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The electronic Belt Fit Test Device – Methodology, Results, and Prospects

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ABSTRACT

Fitting the seat belt correctly will potentially save the lives of passengers car occupants everyday. In an attempt to reduce the risk of injuries, primarily abdominal, caused by inappropriate belt fitting, Transport Canada developed the Belt fit Test Device (BTD). The BTD is a physical hardware measuring device that tests whether the lap and torso belt are appropriately positioned with respect to the bony structures of the pelvis and rib cage of the restrained occupant.

To overcome the deviations of hardware physical tests and to enable review of belt design in early design phases, the Alliance of Automobile Manufacturers funded the development of an electronic simulation and modeling tool in the form of an electronic Belt fit Test Device (eBTD). The development takes place in close co-operation with the Joint Working Group on Abdominal Injury Reduction (JWG-AIR).

The introduced 3D belt routing simulation model takes into account the belt width, the kinematics of belt anchorages, belt types, contact of belt with seat, and the location and position of the belt fit test device itself. Different techniques were used to evaluate the model in which physical tests were compared with simulation results.

The algorithm has the potential to be used to model different human sizes and statures. This could allow for the assessment of different occupant populations and non-standard driving postures. Furthermore, it demonstrates the potential for the study of realistic belt routing parameters through simulation. This could be used as a basis for addressing future safety belt related issues, such as belt comfort, accessibility, etc.

INTRODUCTION

There is overwhelming evidence from field data indicating that seatbelt usage is the single most important safety device for reducing fatal injuries in automobile crashes. While this fact suggests that occupants should wear seat belts while seated in a moving vehicle, it does not necessarily mean that each and every occupant will gain the same benefit of reducing the chances of fatal injury, regardless of how they fit their seatbelt. Therefore, it is necessary to determine how the seatbelt will fit an occupant and develop certain quantitative assessment of the goodness of the fit. Transport Canada determined that the current requirements of the Canadian Motor Vehicle Safety Standards (CMVSS) 208 and 210, 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. Accordingly, a physical Belt fit Test Device (BTD) was developed by Transport Canada as a tool to assess the static deployed geometry of automobile seat belts. 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 50^{th} percentile Canadian adult (both male and female). The surfaces of the lap and torso forms are marked with scales to permit quantification of the 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. Transport Canada has established four fit criteria with respect to the clavicle, sternum and the outboard and inboard lap scales. The premise is that belts that meeting these criteria should adequately restrain the occupant in a crash, without causing serious injuries to soft tissue and organs from belt forces.

Recently, Transport Canada, the Canadian Vehicle Manufacturers Association (CVMA) and the Association of International Automobile Manufacturers of Canada (AIAMC) agreed to participate in a joint working group to develop an approach that relies on certification to the proposed BTD regulation using computer simulation.

Certification by computer simulation could eliminate differences between different test conditions. It also offers the potential of additional benefits from computer modeling such as expanded occupant size models, capability to conduct sensitivity analysis and, reduced test and travel expenses.

COMPUTER-BASED PROGRAM DEVELOPMENT

The initial program development effort focused on creating a valid digital representation of the physical device. The approach implemented three parallel spline curves drawn "taut" over the lap and torso shell surfaces while connected to known belt design anchor points. A frictionless surface was assumed so that forces at each anchor point would pull the mathematically modeled flexible belt to its equilibrium position.

Initial validation efforts compared software analyses output from specific landmarks to results from installation of the physical BTD in two vehicle seats. These promising results led to a follow-up validation comparing software results to installations in ten vehicles. Of the 40 measurements taken, 30 software simulation results were within 1 cm of actual data points. Furthermore, 36 of the 40 simulation results were in congruence with the physical criteria results of either pass/fail. The four incongruent results were appreciably close between the first electronic BTD and physical BTD.

The model demonstrated correlation between an ***e***lectronic **B**elt fit **T**est **D**evice (***e*BTD**). and the physical BTD, except where seats, buckles, etc. have deflected the belt from the equilibrium path that the webbing would take from the anchorage to the BTD.

It was concluded that the seat belt algorithm needed to be refined to include more complex seat belt and restraint system designs (retractable belts, different belt hardware components, seat design elements, etc.).

In 1998, work began on an enhanced prototype version of a software module to include the latest CAD data representation of the H-point machine, the lap and torso surfaces, user-defined inputs for the location of the H-point, heel point, seat back angle, upper outboard, lower inboard and lower outboard anchor points.

