues and organs, rather than the bony structure of the pelvis (Dalmotas, 1980). Shoulder (torso) seat belts presented their own concerns, including possible interference between the belt and occupants' neck and/or cardiac regions.

In response to these concerns, Transport Canada developed the physical BTD to measure static seat belt geometry. Designed to represent the anthropometry of a 50th percentile Canadian adult, it consists of aluminum lap and torso forms that are attached to a 3-dimensional, Society of Automotive Engineers (SAE) H-point machine (Figure 1). These forms are marked with scales that permit the quantification of belt position. Analysis of crash data and related research had determined that a safe lap belt position is one that lies below the bony prominences of the pelvis, called the anterior superior iliac spines (ASIS). For the torso belt, an optimal position is one that lies over the middle third of the clavicle and centre of the sternum.

Figure 1. The physical BTD.

While designs have improved substantially since the 1970s, there remains a need to improve the safety of seat belts. In a review of the recent literature (1983-1995), belt-related injuries to front and/or rear seat occupants were found to occur in 5-58% of all collisions. While injury severity level tended to be low, exposure level is high, especially with the increased rates of belt usage in North America (Anctil & Shewchenko, 2000).

In 1995, amendments were proposed to two Canadian Motor Vehicle Safety Regulations relating to seat belts—CMVSR 208 (*Seat Belt Installations*) and CMVSR 210 (*Seat Belt Anchorages*). The proposed amendment to CMVSR 210 included provisions for abdominal protection using BTD test procedures and criteria (see Table 1).

Table 1.
BTD Criteria

Measurement Criteria
1. Lap Form: x > 1.5cm on inboard and outboard scales
2. Clavicle: 7 < x < 13 cm
3. Sternum: 12 <x < 22 cm
4. Belt contact at each of the clavicle and lap scales

In response to publication of the proposed amendment in Part I of the Canadian Gazette (equivalent to Notice of Proposed Rulemaking), industry expressed concerns that the BTD had not been sufficiently validated. In particular, it was reported that measurement repeatability was unacceptable. Despite previous validation studies demonstrating the BTD to be a reliable and accurate indicator of seat belt fit (i.e., with a measure of repeatability of ±0.2 cm, see Tylko, Gibson, & Shewchenko, 1993), it was decided to postpone regulatory changes based on the BTD and conduct further research in collaboration with industry. In July of 1995, the Joint (government-industry) Working Group on Abdominal Injury Reduction (JWG-AIR) was convened with the objective of identifying and defining a practical and effective means of regulating vehicle design to minimize the risk of belt-induced abdominal injury.

One recommendation made by this group was the development of an 'electronic' version of the BTD, which, in addition to providing a convenient tool to assess seat belt fit in current vehicle models, could also be used during the design process, ensuring that seat belt geometry is adequate before a vehicle reaches production. Furthermore, an electronic version could, theoretically, be easily adjusted to represent a wider range of occupant sizes.

Electronic certification refers to the use of computerized methods to certify that a vehicle component meets regulatory standards or specifications. Transport Canada is currently considering a memorandum of understanding (MOU) with industry based on the electronic BTD. The MOU would enable manufacturers to choose between two methods, electronic and physical, to demonstrate that their vehicle seat belt designs meet the minimum acceptable belt fit criteria, as set out by Transport Canada (St-Laurent & Gardner, 1992). For more information on the proposed structure of this MOU, see the final section of this paper.

What follows is a review of the history of the development of the physical BTD and the *e*BTD. Future work, including the integration of BTD capabilities within the Automotive Seat and Package Evaluation and Comparison Tools (ASPECT) manikin, as well as the proposed MOU with industry, will also be discussed.

HISTORY

Physical BTD

The BTD has undergone significant development since its earliest prototypes, including redefining the materials used to fabricate the lap and torso forms, considerations regarding occupant slouching, calibration and validation work, and development of operational procedures and guidelines.

In 1990, production of the finalized lap and torso forms began using numerically controlled machining techniques, and hardware to attach the forms to the H-point machine was produced. The resultant package became known as the "BTD conversion kit", and is compatible with the H-point machine as described and illustrated in SAE J826 JUN92. The conversion kit may also be used with other versions of the H-point machine, requiring some modifications.

