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TNO Crash-Safety Research Centre

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A Mathematical Human Body Model for Frontal and Rearward Seated Automotive Impact Loading

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ABSTRACT

Mathematical modelling is widely used for crash-safety research and design. However, most occupant models used in crash simulations are based on crash dummies and thereby inherit their apparent limitations. Several models simulating parts of the real human body have been published, but only few describe the entire human body and these models were developed and validated only for a limited range of conditions.

This paper describes a human body model for both frontal and rearward loading. A combination of modelling techniques is applied using rigid bodies for most body segments, but describing the thorax as a flexible structure. The skin is described in detail using an arbitrary surface. Static and dynamic properties of the articulations have been derived from literature. The RAMSIS anthropometric database has been used to define a model representing a 50th percentile male.

The model has been validated using volunteer tests performed at NBDL ranging from 3-15 G severity, and using established dummy biofidelity requirements for blunt thoracic impact. A satisfactory prediction has been obtained for chest deflections, head kinematics and accelerations and for kinematics and accelerations at the upper thoracic vertebra (T1).

Recommendations are given for further development and validation of the model, and for validation of models of different body sizes.

INTRODUCTION

Current crash-safety design and research is largely based on mechanical human body models (crash-dummies). In addition to mechanical testing, mathematical modelling is widely used. However, most occupant models used in crash simulations are based on crash dummies and thereby inherit apparent differences between dummies and the real human body. Mathematical modelling of the real human body potentially offers improved biofidelity and allows the study of aspects like body size, posture, muscular activity and post fracture response. Detailed human body modelling potentially allows analysis of injury mechanisms on a material level.

A large number of models describing specific parts of the body have been published but only a few of these models describe the response of the entire human body in impact conditions. Models simulating the response of car occupants have been published for lateral loading (Huang et al. 1994a, 1994b; Irwin 1994), frontal loading (Ma et al., 1995), and rearward loading (Jakobsson et al., 1994, Kroonenberg et al. 1997). A model for vertical loading has been published by Prasad and King (1974) and pedestrian models have been published by Ishikawa et al. (1993) and Yang et al. (1997).

This paper provides a step towards an "omni-directional" human body model for impact simulation. A model representing a 50th percentile male is presented and validated for frontal loading. The model is an extension of the human model by Kroonenberg et al. (1997) which was validated for rearward loading. To provide an efficient and robust design tool, the model has been developed using multibody techniques. A detailed description of the outside geometry (skin) has been obtained using an arbitrary surface. The anthropometry of the human model presented is based on the RAMSIS database (Flügel, 1986; Geuß, 1994; see further Appendix A).

MODEL SETUP

The model has been developed aiming at omni-directional biofidelity where the highest priority was given to the torso and the head-neck system. The model has to provide a biofidelic interaction with the seat back which requires a realistic surface description for pelvis, spine, thorax, neck and head. The whole spine has to be biofidelic in forward/rearward bending but also in compression/elongation and the surface description of the model has to be coupled realistically to the spinal model. An accurate prediction of head kinematics and neck loads is needed. For frontal impact the model has to provide a biofidelic interaction with belts and airbags which requires an accurate surface description for the frontal area of upper and lower torso. Especially for the sternal area a realistic prediction of the chest deflection is needed.

The model was set up for optimal efficiency and robustness. This has been achieved using multibody techniques available in MADYMO version 5.3.1. Most skeletal structures have been modelled as rigid bodies connected by joints. Deformation of the rib cage has been accomplished using flexible bodies (Koppens et al., 1993). A detailed model of the outer surface (skin) has been implemented as an "arbitrary surface". The lumped joint resistance resulting from ligamentous and muscular tissues has been implemented using non-linear stiffness functions and energy dissipation was implemented using hysteresis or damping.

ANTHROPOMETRY – In the area of vehicle crash-safety design, limited attention is being paid to variations of body size. For adults, current regulations prescribe testing with dummies representing a “50th percentile male” only. For frontal impact two other dummy sizes are available representing a small female (5th percentile) and a large male (95th percentile) (Mertz et al., 1989). A small female dummy for side impact has been introduced as well (Daniel et al., 1995). Due to the time and cost involved in design and production of new physical dummies the number of available dummy sizes will remain limited. Where the current dummy sizes do represent variations in length and the associated body mass they do not cover variations in body proportions. Published anthropometric human body models do describe such variations in body proportions.

In impact simulations GEBOD is often used to generate models representing arbitrary body sizes. GEBOD produces geometric and inertia properties of human beings (Baughman, 1983). Joint resistance models for an adult male GEBOD model are described by Ma et al. (1995). GEBOD generates a model consisting of 15 segments: head, neck, upper arms, lower arms, thorax, abdomen, pelvis, upper legs, lower legs and feet. Computations for the geometrical parameters and mass distribution are based on a set of 32 body measurements. From these 32 parameters body segment sizes and joint locations are derived. Segments are described by ellipsoids except for the thorax and feet where more complex approximations (so-called elliptical solids) are used. Inertial properties are estimated by calculating the inertial properties of each segment ellipsoid or elliptical solid, assuming homogeneous body density. The 32 body parameters can be measured at a subject or can be generated by GEBOD using regression equations on the basis of body height and/or weight for both adult males and females. For children, regression equations are available on the basis of height, weight, age and combinations of these parameters. A major limitation of GEBOD is the approximation of body segments by simple geometrical volumes.

In our study the RAMSIS model has been used as main anthropometry source. Detailed information and further references with respect to the RAMSIS model can be found in Appendix A. RAMSIS has primarily been developed for ergonomic analyses and allows the generation of models with a wide range of anthropometry parameters. The RAMSIS model describes the human body as a set of rigid bodies connected by kinematic joints and the skin is described as a triangulated surface. We have chosen RAMSIS as a basis for our human model for the following reasons:

1. RAMSIS provides a detailed geometric description of the body segments based on extensive anthropometric measurements on various civilian populations including automotive seated postures. The skin of the entire body is described as one “continuous” surface. Segment mass and centres of gravity are derived in RAMSIS using this realistic geometric description.
2. Anthropometric studies have shown that the body dimensions of each individual can be classified according to three dominant and independent features. These features are body height, the amount of body fat, and body proportion, i.e. the ratio of the length of the limbs to the length of the trunk. Using this classification scheme RAMSIS describes the entire population in a realistic way. This method takes into account correlations between body dimensions which are disregarded in GEBOD. (For instance tall persons typically have long legs combined with a comparably short trunk.)
3. RAMSIS provides a mathematical prediction for the increase of the average body height of the entire population during a given time period (“secular growth”).

A translator has been developed to convert RAMSIS models into MADYMO models. The conversion can be performed for any anthropometry specified in RAMSIS and examples of such models are shown in Figure 1.

In this study a "50th percentile" male model from RAMSIS has been converted to MADYMO and extended to allow crash simulation. Only this one body size was studied, since most of the available validation data represents such a 50th percentile male. For this purpose a RAMSIS "50th percentile" male model was created as specified in Appendix B. Due to the selected reference year (1984) this model is only about 2 cm taller than the 50th percentile Hybrid III dummy (see further Appendix B).