Significant program accomplishments include:

- *Seat belt width* – Since seat belt width was needed at the points of interest, i.e., where the belt crosses the various scales, efforts were focused on simulating realistic seat belt width and curvature over the lap and torso forms that is resulting from anchor location and anchor design kinematics at the clavicle, sternum and lap surface areas.
- *Anchor point kinematics* – To model anchor point kinematics, it was necessary that the common types of seat belt anchors, buckles and retractors, that represented approximately 95% of seat belt designs, were analyzed to determine the main parameters that could be used to mathematically model their kinematic behavior.
- *Further refinements* – Other work performed to enhance the eBTD module included: refinement of the user-interface, increasing the software stability, determining proper measurements when the belt does not contact the surface, inboard lower anchor stiffness model, and inclusion of an error estimate.

Refining the user-interface entailed creating user friendly windows for accepting user input for relevant parameters. Additions were also made to ease data translation from CAD systems into the module via an Initial Graphics Exchange Specification (IGES) data translator.

This paper describes the status of the eBTD and the efforts undertaken to assure validation of the results obtained from electronic means as compared with those expected from a physical test.

BELT FIT METHODOLOGY – The belt routing calculation is based on three main components; they are the representation of the belt including anchor kinematics, the representation of the eBTD manikin, and the interaction, i.e. the contact of these two components. Once the belt routing calculation is determined, the scale values are computed according to the BTD deployment manual [8].

BASIC CONCEPT OF SIMULATION – The belt routing simulation is based on several assumptions:

1. The weight of the seat belt band is very low compared to the tension forces.
2. Because of the unruffled texture of the BTD shells, the friction between the seat belt band and shells is very low and negligible.
3. The tension forces in the seat belt band are much larger than inertia forces in the anchors.

4. Environmental considerations do not affect the outcome.

Hence the seat belt band can be appropriately modeled by a massless object, which is not affected by friction on the shells. The anchors can be modeled by flexible objects which are driven completely by the belt and are not obstructed by the environment. Earlier versions of the software had taken into account frictional forces, but the results showed that the influence of the friction to the scale readouts is negligible. Therefore no friction is taken into account in the current version.

The essential concept of the belt routing simulation is to consider the seat belt band as a wide, thin rubber band, which is fixed at its ends and is stretched across the eBTD shells, as shown in Figure 1. This rubber band is represented by a simple, dynamic, multi-body system consisting of particles connected with linear springs, called the *spring network*. Neglecting gravity, the simulation calculates the mechanical static force of equilibrium of the spring network subjected to certain constraints. The boundary conditions are the attachment of the network to the overall system with special anchors. Contact between the manikin CAD-Model of the BTD (eBTD) and the belt are also considered within the equilibrium conditions. Since the alignment, with respect to position and orientation of the anchors is not known in advance, the computation also provides corresponding anchor alignments.

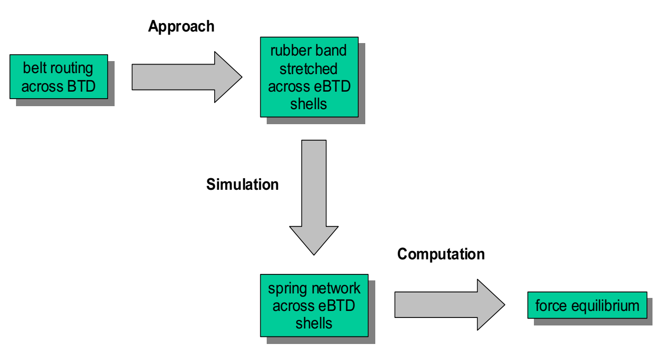

Figure 1: Basic concept of belt simulation

COMPONENTS OF THE SEAT BELT SIMULATION - The entire belt simulation essentially consists of the three components:

- Spring network representing the seat belt band
- Kinematic link chains representing the seat belt anchors
- CAD-Model of the BTD

These components are described in more detail in the subsequent sections.

Spring Network – As shown in Figure 2, the seat belt band is modeled by a network of massless particles connected by ideal massless linear springs, called the *spring network*. The network is structured as a matrix. Currently five particles are arranged along the transverse direction and an automatically determined number of particles are uniformly arranged along the longitudinal direction of the seat belt band. The number of particles is calculated so that the longitudinal distance of neighboring particles is approximately 15 mm.

An ideal linear spring is characterized by a default length, l_0, and a spring constant, c. For the length, l, of a deflection, the induced spring force, F, is given by

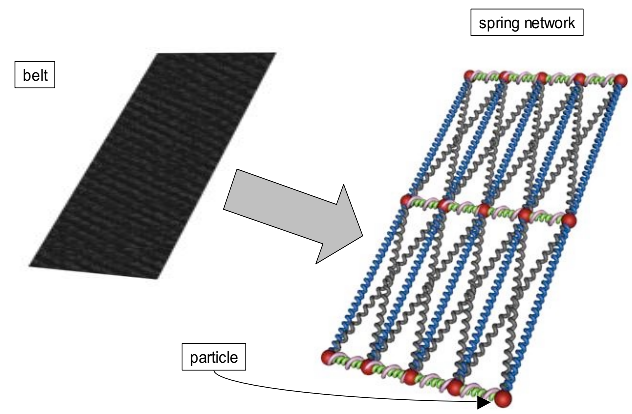

Figure 2: Representation of the seat belt band by a spring network

$$F = c(l - l_0)\,.$$

These springs tend to cause a deflection of a length equal to its default length, l_0. The amplitude of this deflection depends on the spring constant, c.