Validation work on the physical BTD took several forms. Once the design was finalized in 1990, BTD scores were validated against previously-collected human belt fit data. In general, there was good correlation between BTD lap belt scores and the vertical distance from the lap belt top to the ASIS on the human subjects (Tylko, Gibson, & Shewchenko, 1993). Using a computer-based solid modeling program, a second study compared the BTD with four human subjects who represented 5th and 50th percentile females, and 50th and 95th percentile males (Tylko, Gibson, Descôteaux, & Fournier, 1994). Overall, the study confirmed that the BTD and the pass/fail criteria that had been proposed (see Table 1) were representative for this group of humans in terms of position in the seat and prediction of allowable seat belt anchorage positions. This study also assessed the effect that using the BTD would have on acceptable seat belt anchorage locations, as compared to that allowable with CMVSR 210. For the lap belt, the allowable anchorage positions for the BTD are similar to the CMVSR 210 requirements, but allow a more vertical belt position and restrict the position to the rear. For the torso belt, the allowable anchorage positions for the BTD are much more tightly restricted than for CMVSR 210. This reflects the quality of belt-fit at the shoulder, which is not addressed by CMVSR 210.

Other validation studies have demonstrated good repeatability of measurements using a BTD kit attached to different vintages of H-point machines (Tylko, Gibson, Descôteaux, Fournier, 1994). In-vehicle BTD measurements allowed identification of the 'repeatability of scale', which is established by comparing and matching the number of measurements which lie within one standard deviation of the mean. The proportion of total measurements that represent acceptable matches is reported as the repeatability. Data collected from 37 vehicles in 1991-1992 estimated the repeatability to be between ±0.2 cm (Tylko, Gibson, & Shewchenko, 1993). Inter-rater reliability was reported to be 89%, when seat belt systems were evaluated on the basis of a pass or fail. Finally, the seat belt systems of 72 representative vehicles from the 1993/94 vehicle fleet were measured using the BTD and the proposed pass/fail criteria (Tylko & Gibson, 1994). While only 26 vehicles (36%) met all the proposed criteria in all seating positions, 65% of the remaining vehicles failed because of the lap criteria, 28% failed due to the clavicle criteria, and 8% failed the sternum criteria. Of the vehicles that failed to meet the lap criteria, more than 80% failed in the rear seating positions. Failures were also more frequent in the rear seats than the front for the clavicle and sternum criteria. Contact problems predominated in the front seats, due to the geometric characteristics of door-mounted systems, which are no longer used in current vehicle design.

In order to ensure that the BTD is used in a repeatable and consistent manner, it has been important to develop straightforward operational procedures. The development of detailed procedures began with the inception of the BTD and, consequently, they have undergone extensive and frequent revisions. The finalized operational procedure is outlined in the Operational Manual (Shewchenko, 1997a), and includes a description of the positioning method, as well as copies of suggested data recording forms. There is also an accompanying Conversion Manual (Shewchenko, 1997b) that includes procedures for H-point machine modification, and engineering drawings of BTD components.

Electronic BTD

In 1995, the Ergonomics Division at Transport Canada commissioned Génicom Inc. of Montreal, Canada, to assess the feasibility of developing an electronic version of the BTD. This work was instigated not only because of validity issues relating to the physical BTD, but because of a desire to improve belt fit for a wider range of the occupant population.

The *Safework*™ electronic BTD was accomplished by first re-creating H-point engineering drawings in CAD format. Lap and torso form data were available in Initial Graphics Exchange Specification (IGES) format, and were added later. A flexible seat belt algorithm was written in C programming language, and was represented as a series of spline curves, that lay on top of the lap and torso forms. By superimposing the BTD scales onto the forms, belt fit was able to be electronically assessed.

In addition to its development, the *Safework*™ electronic BTD was validated against physical data from a seating simulator and, later, 10 vehicle designs (Noy, Battista, & Carrier, 1997; Noy & Battista, 1998). Comparisons with the seating simulator were extremely well correlated; however, when compared to BTD scores from real vehicle seats, 25 per cent of the electronic BTD scores differed by more than one cm. Variability in seat belt hardware was believed to be the most significant contributing variable to the discordance between scores. A more sophisticated seat belt routing algorithm was recommended; however, due to incompatibility problems between *Safework*™ and manufacturers' own design software, as well as difficulty obtaining electronic vehicle data for validation testing, development work did not continue. A more complete summary of the initial work on the electronic BTD can be found in Noy, Battista and Carrier, 1997.

In the fall of 1998, JWG-AIR members decided to redirect their efforts to develop an electronic version of the BTD within the RAMSIS™ environment. Created with help from the German automotive industry, RAMSIS™ human modeling is currently used by over 70 per cent of automotive manufacturers. The wide use of RAMSIS™ facilitates acceptance by many, and ensures that design, and certification, software are compatible. An action plan proposed at that time by Transport Canada anticipated completion of the fully validated *e*BTD module by January 2000, with planning of the related MOU beginning in April of the same year.