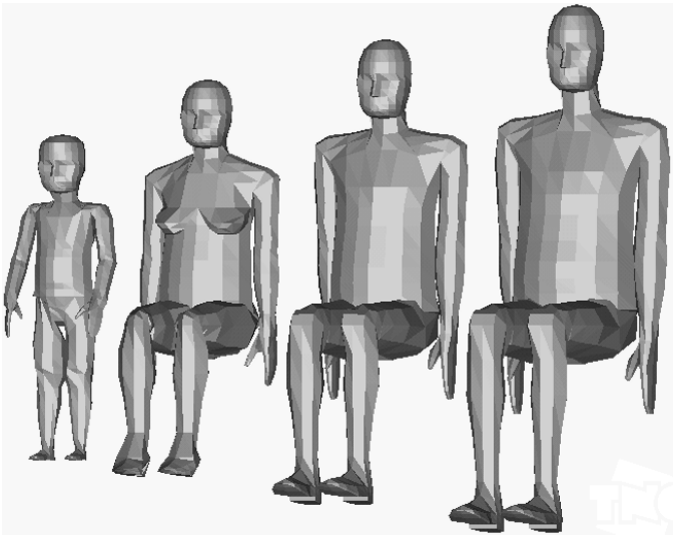

Figure 1. MADYMO human models of various body sizes generated from the RAMSIS model, from left to right: 3 year old child, extremely small female, 50th percentile male, extremely large male.

This RAMSIS human model was converted to MADYMO which provided: joint locations, joint ranges of motion, segment masses and centres of gravity, and a triangulated skin connected to various body segments. This model was extended as follows. Rotational inertia was derived by integration over segment volume. Here for each segment a homogeneous density was assumed. Joint resistance models were added and joints were added in the spine as described below for specific body parts.

SPINE AND NECK – The spine model including the neck is based on a human model validated for rear-end sled tests with volunteer and cadavers up to 30 km/h (Kroonenberg et al. 1997). In this model all vertebrae are modelled as rigid bodies. Joint translational and rotational resistance has been implemented using lumped joint resistance models based on Prasad and King (1974) and de Jager et al. (1996). These resistance models represent the dynamic response and include effects of muscular resistance in a global manner. The model by Kroonenberg et al. (1997) was limited to loading in the midsaggital plane. For the current model realistic lateral bending properties were added using data from Kapandji (1974). Where the RAMSIS model contains only 7 joints in the whole spine, now 25 joints are specified. Figure 2 shows joint locations in the current model and in Figure 3 these joint locations are shown together with those of the RAMSIS model. Joint locations in thoracic spine and neck were chosen slightly in front of the location of the RAMSIS joints in order to obtain a joint-skin distance corresponding to Kroonenberg et al. (1997). Figures 2 and 3 show the spine models in the neutral position which has been defined according to the RAMSIS model and thereby represents the mild spinal curvature of a standing person. The range of motion of the whole spine model was found to match the RAMSIS model.

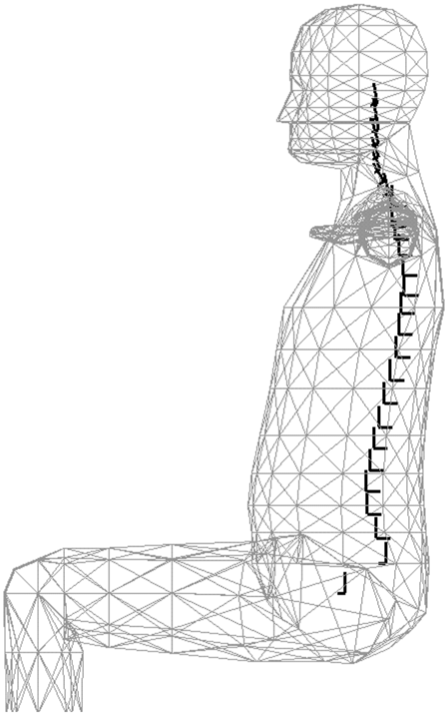

Figure 2. The skin of the model in lateral view with joint locations of spine, neck and hips shown as markers.

Figure 3. Spine, neck and hip joint locations of the current model (markers) and of the RAMSIS model (solid line).

THORAX – In impact the human thorax deforms in a complex 3D manner due to contacts, but also due to spinal deformations. For the current study it was considered sufficient to have a realistic prediction of the chest deflection in blunt frontal impact. Such a prediction of chest deflection is needed to evaluate belt and airbag interactions and is also available in the Hybrid III dummy.

The thorax model consists of 7 flexible bodies (Koppens et al., 1993) which have been selected in such a way that in blunt frontal thoracic impact the combination of these models shows the same response as the model by Lobdell (1973).

SHOULDERS – The shoulder mechanism forms a moving base for the upper extremity. It contains a number of joints connecting the humerus, the scapula, the clavicle and finally the sternum. Furthermore, the scapula contacts the back of the thorax; it can glide over the so-called scapulothoracic gliding plane. This connection makes the shoulder a closed chain mechanism.

In the model the clavicle, scapula and humerus are represented as rigid bodies connected by spherical joints. The clavicles are connected with a spherical joint to the upper sternum, which is part of the thorax model described above. In the real human body, the scapula contacts the thorax. Active muscle force is needed to maintain this contact and to stabilize the shoulder girdle. These complex interactions between shoulder and thorax have been modelled as a set of passive force models. The scapula is supported on the spine with spring-damper models (point restraints) at several vertebral levels. Thus the load transfer from shoulder to spine is modelled by the skeletal connection (scapula-clavicle-sternum-ribs-spine) and by these additional force models. The resulting resistance of the shoulder model was verified against published quasi-static volunteer data. A following step will be to collect relevant dynamic response data and data enabling separate verification of the different model components.

LIMBS – The limbs have been modelled as rigid bodies connected by joints. All joints are described as spherical joints and thereby describe three rotational degrees of freedom. Degrees of freedom, in which voluntary movement is not possible are also included since in impact some passive bending is possible in all rotational directions in all human joints. The resistance parameters are based on literature data on human passive joint properties (Engin et al., 1979-1989, Kapandji 1974, Ma et al., 1995). The model contains a 3-segment thumb and a 3-segment description of the combined fingers. Currently the joints of thumbs and fingers are locked and thereby the hand behaves as a rigid segment. The rotations of the toes with respect to the foot are also locked for simplicity.

ARBITRARY SURFACE DESCRIPTION – Traditional contact algorithms used in crash simulations describe interactions between analytical surfaces like ellipsoids, planes and cylinders, and also finite elements. Recently a contact algorithm has been developed for “arbitrary surfaces” (MADYMO, 1997). Arbitrary surfaces consist of triangular or quadrangular facets which are supported by nodes (vertices) on rigid bodies and/or flexible bodies. Contact can be simulated with other arbitrary surfaces, with ellipsoids, planes and cylinders or with finite elements. In these contacts the compliance of the materials is taken into account by allowing penetrations in the contacting surfaces. For each node of the facet surface the local contact stress is calculated applying a user-defined function of the penetration. The contact force on each node is obtained by multiplying the calculated contact stress by the area around the node. This contact force is transferred from the surface model to the applicable rigid body or flexible body.