The particles are connected by the following types of linear springs as shown in Figure 3:

- Longitudinal: The essential movement of the belt is driven by the longitudinal springs. Since their default length is zero, the particles have a tendency to minimize the longitudinal distances between themselves, i.e. the network will be stretched in that direction.
- Lateral: The objective of these springs is to stabilize the local belt patch bordered by four adjacent particles as a band of constant width. Since four springs represent the seat belt width, their default length is one quarter of the belt width.

- Long lateral: The objective of the long lateral springs is to stabilize the belt as a band of constant width. Hence their default length is equal to the seat belt width.
- Diagonal: Two crossing diagonal springs in a local belt patch force opposite adjacent border particles, connected by lateral and longitudinal springs respectively, to be essentially parallel. This is supported by adapting the default length to the mean current lengths of both crossing springs. All belt patches (four adjacent particles) are equipped with these springs except for the border patches at the anchors. Omitting the diagonal springs in these patches allows the seat belt to run aslope into the belt edges of the anchors.

The stiffness constants for these four types of springs are set so that the final calculated seat belt routing fits to the available experimental seat belt routing data and the computation of the force equilibrium equations for the network is achieved. Currently the longitudinal and lateral spring constants are equal. The constant of the long lateral spring is one-half and the constant of the diagonal springs is one-tenth of the longitudinal and transverse spring constants.

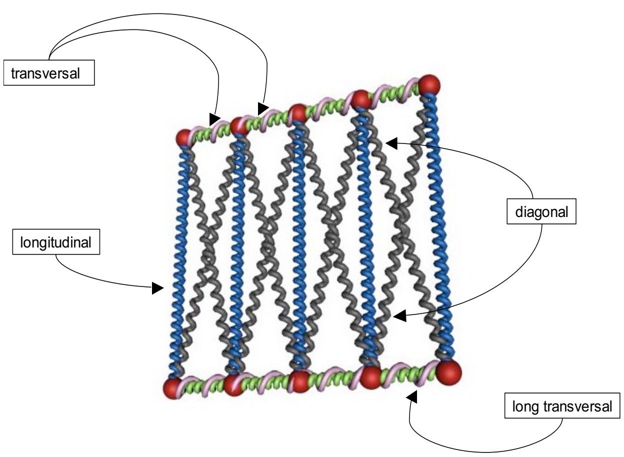

Figure 3: Different springs in the network

Seat Belt Anchors - All seat belt anchor kinematics are represented by kinematic link chains. These link chains are defined by the specification of link lengths and joint properties as degrees of freedom and ranges of motion. These kinematic chains are organized in classes. For each supported anchor class a corresponding link chain is implemented, which can be parameterized by values given by the user.

At the end of each link chain a corresponding seat belt edge is connected to the link chain. The length of this edge is equal to the seat belt width and a border particle row is uniformly fixed to this edge. In particular, particles cannot move across this edge. This means that in the case of the lower inboard anchor, particles do not move from the torso belt to the lap belt and vice versa during the simulation. The same is analogously valid for the upper outboard anchor with respect to the torso and retractor belt. The particles are distributed over the torso, lap and retractor belt in advance, so that approximately the same particle density (particle number per belt length) is achieved in the final belt routing. As an example see Figure 4 for the representation of the upper anchor.

While all anchor kinematics can be completely parameterized via the graphical user interface, anchor class B.2 plays an exceptional role. In spite of all other classes, this anchor possesses a continuous flexible part, which has no direct correspondence in a usual link

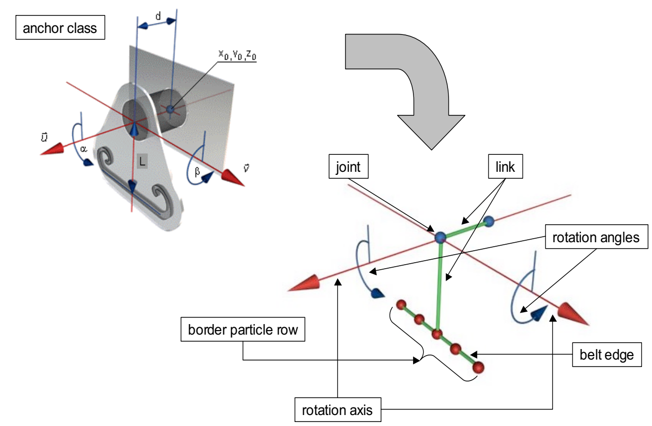

Figure 4: Representation of seat belt anchors

chain. Hence this part is uniformly discrete and approximated by a fine link chain as shown in Figure 5. Those joints are equipped with one range of motion, whose amplitude depends on the user specified stiffness parameter. This parameter ranges from softest (flexible) to stiff (rigid).