RAMSIS™ *eBTD*

Initial work by tecmath AG on their version of the *e*BTD focused on establishing an enhanced prototype. This included first confirming that they had the correct, and most up-to-date, CAD data for all the BTD components. This included not only the H-point machine, torso and lap forms, but the modified seat, and back, pan as well. They also concentrated on defining and creating the user-defined inputs that would eventually be used to calculate BTD scores. These include the H-point, heel hard point, seat back angle, and lower inboard, outboard, and upper outboard, anchor points. All inputs were designed so that they could be made using a Windows-based, graphical user interface. A stand-alone prototype module was distributed to working group members in November, 1999 for beta testing.

Feedback from group members indicated promise for the module. In general, users were able to import their vehicle data into the RAMSIS™ environment, although some experienced difficulties. Most errors that were identified during beta-testing were corrected in time for the next release of RAMSIS™ version 3.5 in May, 2000. The major limitation of the software, however, remained its inability to realistically model seat belt anchor kinematics. A technical sub-committee was established, and recommended a library of basic common seat belt anchorage designs from which users could make an appropriate selection. Once the appropriate anchorage hardware is defined (from the library), the user will then be required to input associated variables such as anchorage length, width, and range of motion, which will all be defined in relation to the fixed anchorage point. Using this information, the *e*BTD will then calculate the resultant seat belt angles and belt fit. As well, in order to determine the seat belt's first points of contact on the torso and lap forms (which determines whether a seat belt system passes/fails the criteria), the sub-group decided that the software would need to adequately model belt width. The sub-group also decided that a numerical model to generate error estimation be integrated into the *e*BTD's math model.

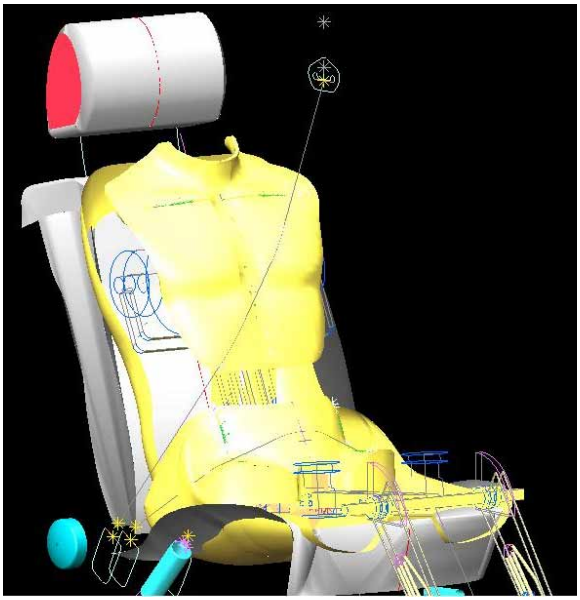

Figure 2. The RAMSIS™ *e*BTD

At present, work on the *e*BTD module is ongoing, and a new Beta release is expected in June, 2001. This version will contain a library of seven common anchorage designs (two upper, two lower inboard, and three lower outboard), which account for between 90-95 per cent of available designs. Future releases will be updated as novel anchorage designs are introduced. Modeling of belt width will be done by using two ellipsoid tubes near the inner and outer points of belt webbing contact with the lap and torso shells. Belt edge lines will, like the centre line, follow the contours of the torso and lap forms, thus, realistically model belt twisting. Finally, error estimation will be calculated by taking into account six possible sources of error. Validation studies between physical BTD measurements and the Beta *e*BTD module will test and refine the model. These studies will be performed by several manufacturers using their own vehicles, as well as with physical data collected from frontal, side, and offset crash testing previously done at Transport Canada.

The project time line has since been updated to account for the added work of creating a library of anchorage designs and performing validation testing. The initial release of the finalized *e*BTD will take place in October, 2001, and the MOU with industry is expected to be implemented beginning in January, 2002.

FUTURE WORK

Automotive Seats and Package Evaluation and Comparison Tools (ASPECT) BTD

The ASPECT manikin, which will be known in the future as the HPM-II™ (SAE, 2000), is slated to replace the current SAE recommended practice regarding positioning of vehicle occupants in design and safety applications in 2002. In addition to a physical device, the ASPECT program also produced a CAD representation of the manikin, and three-dimensional surface representations of small female, midsize male, and large male, drivers (Schneider et al., 1999). In order to promote the BTD as an effective safety device, and to be able to implement future usable standards and regulations regarding belt fit, it has been necessary to integrate it with the ASPECT project. A beta version of the physical ASPECT manikin has been distributed to a select number of manufacturers and final design changes will be completed in summer, 2001. Transport Canada has commissioned work assessing the feasibility of integrating belt fit capabilities within the ASPECT manikin, including an assessment of the necessary requirements and design modifications.