The outer surface of our human model (skin) is described as an arbitrary surface consisting of 2174 triangular facets connecting 1068 vertices (nodes). This surface is largely supported by rigid bodies. However, in the thorax area the skin is supported by flexible bodies. This allows the thorax skin to “continuously” deform in response to contact loading and spinal deformation. Currently surface compressive properties are taken from Hybrid III dummy model properties.

POSTURE MAINTENANCE – Lumped joint resistance models have been implemented which include the passive and active muscle response in a global manner. However these joint models have insufficient resistance to maintain specific postures when simulating gravity. In crash-dummies posture maintenance is simulated by using so-called 1G friction settings. For the mathematical model a similar effect has been obtained as follows. For the postures studied first a static simulation with locked joints and with gravity was performed. This simulation provided the muscular torques needed at the joints to counteract gravity. These torques were applied using Hill type muscle models. These were implemented as joint actuators; they were implemented as torque generating components. This torque is a non-linear function of the joint rotation velocity (see Winters and Stark, 1985). The force-velocity relation was based on recent data for eccentric contraction at high strain rates. Krylow and Sandercock (1997) report eccentric forces more than twice the isometric force. Cole et al. (1996) were able to accurately reproduce eccentric loading data from Joyce et al. (1969) and Walmsley and Proske (1981) with a Hill type model. They estimated eccentric forces increasing asymptotically to 2.3 times the isometric force. This ratio was adopted for the posture maintenance model. In the volunteer validation results shown below the posture maintenance model was applied for all joints of the spine and for the hip joints. For the neck joints also some initial compression was simulated to obtain equilibrium for translations. The posture maintenance model was not included in validations based on PMHS responses.

VALIDATION

In order to evaluate the validity of the complete model the following validations were performed:

- volunteer sled tests with frontal loading,
- blunt thoracic impact,
- quasi-static lumbar bending.

A validation for rear-end loading using volunteer and PMHS responses has already been published by Kroonenberg et al. (1997).

FRONTAL SLED TESTS – Volunteer tests with frontal loading were performed at NBDL (Ewing et al., 1968, 1969, 1975, 1977). Sled tests ranging from 3-15 G severity were performed on volunteers restrained by a harness belt on a rigid seat. Accelerations were recorded using a head bracket and a lower neck bracket which was strapped to the back at T1 level. These tests were analyzed by Wismans et al. (1984, 1986) and by Thunnissen et al. (1995) resulting in response corridors. These corridors were used for validation of the whole human body model. The seat was modelled as two rigid planes. The harness belt was modelled using MADYMO conventional belts. Results for 15G, 10G and 3G are shown in Figures 4-6 respectively. For the 15G experiment the full range of validation results is presented. Accelerations are presented in local coordinate systems of head and T1 respectively. Displacements and rotations are presented with respect to sled and seat. The T1 rotation is based on the recent re-analysis from Thunnissen et al. (1995) where a correction was made for displacement of the T1 bracket with respect to the T1 vertebra.

The head X and Z displacements in Figure 4a demonstrate an accurate prediction of head kinematics. Satisfactory correlations have been obtained for head accelerations and rotations (Figures 4a, 5, 6) and for T1 displacement and rotation (Figure 4b).

FRONTAL THORAX IMPACT – To assure the biofidelity of the chest to blunt-frontal midsaggital impact performance guidelines have been derived (Neathery, 1974). Cadaver data was normalized, load levels were increased with 667 N to account for muscle tensing, and penetration was adjusted by subtracting 12.7 mm to indicate the internal sternum deflection. These requirements are accepted biofidelity requirements for crash dummies designed for frontal loading (SAE J 1460). In these tests the human body is placed in a sitting position on a flat, horizontal surface without back support. The arms and legs are extended horizontally and parallel to the midsaggital plane. The subject is placed in a position such that the surface of the thorax on the centerline of the impactor is vertical. The longitudinal centerline of the impactor has the same vertical height as the mid-sternum and lies in the midsaggital plane of the subject. The impactor has a cylindrical end of 152 mm diameter, a flat face and edge radius of 12.7 mm. The mass including instrumentation equals 23.4 kg. Response requirements are given for two impact velocities (4.27 and 6.71 m/s). Corridors are given as force-deflection curves. Validation results are given in Figure 7. In the model the force is derived from the impactor acceleration and the deflection is taken as the mid-sternum displacement with respect to the spine at T10 level. This internal displacement does not include the contact penetration of the impactor into the sternum surface. In the simulations this penetration was found to be about 8 mm for both loading severities which is close to the 12.7 mm penetration assumed for correction of the original data by Neathery (1974). The results in Figure 7 show that the impactor force is slightly underestimated for both impact velocities. However, as mentioned above the forces as measured on cadavers had been increased with 667 N to account for muscle tensing. Thus the model correlates better with the uncorrected forces. The thorax validation has been performed using the complete human model with unsupported back. Thus it shows that the combined thorax-spine model matches chest deflections and impactor forces.