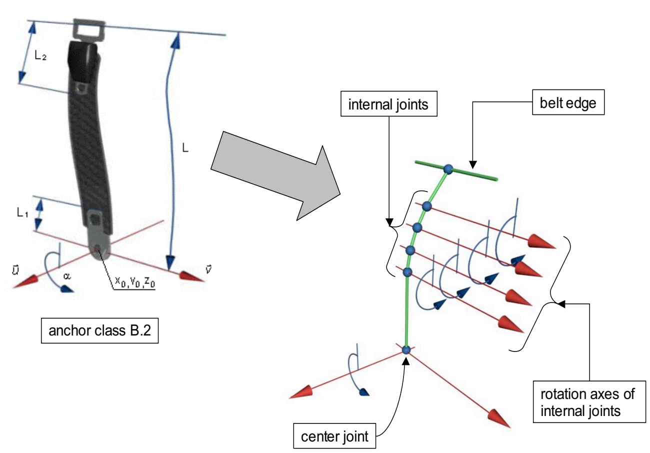

Figure 5: Representation of flexible anchor class parts

CAD Representation of BTD - The CAD-Model of the BTD, was generated in two steps. First CAD surfaces for the torso and lap shell, based on original data from *Biokinetics* [1], were constructed. In addition, the SAE geometric and kinematic representation of the BTD frame was generated in CAD. As a second step, both surfaces were positioned with respect to the frame. For this procedure several measured fiducial points on the scales of the BTD shell were used to correctly adjust the shells to the frame as shown in Figure 6 & 7.

For the belt routing simulation the torso and lap shell surfaces are approximated by triangle surfaces. The

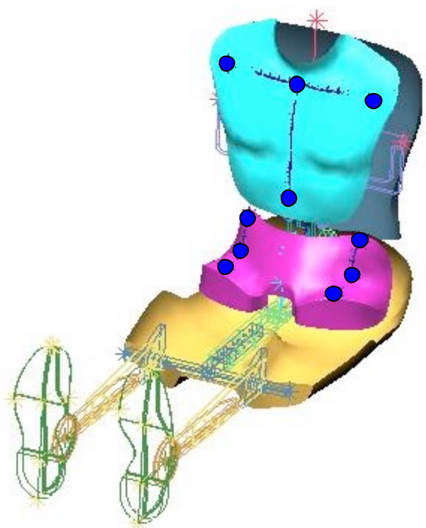

Figure 6: Fiducial points on BTD scales

density of this triangulation is defined by the following two criteria:

1. Maximum distance of the triangles to the shell surface is less than 1.85 mm.
2. Maximum deviation between normal vectors of adjacent triangles is less than 12.5°.

The above requirements dictate that the triangular surfaces will be an appropriate and smooth representation of the original shell surfaces. Therefore, the surface for the torso shell contains about 1,200 triangles and the surface for the lap shell about 1,800 triangles.

The eBTD is assembled by positioning the overall CAD BTD frame while the shells are attached to it. The position of the frame is defined by the following parameters derived from the BTD setup procedure [1]:

1. 3D-Coordinates of BTD H-Point
2. 3D-Coordinates of right BTD Heel Point (y-coordinate automatically adjusted to eBTD dimensions)
3. Inclination of the BTD torso

4. The ankles of the eBTD are rigid.

<u>Computation of Seat Belt Routing</u> - As mentioned above, the final belt routing is simulated as a linear spring network subjected to static equilibrium. Since there is no closed form solution possible for the corresponding equilibrium equations, the solution of those equations has to be calculated numerically using an iterative approach. The nature of the iterative schemes is highly dependent on the initial configuration. Successive iterations of the configurations are calculated until a termination criterion is fulfilled.