A hardware feasibility study demonstrated that integrating belt fit capabilities with the ASPECT manikin is possible without changing any of the underlying hardware. A physical ASPECT-BTD prototype, with corresponding operational procedures, is slated for delivery in March, 2001. Furthermore, the development of a CAD representation of the ASPECT-BTD is ongoing. Plans for the future substitution of this model into the RAMSIS™ *e*BTD software have not yet been established, however, tecmath AG has been involved in the ASPECT project since 1996, and has been successful in implementing the ASPECT products into the RAMSIS™ model, making this a likely possibility.

Proposed Memorandum of Understanding (MOU) with industry

The MOU will be applicable to all light-duty passenger vehicles. Manufacturers will have the choice of providing supporting documentation based on either the electronic, or the physical, BTD. The choice to provide results based on the electronic version, however, will depend on whether the vehicle's seat belt system falls within the scope of the *e*BTD's mathematical model. Manufacturers will also have the option of using either the RAMSIS™ *e*BTD or their own software, providing the numerical methods used are correlated to the physical device. While it will be the intention of the MOU that all seating positions meet the criteria, the implementation of the MOU will be incremental in nature.

Chronologically, the front outboard seating positions will be the first to be required to meet the belt fit criteria. The rear seating positions will follow, once the issues that are unique to these positions have been addressed. Eventually, all designated seating positions will be required to meet the criteria. The wording of the MOU will explicitly set out the phase-in of seating positions, and of vehicle year models, that will be covered.

As previously stated, timing of the implementation of the MOU has been moved forward to January, 2002. In the interim, a second sub-group comprised of representatives from the Canadian Vehicle Manufacturer's Association (CVMA), the Alliance of International Automobile Manufacturers of Canada (AIAMC), regulatory working group members, and their counterparts at Transport Canada has arranged meet to discuss further development of the MOU.

CONCLUSIONS

Transport Canada's top priority is safety. This includes ensuring safe seat belt fit for all Canadians. The development of the physical and electronic versions of the BTD has been ongoing for many years, and has culminated in the development of a usable and accepted device, the RAMSIS™ *e*BTD. As a static measure of seat belt fit, the *e*BTD makes an ideal first application for electronic certification, and could, depending on the outcome, pave the way for electronic certification in other domains. Depending on the application, this could greatly reduce costs of physical testing programs. With continued cooperation, government, industry and the driving public may all soon be able to realize the benefits of this approach.

REFERENCES

Anctil, B. & Shewchenko, N. (2000). Implementation of the belt fit assessment capabilities with the ASPECT mannequin—requirements and hardware modifications. *Contract report to Transport Canada, BAL report R00-15.*

Dalmotas, D. J. (1980). Mechanisms of injury to vehicle occupants restrained by three-point seat belts. *24th Stapp Car Crash Conference*, 439-476.

Noy, Y.I., & Battista, V. (1998). Prospects for electronic compliance with belt fit requirements. *14th International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 98-S9-O-13.*

Noy, Y.I., Battista, V., & Carrier, R. (1997). Development of an electronic belt fit test device. *Anthropomorphic Dummies and Crash Instrumentation Sensors SP-1261, SAE Paper No. 971137.*

St-Laurent, A. & Gardner, W. (1992). Proposed requirements for the protection of front seat occupants in frontal impacts. *Transport Canada Publication No. TP11476(E).*

Schneider, L.W., Reed, M.P., Roe, R.W., Manary, M.A., Flannagan, C.A.C., Hubbard, R.P., & Rupp, G.L. (1999). ASPECT: The next-generation H-point machine and related vehicle and seat design and measurement tools. *SAE International Congress and Exposition, paper No.1999-01-0962.*

Shewchenko, N. (1997a). Operational manual for the belt deployment test device. *Contract report to Transport Canada, BAL report D97-06.*

Shewchenko, N. (1997b). Conversion manual for the belt deployment test device. *Contract report to Transport Canada, BAL report D97-07.*

Society of Automotive Engineers (SAE)(2000). Update, *November edition.*

Tylko, S., & Gibson, T. (1994). Belt fit test device fleet measurement. *Contract report to Transport Canada, BAL report R94-02.*

Tylko, S., Gibson, T., Descôteaux, J., & Fournier, E. (1994). A demonstration of the capabilities of the belt-fit test device. *Contract report to Transport Canada, BAL report R93-06/sb.*

Tylko, S., Gibson, T., & Shewchenko, N. (1993). Towards the development of a seat belt fit compliance procedure based on the belt fit test device (BTD). *Contract report to Transport Canada, BAL report R92-11B.*