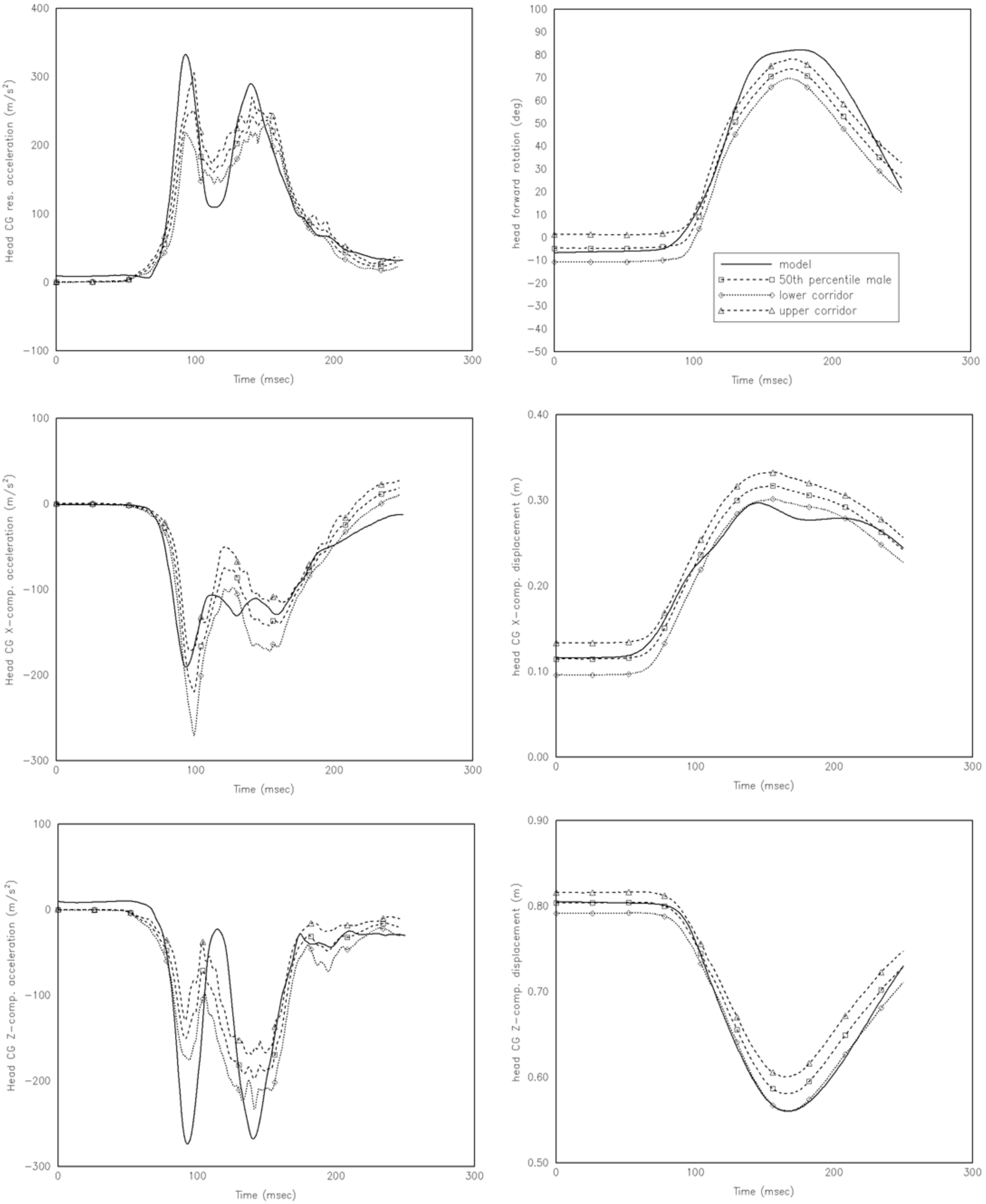

Figure 4a. Validation results for 15G frontal loading with harness belt on rigid seat (head).

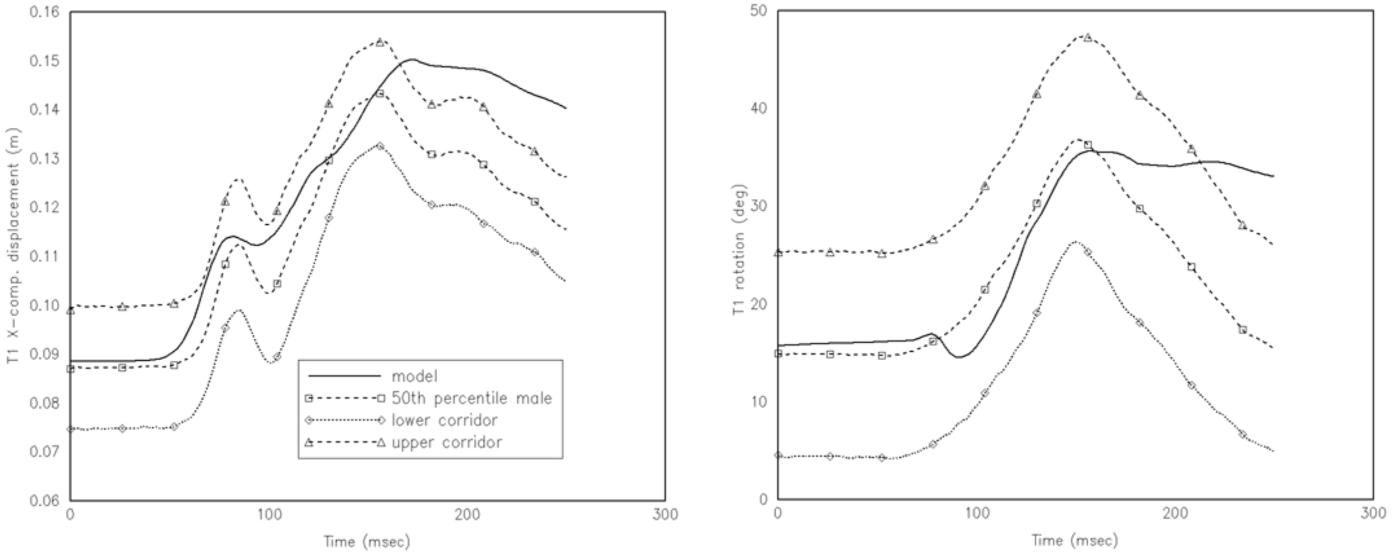

Figure 4b. Validation results for 15G frontal loading with harness belt on rigid seat (T1).

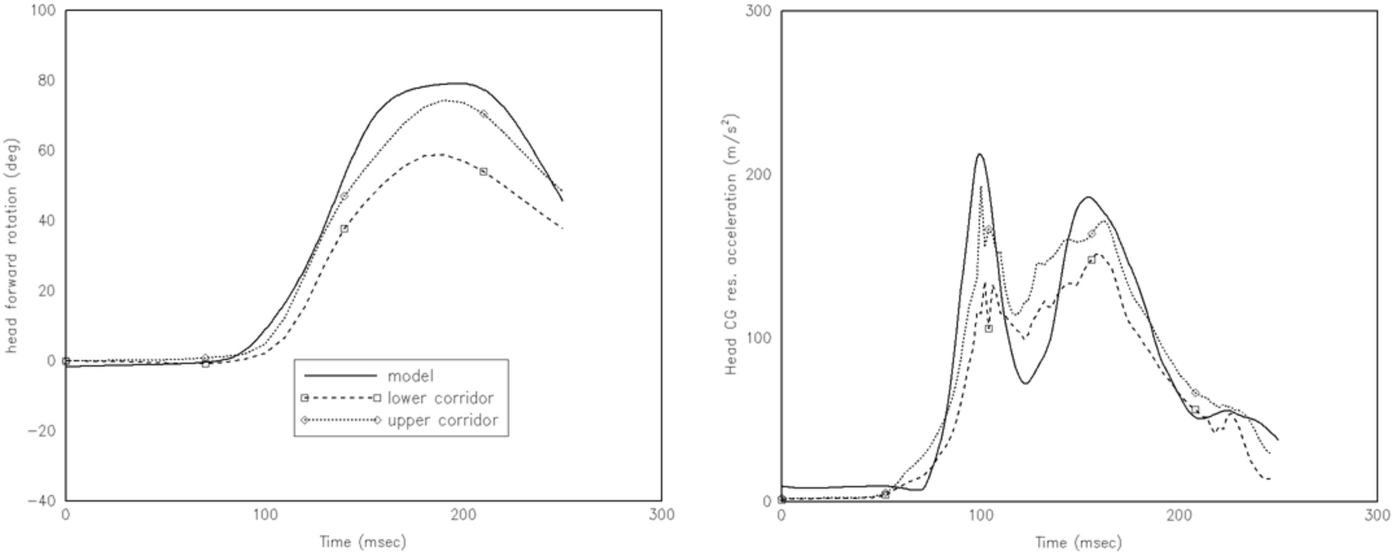

Figure 5. Validation results for 10G frontal loading with harness belt on rigid seat.