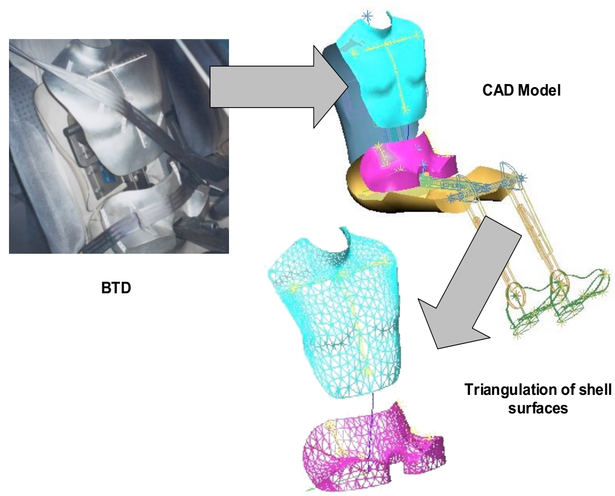

Figure 7: eBTD: CAD representation of BTD

<u>Belt Initial Positioning</u> - The method of determining the initial seat belt routing makes use of the position of the eBTD, in particular, of the torso and lap shells, and of the anchor definitions and locations. An initial seat belt routing is then calculated, which is a simple estimation not far from the expected final seat belt routing and runs on the outer side of the shells. To be more precise, the shape of the seat belt routing is considered as a polygon of three pieces. The middle part of the polygon is determined by certain reference points fixed to the corresponding scales and is connected at its ends to the anchors in their default alignments except for the lower inboard anchor, which is automatically aligned to the middle part of the initial lap belt. The initial retractor belt routing runs linearly from the upper anchor to the fixation to the car body.

Figure 8 illustrates the initial seat belt routing for the torso and lap belt.

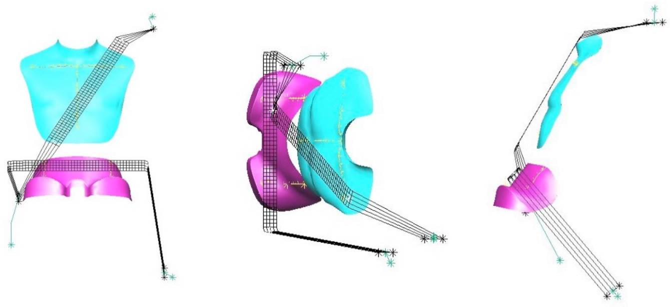

Figure 8: Initial positioning of seat belt.

ITERATIVE APPROACH:

Equilibrium conditions - The calculation of the static mechanical equilibrium of the spring network primarily affects the position of the particles. Since the border particles are fixed to the link chains representing the anchors, the particle positions affect the alignment of the anchors.

Rigid particle equilibrium - In each iteration step, all current forces induced by the springs are calculated, in particular the total resulting force in each particle:

$$F_{result} = F_{longitidual} + F_{lateral} + F_{longlateral} + F_{diagonal} \, .$$

Depending on the total resulting forces, the particles are moved towards the static equilibrium configuration (Figure 9). This results in new positions where the resulting forces are smaller than in the current positions. Due to the structure of the springs network, torques do not exist and hence are not part of the equilibrium equations.

Small resulting forces in all particles indicate that the equilibrium configuration is reached. Hence the termination criteria consist of checking the resulting forces and movement steps of the particles respectively against a given tolerance of 0.05 mm. The simulation process stops, when a given number of iteration steps is reached or termination criteria are fullfilled.

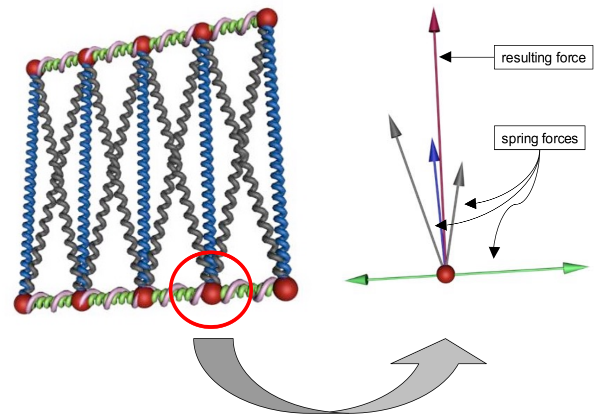

Figure 9: Movement of the belt representing particles

Anchorage simulation - The movement of the particles described above is free and unrestricted in space. But all border particles fixed to the anchors are subjected to the range of motions in conjunction with the link lengths of the kinematic chains modeling these anchors i.e. they have to be located on the reach envelopes of the link chains. Hence the movement of these particles in space induced by the static mechanical equilibrium has to be transformed into joint rotations. This is done with moments that are induced in each joint by the spring forces in the border particles. These moments are not affected by internal inertial forces of the anchors. The moments are projected to the current rotation axes of the joint and transferred into joint rotation angles (see Figure 10). All rotation angles combined define the new alignment of the anchor, whereby these angles are restricted to the range of motion given by the user.

Small rotation angles in all joints indicate that the equilibrium configuration is reached. Hence the termination criteria consist of checking the rotation angles of the joints against a given tolerance of 0.01°. Moreover, these criteria are combined with the corresponding ones given above.

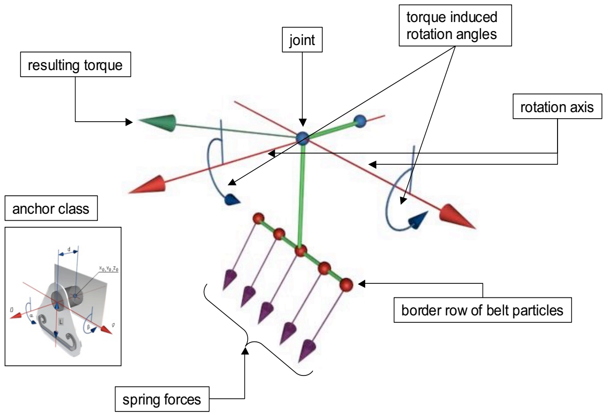

Figure 10: Rotation of anchor

Contact between different components - The movement of the belt is only restricted by the anchors. The torso and lap shells are considered by a separate contact algorithm between the particles and shell the surfaces.

The anchors are assumed not to be obstructed by environmental objects. Hence there is no contact control of the anchors except for the seat belt edge, which is implicitly checked for all the particles in the vicinity of the edge surface.

Contact check - All particles of the spring network have either the status *free* (positioned free in space) or the status *contact* (positioned on a shell). At the beginning of the calculation all particles of the initial seat belt routing have the status *free*.

The movement for all *free* particles is calculated as explained above. Before the particles are moved to the new positions, the algorithm checks if particles would penetrate triangles of the shells. In that case the corresponding movement is restricted and the particle is placed on the intersection point on the shell and gets the status *contact*.

The movement for all *contact* particles is calculated as described below. Before the particles are moved to the new positions the algorithm checks if particles would leave the triangles of the shells. In that case the particle gets the status *free* again.

Figure 11 illustrates the movement of one particle, which changes from *free* to *contact* and back to *free* movement.

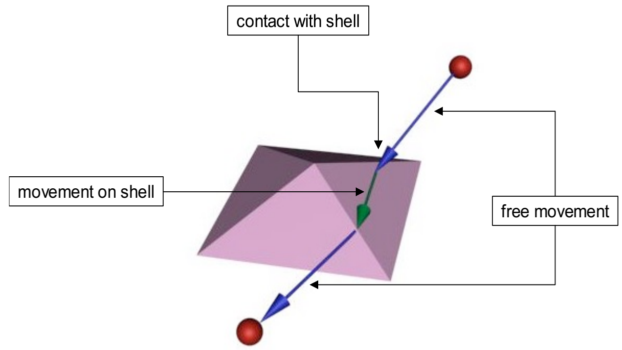

Figure 11: Particle movement relative to shell

Rigid particle Movement - As a particle is located on a shell, in particular on one triangle of the shell, the calculation of the movement is adapted to the new situation. In a first step the movement is determined and in a second step the resulting force is projected onto the triangle where the particle is located, if the force direction is to the inner side of the triangle and the shell respectively. This projected force is assumed to be not affected by friction forces caused by the shells. Depending on this modified force the particle is moved towards the static mechanical equilibrium configuration. During one iteration step a particle on a triangle moves at most to the border of the triangle, while longer steps are cut at the border. A simple example of a movement on a triangle is shown in Figure 12.

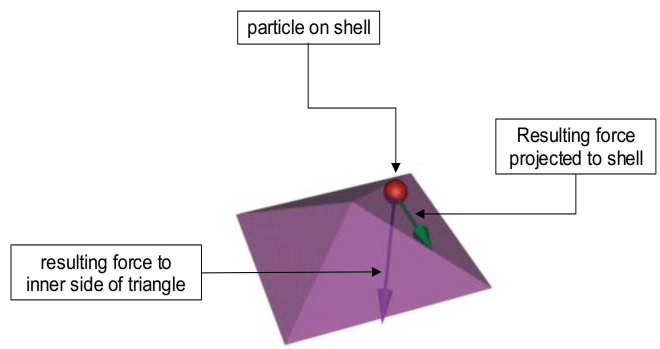

Figure 12: Projected force on shell

Determination of Scale Values - The scale values of the final belt routing are determined according to the BTD manual [8]. Firstly all elements, comprising the eBTD with scales and the belt routing, is projected onto an xz-plane. Secondly, the relevant belt edges are intersected with the corresponding scales (torso belt: lower edge, lap belt: upper edge). Thirdly, the scale readouts are determined (Figure 13). Moreover, the algorithm checks whether at least one edge of the seat belt band touches the scale for each scale readout. Using this information, together with the pass/fail criteria, the algorithm provides the values of the scale readouts and indicates by green/red colors whether the pass/fail criteria are fulfilled. If no seat belt edge touches the scale, the corresponding scale readout is automatically marked by *fail* and no value is displayed.