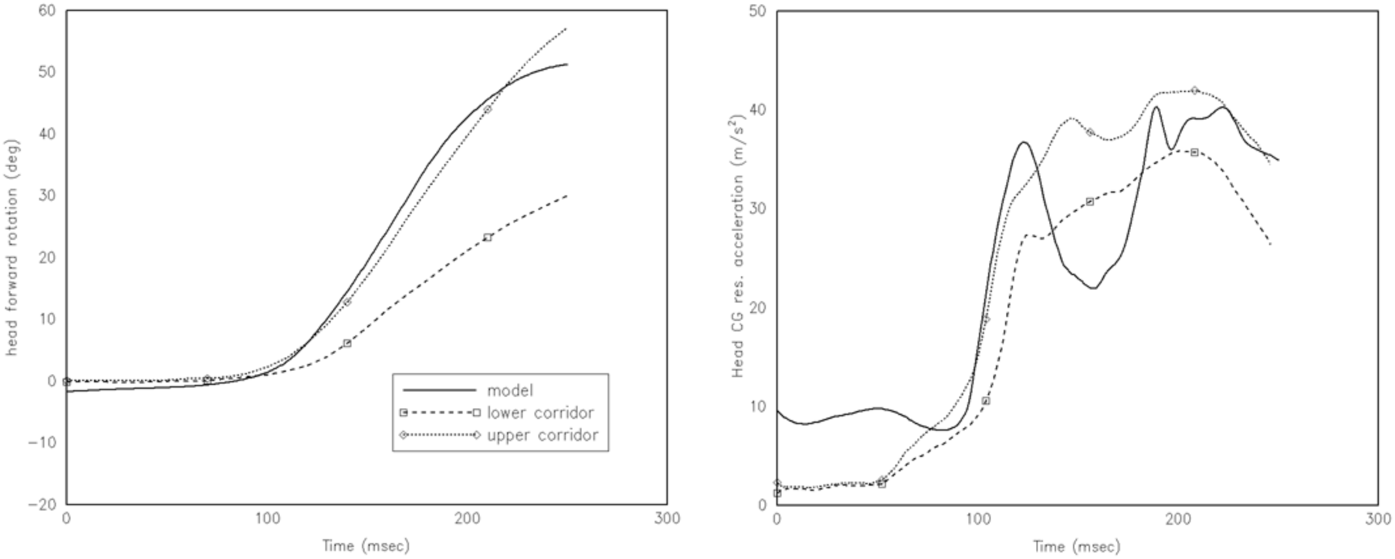

Figure 6. Validation results for 3G frontal loading with harness belt on rigid seat.

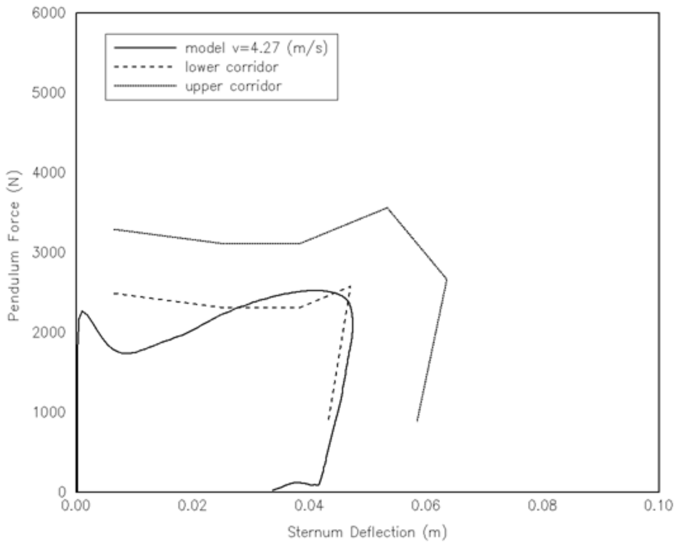

Figure 7a. Validation for 4.27 m/s blunt-frontal midsaggital impact to the thorax according to Neathery (1974).

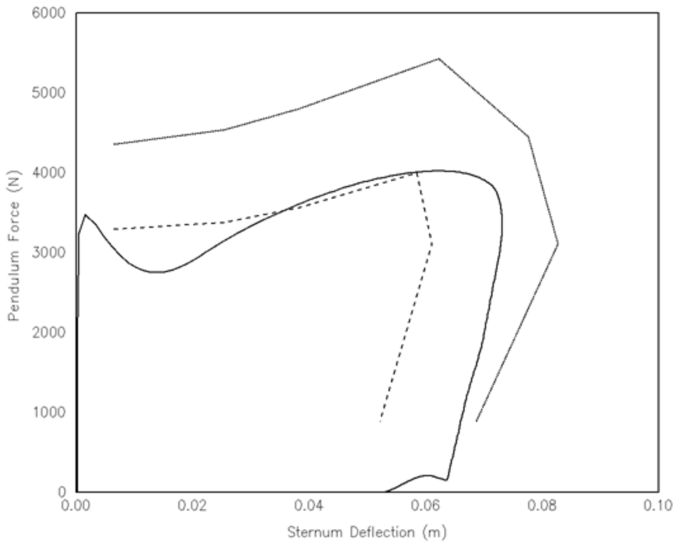

Figure 7b. Validation for 6.71 m/s blunt-frontal midsaggital impact to the thorax according to Neathery (1974).

QUASI-STATIC SPINE BENDING – The performance of the spine (S1-T8) in flexion and extension has been tested by comparison with experimental quasi-static data from volunteers. Nyquist and Murton (1975) carried out volunteer tests to determine the quasi-static bending response characteristics of the human lower torso for sagittal flexion (forward bending) and extension (rearward bending). The effects of muscle tensing and knee bend on the response were evaluated. Each test subject was positioned on his side with legs immobilized and upper torso supported by a dolly free to roll on the floor. Film analysis targets, posted and strapped to the subject, were referenced to the skeletal structure and monitored by an overhead camera during the test. A force applied near the shoulders provided a bending moment at the lower torso, causing lumbar bending and hip joint articulation. The data was analyzed to provide sixteen loading corridors of moment of applied force about the H-point axis versus thorax-pelvis relative angle and versus pelvis-femur relative angle. The thorax-pelvis angle is defined as the angle between the tangent of the human back at T8 and the line connecting the anterior, superior iliac spine and the pubic crest. The pelvis-femur angle is defined as the angle between the femur link axis and the line connecting the anterior, superior iliac spine and the pubic crest. A car occupant is usually seated, therefore only the corridors of the volunteers with their knees bent have been used. Figure 8 compares the quasi-static response of the model to corridors from Nyquist and Murton (1975) for relaxed and tensed subjects. The experimental corridors for flexion and extension do not match exactly because they were determined in slightly different initial positions. Apparently for both flexion and extension the model resistance is either within or slightly above the relaxed corridor.

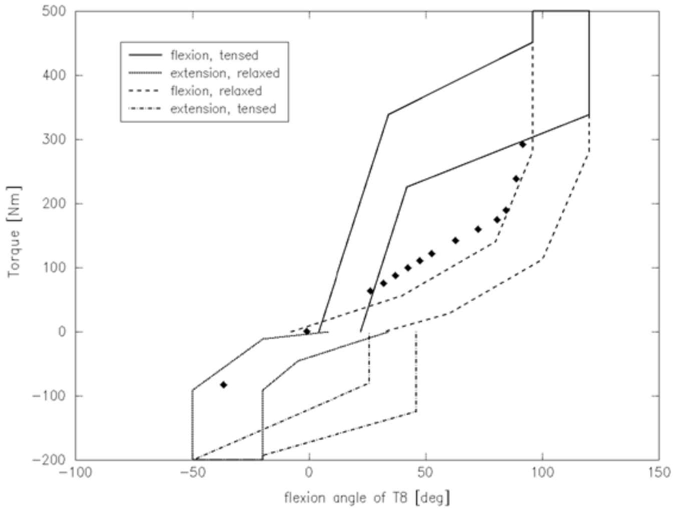

Figure 8. Quasi-static bending resistance of the spine (S1-T8) compared to corridors for relaxed and tensed volunteers from Nyquist and Murton (1975), forward bending is positive.

DISCUSSION

A mathematical human body model representing a 50th percentile male has been developed for frontal and rearward loading. The human geometry was derived from the RAMSIS anthropometric model (see Appendix A and B). This provided a realistic and detailed surface description, in particular for seated automotive postures. The model was extended for crash-simulations and validated for frontal loading in addition to the rearward validation already described by Kroonenberg et al. (1997). The model allows simulation of global injury criteria like chest-deflection, acceleration, and neck loads. For a more detailed analysis, submodels can easily be integrated into the current whole body model.

The thorax model was developed using blunt thoracic impact data. A continuously deforming skin was obtained using flexible bodies. Further effort is needed for validation with belt and airbags, and to implement biofidelic characteristics in locations like the abdomen. In modelling the shoulder a lack of dynamic and detailed data was noted and further effort is needed to gather such data.

The skin of the entire human body is described as one “continuous” arbitrary surface. Currently surface compressive properties are taken from Hybrid III dummy model properties. In the future these will be updated using human material and segment test data.

Frontal loading validations were performed in simplified conditions using rigid impactors or rigid seats. The spine model has been taken from the model published by Kroonenberg et al. (1997) which was validated for rear-end tests with rigid seats. A next step will be to validate the model in interaction with airbags, belts and deforming seats. Here the detailed surface description will be an advantage as compared to the ellipsoid description generally used in multibody occupant models. The model was setup as a full 3D model and thereby will be a basis for an omnidirectional model. The model will be extended for evaluation of lateral loading and validated towards ISO biofidelity requirements (ISO-N455-1996).

For reasons of simplicity lumped joint resistance models have been applied. These models describe the rotational and translational resistance resulting from all tissues and include the passive and active muscular response in a global manner. However, these models have insufficient resistance to maintain specific postures when simulating gravity. In the real body an initial muscular activity is required for posture maintenance. Additional reflex induced activity results after (impact) loading. In this paper the initial activity was simulated in a way comparable to a 1G joint friction setting applied in crash-dummies. Van der Horst et al. (1997) showed that additional reflex induced activity has a large influence on the head-neck response using detailed 3D multi-segment muscle models. However, a general method to predict the timing and level of reflex induced activity has not yet been provided. Ongoing experimental and simulation work is focusing on the role of initial muscular activity and reflex induced activity, and to find practical and general methods to include the role of muscles into (complete) human body models.

The current crash-safety design is largely based on a limited set of body sizes (usually 5th, 50th and 95th percentile crash-dummies). Happee et al. (1998) simulated frontal impacts with 30 different body sizes and found a wide range of results largely exceeding the range of results for standard dummies. These simulations were performed using "scaled dummy models". Using RAMSIS anthropometries a series of human body models of different sizes will be developed and validated using test data from biological specimens of varying anthropometry. This will allow, on the longer term, to base crash-safety design on real human body models taking into account the large anthropometry variations in current and future populations.

CONCLUSIONS

A 50th percentile male human model for frontal and rearward loading has been developed. This model is considered a first step towards an omnidirectional human model of variable body dimensions.

In the frontal validations presented a satisfactory prediction has been obtained for chest deflection, head kinematics and accelerations and for kinematics and accelerations at the upper thoracic vertebra (T1).

Recommendations include further development of the thorax and shoulder model, further validation for frontal and rearward loading, extension towards lateral loading and validation for different body sizes.

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APPENDIX A: RAMSIS - A 3 DIMENSIONAL HUMAN MODEL FOR ERGONOMIC DESIGN AND ANALYSIS OF THE DRIVER'S COMPARTMENT

This appendix is based on SAE paper 970088, and has been updated in August 1998 by H. Speyer and A. Seidl from Tecmath, Kaiserlautern, Germany

STARTING POINT

The early integration of ergonomic considerations into the design process of workplaces requires the use of adequate design tools. In past decades, templates of human percentile types (e.g. SAE-templates and DIN-templates) have proven worthwhile. These templates enable designers to create a 2-dimensional layout of the workplace. However, while the design process of machines has been considerably improved and accelerated by the employment of 3-dimensional CAD-systems, the development of the templates has to a large extent remained on the 2-dimensional level. Having to perform an ergonomic analysis of a 3-dimensional workplace by using 2-dimensional templates presents a range of problems to designers, and in some cases these problems are almost insurmountable. In addition to the basic discrepancy in the dimension of the templates and the workplaces to be designed, the available templates are controversial in view of their anthropometric design as well as in their correct use in ergonomic analyses.

There are three reasons which speak against the direct transfer of standard templates to a 3D-computerized system, which are anthropometric consistency, posture adjustment, and comfort assessment. Let us briefly consider each of these factors:

ANTHROPOMETRIC CONSISTENCY – The conventional templates resulted from measuring the lengths of human body parts of a large number of persons. The data was statistically analyzed by calculating percentiles of these measurements. For the template model, identical percentiles of various component body dimensions were composed (i.e. the body segment lengths of the 95th-percentile template correspond to the 95th-percentile of each body part). This process results in a manikin whose dimensions are artificial and completely unrealistic. In reality, tall persons (e. g. with 95th percentile of body height) typically have very long legs (high percentile of leg length) combined with a comparably short trunk (moderate percentile of sitting height). To restate, just because a person is tall with long legs, it does not follow that he or she necessarily has a long torso.

POSTURE ADJUSTMENT – When using templates, posture adjustment is accomplished either by a designer's "aesthetic intuition" or by the premise of a set of fixed posture angles (e.g. from SAE or DIN). However, as a particular posture results from the interaction of a large number of joints and depends to a high degree on the constraints which the template is supposed to fit, it is vital to have a procedure which can predict realistic, physical postures based on those constraints.