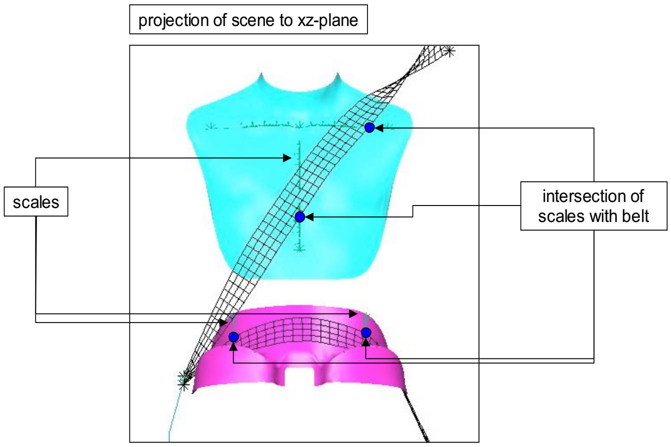

Figure 13: Determination of scale values

***e*BTD EVALUATION** – The issue of variability of physical measurement is commonly known in all engineering endeavors that involves modeling and simulation of a physical quantity. The eBTD model is no exception. Verification and Validation (V&V) of such model has been an essential development objective of the software. A software developer performs software V&V to ensure code correctness, reliability and robustness. The objective of the eBTD model V&V is to ensure that the end product is a predictive model based on fundamental physics of the problem being solved.

eBTD VERIFICATION AND VALIDATION PROCESS - Since the eBTD is intended to be used as a simulation tool in the design process as well as a virtual certification tool, a V&V process is required to quantify the level of confidence in the predictions made with the models built using this software. The expected outcome of the V&V process is the ability to quantify the level of agreement between experimental and predicted results, as well as quantify the accuracy of the numerical models when used in a predictive mode.

Verification and Validation definitions used in this report are adopted from [10]:

- ***Verification*** is the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution approach.
- ***Validation*** is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

Verification and Validation are processes that collect evidence of a models correctness or accuracy for a specific set of parameters; thus, V&V cannot prove that a model is correct and accurate for all possible conditions and applications, but rather provide evidence that a model is sufficiently accurate. Therefore, V&V are ongoing activities that end when the desired sufficiency is reached.

Verification is concerned with identifying and removing errors in the model by comparing numerical solutions to analytical or highly accurate benchmark solutions.

Validation, on the other hand, is concerned with quantifying the accuracy of the model by comparing numerical solutions to experimental data.

In short, verification deals with the mathematics associated with the model, whereas validation deals with the physics associated with the model. Because modeling and/or mathematical errors can cancel, giving the impression of correctness (right answer for the wrong reason), verification must be performed before the validation activity begins.

Following the above logic, the software developer (Human Solutions Inc.) followed a mathematical based ***verification*** approach, to assure that the mathematical model perform as formulated. Therefore, it thought a **D**esign **O**f **E**xperiment (DOE) approach to take into account the effect of the greatest number of variables that affect the results. This approach enables the analysis to be carried out of the effects of different errors on the computations and as such, seeks to address as many sources of variability as possible. Since the determination of the error bounds is a mathematical objective of the eBTD model development, it was logical to rely on a DOE approach to assess these errors. Accordingly variability had to be dealt with as an outcome of the DOE approach. Human Solutions's evaluation approach was designed such that the necessary input parameters were measured or deduced out of measurements in real vehicles. The idea behind this approach is to eliminate the manufacturing tolerances and to consider the real position of the eBTD in the vehicle of interest, i.e. the scenario is reconstructed in the simulation software exactly as it can be observed in reality. The resulting calculated scale values were compared with values taken from experiments with real vehicles of the corresponding make and model. From the available 34 data sets, 15 vehicles were considered for comparison. The mean differences for the individual belt fit scales using data corrected to match the position of the eBTD were in the range of -0.2 cm and -0.7 cm with corresponding standard deviations of 0.8 cm and 2.5 cm. With corrections to the anchorages, then the mean differences range from 0.1 cm and -0.3 cm with corresponding standard deviations of 0.3 cm depending on the specific interpretation of the tests [12].

The above verification effort was followed by a number of physical tests by Biokinetics [13] with the objective of ***validating*** the physical phenomenon. In these tests, it was necessary to follow an approach that seeks to reduce, and perhaps eliminate the sources of variability and errors. Biokinetics used design data as input parameters to run the belt routing simulations. Design data in this context corresponds to parameters that are measured or derived from CAD drawings. These data were provided by vehicle manufacturers for the vehicles tested. The resulting calculated belt score values were then compared with values measured in experiments with real cars of the same make and model. The deviations between the measured and the calculated scales were in the range of -7.0 cm and 3.0 cm. While the discrepancies are large, a statistical test that compares the average deviation between measured and calculated scale values could not be conducted since the evaluation was based on four vehicles only.

Further validation tests are under way to provide evidence that an eBTD model is sufficiently accurate, and to define the sufficiency criterion for model adequacy.

PROSPECTS

In Addition to further refinements of the simulation methodology, the described approach can be transferred to other fields of applications as the results can be used as input parameters for these fields.