COMFORT FEELING – Another weak point of the commonly used templates is that they fail to provide feedback concerning the ergonomic quality of designs. Designers are unable to quantify how the designs affect a real person's likely perception of or level of comfort.

OBJECTIVE

Since May 1988, the research project 3D-SOFTDUMMY was cooperatively carried out by several organizations including the company TECMATH in Kaiserslautern, the Institute for Ergonomics (IfE) in Munich, the Department of Ergonomics of the Technical University of Munich (TUM) and the Department of Work Sciences at the Catholic University of Eichstätt. The objective of the project was to overcome the limitations, outlined above, of current ergonomic tools. The 3D-SOFTDUMMY Project was administered by Forschungsvereinigung Automobiltechnik (Research Association for Automotive Engineering, FAT). FAT members include the seven German automobile companies AUDI, BMW, FORD, MERCEDES-BENZ, OPEL, PORSCHE, VOLKSWAGEN, as well as two manufacturers of automobile seats, KEIPER RECARO and NAUE/JOHNSON CONTROLS.

MEASUREMENT AND MODELING OF ERGONOMIC DATA

Since the amount and types of available data were insufficient for the complete definition of a comprehensive human model, new measuring methods had to be developed for RAMSIS. The new measuring methods must be capable of ascertaining 3-dimensional data in a form which can be directly transferred to the CAD-system. According to the deficiencies mentioned above the research project 3D-SOFTDUMMY/RAMSIS covers three main categories of ergonomic data. These are:

1. anthropometric data
2. data concerning postures and movements, and
3. data dealing with perceived comfort of postures and adequacy of spinal position.

Applying statistical procedures to these data yields "typologies" of body dimensions, posture, and comfort. In an upcoming development RAMSIS will be provided with an open interface so that RAMSIS can be linked to the various available anthropometric databases.

A conceptually new idea distinguishing RAMSIS from other human model systems is the ability to use the human model itself as a measuring gauge of anthropometric measurements. The procedure is the same for anthropometric data as for the analysis of posture and movement. There are three basic steps:

1. The person to be measured is recorded by CCD video cameras, and the images are read into a computer.
2. Using the optical parameters of the cameras, the 3-dimensional human model is mathematically projected onto corresponding focal planes in the computer.
3. The unknown anthropometric parameters (body dimensions and/or posture) of the human model are systematically varied until the images of the test person and the computerized model are identical.

ANTHROPOMETRY

Measurements – By using two electronic cameras, the non-contact video anthropometric measurement system produces front and side view images of the test person in a number of selected postures. The camera images are read into the computer, where they are overlaid with the images of the computerized human model. The dimensions (length, depth and breadth/circumference) of each body element of the human model is varied until the model's images of are completely congruent with the corresponding images of the test person. By evaluation of the various postures it is possible to calculate the position of the kinematic pivots of the respective body elements.

Modeling – The anthropometric data obtained by the non-contact video measurements as well as the results of the anthropologist Dr. Greil based on the massive amounts of anthropometric data produced in the former East Germany have shown that the body dimensions of each individual can be classified according to three dominant and independent features. These features are body height, the amount of body fat, and body proportion, i.e. the ratio of the length of the limbs to the length of the trunk. Using this classification scheme it is possible to describe the entire population in a realistic way.

By applying extrapolation techniques based on anthropometric data covering a time interval of 40 years it was possible to generate a mathematical prediction model for the increase of the average body height of the entire population during a given time period ("secular growth"). The model was implemented into RAMSIS.

POSTURE AND MOVEMENT

Measurements – For the 3-dimensional posture analysis, the person to be measured is recorded simultaneously from up to four freely selectable camera positions. The adjustment of the human model to the actual postures recorded was performed interactively by variation of the joint angles until the human model was completely congruent to the recorded images.

Using a procedure for the exact splitting of video segments into single images, which was also developed in the course of this research project, the system for posture analysis has been extended to the analysis of movements. Here again, the movement of a person is recorded by up to four cameras located at arbitrary positions. The video signal is provided with a time code and recorded on a Hi8 video tape. Using a computer controlled video unit, the information on each video tape is then split into a time-exact sequence of single pictures, which can be analyzed by means of the posture measurement system.

Modeling – The measurement of posture data for RAMSIS was carried out on two mock-ups. In addition to posture measurement for the driving position at various placements of the pedals, steering wheel and seat, further tasks which are typical for the operation of a car have been included in the test range. These items include investigations of the field of vision, reach studies, and studies of entering and exiting the vehicle.

Based on the probability distribution of postures with respect to various body dimensions and various tasks, a multidimensional "postural function" has been developed for each joint. Using these functions, RAMSIS is able to simulate the real posture of the test persons performing certain tasks in the car.

COMFORT

Measurements – The measurement of postural comfort was carried out on a mock-up, which was developed and provided by AUDI. In this mock-up, the position of the controls can be varied to such a large extent that the dimensions of nearly any vehicle - from a sports car to a small truck - can be simulated. In addition, the mock-up has been extended in functionality to include simulations of the field of vision and acoustics. For the measurement of comfort the test persons were requested to take three different postures, which roughly correspond to the package of a minibus, a mid-size car and a sports car. In each position, the test subjects carried out a ten minute driving task, during which a 3-dimensional posture measurement was executed. Subsequent to the posture experiments, the feeling of comfort of the test persons was analyzed by means of a psychological investigation. A standardized questionnaire (by Krist) was used to evaluate the the test persons' feeling of comfort.

A series of longer (4 hours) driving simulations was conducted with a reduced number of selected test subjects. The objective of these tests was to clarify the evolution of discomfort and postural changes over long periods of driving.

MODELING

The questionnaire data for each test subject was correlated with the corresponding recorded postures. Thus, it was possible to calculate regression coefficients, which - applied to postures of the RAMSIS model - make it possible to give a prognosis regarding the expected postural comfort of a given driving position. Using this function, the designer is able to immediately and qualitatively judge the ergonomic and postural implications of variations of the workplace dimensions.

THE CAD TOOL RAMSIS

The data obtained through the ergonomic testing described above had to be transferred into an easy-to-use CAD tool: RAMSIS. The kernel of the CAD tool RAMSIS is the human model with archives containing the data referring to posture and comfort as well as the anthropometric database. Various modules are arranged around this core to make RAMSIS a functional and valuable tool.

Data exchange with CAD systems is supported by RAMSIS via VDA and IGES interfaces. Elementary CAD functions also enable users to manipulate imported CAD geometry inside RAMSIS. RAMSIS runs on UNIX workstation systems of important manufacturers (HP, Silicon Graphics, SUN). Several automotive firms have integrated RAMSIS directly into their CAD system.

THE GEOMETRIC KINEMATIC MODEL – While the appearance of a human being is completely determined by the body surface, the moveability is controlled by the skeleton. RAMSIS is similarly defined using two levels which are:

- an internal model and
- an external model.

The internal model - just like the human skeleton - can be looked at as a frame. In addition, it is the basis of the kinematic model. Through an analysis of the human skeleton, a structure of the internal model was derived which represents an optimal compromise between two conflicting goals. These are:

- implementation of all essential postural and kinematic characteristics into the model
- restriction of the number of joints and their degrees of freedom to a minimum in order to ensure good performance with regard to the rapid calculation of movements.

As a special feature, the internal model of RAMSIS is equipped with an “H-Point”. By making this point congruent with the SAE-Seating Reference Point (SgRP) of a given seat, the correct relationship between the seated model and the seat is guaranteed. As was the case with the data concerning comfort and position, the data required to determine the RAMSIS H-Point was extracted from measurements made on a representative sample of test subjects. Using the RAMSIS measurement system, the offset between the center of the hips and the SgRP was determined for the sample of test subjects. By statistical analysis the parameters for the offset which varies by sex, body dimension and seat were extracted and implemented into RAMSIS.

The external model represents the body surface. In contrast to most existing human models, the body surface of RAMSIS is not modeled by rigid, geometrically simple objects (prismatic bodies, ellipsoids) but rather by use of an extensive network of posture dependent “controlling points”. These points (about 1200 in the standard model) are attached to the internal model. The attachment relation is not static, but varies in accordance with the joint positions. For the calculation of the skin surface a surface generator runs over the controlling points. The generator may be varied to produce the desired degree of refinement in the model by piecewise linear interpolation or polynominal spline surface interpolation. The benefit of this approach compared to other modeling concepts is above all an essential improvement of the appearance of the skin in the vicinity of the model’s joints. In the future the deformation of larger soft body parts according to posture will also be modeled using this concept (e.g. the swelling of the abdominal region in a seated posture).

ANTHROPOMETRIC DATABASE – Beside the commonly used percentile data, the anthropometric database puts the anthropometric typology described above at the disposal of the designer. This results in a more realistic ergonomic analysis of the design. By applying the secular growth model to these anthropometric body types the user is able to make sure that the design will still be adequate in future years. The user is also able to import into RAMSIS measurement data of specific individuals for use during the design process. This can be accomplished either by using the RAMSIS anthropometric measuring system or by an interface to conventional anthropometric data (anthropometric editor). In a recent development step this editor has been extended to enable users to even more efficiently select the optimal sample of RAMSIS manikins corresponding to the task to be analyzed.

AUTOMATIC SIMULATION OF POSTURES – In many of today’s computer models, changes in position and posture are performed through the input of values for each joint angle. This procedure, which is doubtful in ergonomic view, is very difficult, time consuming and therefore unacceptable for regular professional application.

For these reasons RAMSIS has been incorporated with an easy-to-use posture prediction module which enables users to automatically adjust the manikin’s posture according to specific tasks. Based on the above models of posture and comfort, sophisticated optimization algorithms are applied to correctly and repeatably calculate posture and comfort feeling. The designer stipulates the task he wants to simulate using RAMSIS by interactively defining model constraints (e.g. hands at the steering wheel, feet on the pedals). These constraints can be saved and reused with other human models and other similar subsequent applications. Additional conditions such as avoiding the penetration of body parts are also taken into consideration. Thus the results of the analysis are raised to a new level of quality and open the door to substantially improved results.

FUNCTIONS FOR ERGONOMIC ANALYSIS AND FIELD OF VIEW SIMULATION – RAMSIS contains special functions for reach analysis. In the most simple case, distances can be calculated between the model and environmental objects. More complex functions make it possible to determine the surface of reachable limits for any link chain of body elements. These surfaces are actually calculated, taking into consideration the model's complete kinematics, and not - as is the case with many other human models - retrieved from memory of stored approximations (e.g. as ellipsoid surfaces).

For the designer, the simulation of the field of vision presents another important analysis feature. RAMSIS users can "sit down inside the model" and look at the proposed workplace design through the model's eyes. Switching from the left eye to the right eye and back again provides a simple and exact method of detecting hidden or partially hidden objects.

In 1996 the vision simulation was extended to include planar and spherical mirrors. After defining location and size of the mirror users can immediately see what the manikin is able to see in the mirror.

Reoccurring analysis tasks can be accomplished automatically with the aid of a macro function. The necessary command sequence can be recorded using a macro recorder and can then be run again as often as needed with parameters appropriate for the given situation.

CURRENT AND UPCOMING DEVELOPMENTS

Due to the specific features mentioned above RAMSIS is regarded to be the most advanced human model for the ergonomic development of cars today. Nevertheless, the databases as well as the simulation models and analysis features are being continuously upgraded. In addition, TECMATH is participating in the most important R&D projects related to ergonomic analysis and simulation.

ASPECT – ASPECT (Advanced Seat Production Evaluation and Comparison Tool) is a project initiated by the SAE (Society of Automotive Engineers). The aim of ASPECT is the development of a new SAE H-point measuring manikin and of methods to extrapolate the measurement values to people of other sizes. The R&D work is cooperatively carried out by the Michigan State University, UMTRI (University of Michigan - Transportation Research Institute), and TECMATH. The industrial partners are car and seat manufacturers from all over the world.

ADVANCED INFORMATION TECHNOLOGY (AIT) – The main goal of this project is the development of an open ergonomic bus system. The project has been founded by the European Community. The development partners are European car companies and airplane companies.

OTHER PROJECTS – Other examples for TECMATH R&D cooperations are the D4m project for the development of a realistic simulation of muscles and the deformations of the human skin and the development of an automated process chains for the production of individually tailored clothes.

RAMSIS CUSTOMERS

Since 1995 RAMSIS is distributed worldwide. More than 50% of all car manufacturers worldwide use RAMSIS to design their cars. All German car companies, Rover and SAAB in Europe, Korean companies like Daewoo and Samsung, Japanese Companies like Honda and Mazda as well as Ford and General Motors in the U. S. decided for RAMSIS. Another field of application is the truck design. Daimler-Benz, Scania and Freightliner optimize their vehicles using RAMSIS.

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APPENDIX B: SELECTED 50TH PERCENTILE MALE ANTHROPOMETRY

RAMSIS models have been developed for several populations including Germany, USA/Canada, Japan/Korea. The German population was surveyed as described in Table B1. Age was one of the stratification variables, i. e. the age distribution was representative of the population age distribution. From this population a 50th percentile male model was generated using RAMSIS options as specified in Table B2.

Table B1. The RAMSIS German population survey.

country	Germany
period	1982-1984
number of females	3059
number of males	3052
age range	18-59

Table B2. RAMSIS anthropometry parameters of the validated “50^{th} percentile male model”.

parameter	option	remark
population	German, 1984	RAMSIS version 3.1
gender	male	
length (standing)	1.74 m (medium)	Hybrid III 50th percentile=1.72 m
body mass	75.7 kg (medium corpulence)	Hybrid III 50th percentile=77 kg
erect seating height	0.92 m (medium torso length)	
shoe model	GINO	
hand model	mitten like	the four fingers are merged
posture	seated	provides realistic skin description for seated car occupant
range of motion	medium	normal range of motion selected for the joints