ENHANCEMENT OF SIMULATION – To enhance the current simulation further developments are underway. First a contact between belt webbing and anchor kinematics and the eBTD elements is being developed. This is necessary to achieve better results for some scenarios in which a contact of the belt and interfering geometries of the upholsteries occurs.

Second, for the definition of some anchor kinematics a stiffness parameter is necessary. To describe this important influence more realistically a calibration procedure was developed to measure the stiffness properties. By inputting force and deflection values measured in tests into the software an automatic calibration defines the spring rates of the according anchor class.

Furthermore, an extension of the anchor kinematics library will enlarge the use of the simulation software by enabling the coverage of a higher number of scenarios. Here two principal approaches are conceivable: To incorporate the kinematic properties of existing anchors or to provide a kit that enables the user to define his own anchor kinematics.

In an early design phase the principal package of the occupant compartment is known but often not necessarily the details of the interior design that could possibly influence the belt routing significantly. Examples are the contours of the seat pan and the back rest in case a contact between the belt and the upholstery occurs. Consequently a generic seat with morphing functionalities to adapt to the seat is of great potential.

Depending on the principal design of the seat belt and its anchors different twists of the belt in buckled up conditions can be observed. A functionally to define this twist is needed in future development.

TRANSFER OF TECHNOLOGY ONTO HUMAN MODELS – Since the BTD represents one anthropometric type in one situation, huge benefits may result from transferring the described technology to human models representing occupants of different size and gender. Thus whole populations represented through manikins with different anthropometric properties in many postures can be analyzed. The belt routing can be assessed in a general sense, i.e. whether the belt lies too close to the neck or too close to the shoulder or even on the upper arm (Figure 14). Additional checks can be performed in the case where the human model represents a bony structure, i.e. the basis for the original BTD criteria, or where the belt stretches over the bony structures of the torso (Figure 15).

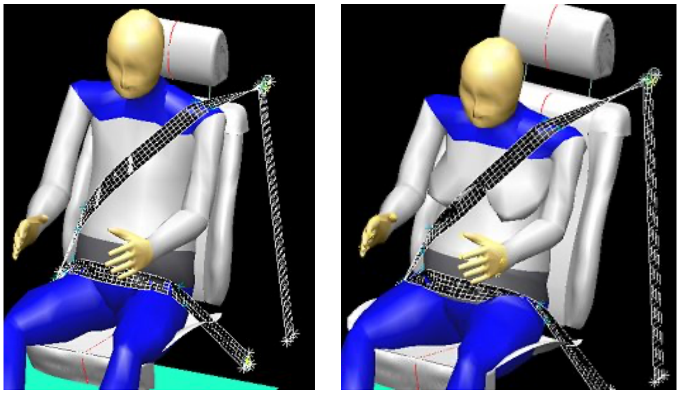

Figure 14: Belt routing for different RAMSIS manikins

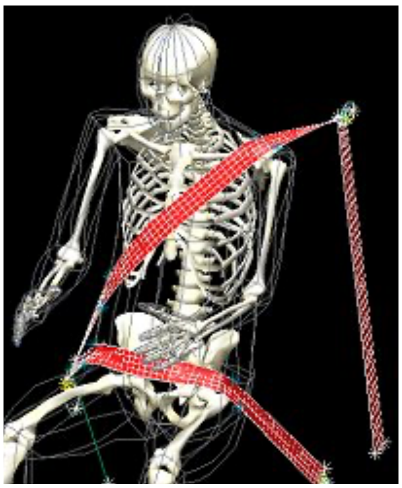

Figure 15: Belt routing and bony structure of RAMSIS

USAGE IN RELATED AREAS – There are many fields of application in which a realistic 3-dimensional model can be used. Firstly, besides testing an existing belt restraint package with given seat travel path and given anchor kinematics and applicable adjustments, the belt routing module can be used to find optimal locations, types, and adjustments of anchors. Secondly, it is conceivable to use the simulation results to provide a first estimate of the perceived comfort. Here, contact surface detachment points from the torso, and angles in which the belt leaves the human body could be used as input parameters for future simulation models.

CONCLUSION

Transport Canada introduced a physical test device to assess the seat belt routing over human bodies to prevent abdominal injuries. A software module was developed to estimate the pass or fail of a belt restraint package already in existing in the early CAD design phases as well as to avoid the expenses and effort required to fabricate and validate prototype systems.

The main influenctial parameters tackled are: contact, kinematics, static equilibrium etc. The software module being developed is undergoing continuous evaluation and enhancement to assure numerical predictability that is close to physical reality. Initial evaluations have proven successful and future versions may be even more promising since new functionalities would be included to reflect maturing technologies. The software also offers great potential for use for other related areas.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

BTD: Belt Fit Test Device

eBTD: Electronic Belt Fit Test Device

JWG-AIR: Joint Working Group – Abdominal Injury Reduction