SCALABILITY OF HUMAN MODELS

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ABSTRACT

The objective of this work was to create a scalable human occupant model that allows adaptation of human models with respect to size, weight and several mechanical parameters. Therefore, for the first time two scalable facet human models were developed in MADYMO. First, a scalable human male was created from an existing 50th percentile human occupant. But since the anthropometry between males and females differs too severely, a scalable human female was created as well to be able to obtain female models with different anthropometry.

Using these models in the MADYMO / Scaler, a target model anthropometry could be created either by defining an anthropometry set of 35 values, by defining 16 fixed scale factors or by using the GEBOD anthropometry database (BAUGHMAN, 1986). Additional to the geometric properties, the following mechanical properties were also scaled using appropriate scaling rules: mass, inertia, stiffness and contact characteristics. Several anthropometrically extreme models, ranging from small children to large adults, have been created using the 3 possible methods to provide the input. Direct definition of anthropometry values and definition of fixed scaling factors resulted in realistic scaled models, whereas using the GEBOD anthropometry database could lead to unrealistic ones, especially when scaling towards children.

A frontal crash application has been developed, using the original 50th percentile human occupant as released with MADYMO and two scaled male models of 65 kg and 85 kg weight with equal height as the base model, to demonstrate the benefit of the scalable models.

INTRODUCTION

Computers are getting faster and faster nowadays and possibilities for numerical simulations are increasing. Due to that, numerical automotive (impact) simulations are getting more and more important for the automotive industry, since they provide a cheap and effective way to help improving occupant safety on next generations of cars. In a crash, humans with different body sizes need to be protected rather than crash test dummies of only average sizes (HAPPEE ET AL., 1998, VAN HOOF ET AL., 2003). This results in the need for a scalable human occupant model, which should be easy to handle and can provide the possibility to adapt a models anthropometry due to the needs of the desired application, as was developed during this work.

GENERAL SCALING PROCEDURE

MADYMO / Scaler

The MADYMO / Scaler has been created to scale occupant models in MADYMO (DE LANGE, 2005). It allows the user to scale a model in three different ways:

- Specifying gender, mass and standing height for creating a model based on the GEBOD anthropometry database (BAUGHMAN, 1986)
- Specifying a data set of 35 anthropometry values according to Table 1
- Specifying direct scaling factors λ_x, λ_y, λ_z and λ_{xyz} for each dimension of the 14 scalable body sections of Table 2.

The definitions of the anthropometry values are given in the MADYMO Utilities Manual Release 6.3.1 (2006). With respect to the dimensions, x is always referring to the depth of a body section (e.g. "chest depth" for body region "thoracic spine"), y to its lateral width (e.g. "head breadth" for region "Head") and z to its height (e.g. "Knee height seated" for region "lower leg").

To obtain the scaling factors λ_x, λ_y and λ_z (in case they are not specified directly) the target anthropometry values X_i (or the values retrieved out of the GEBOD database) were divided by the corresponding reference anthropometry values $X_{i,ref}$ given in the parameterised model file. (Equation 1)

$$\lambda_i = \frac{X_i}{X_{i,ref}} \qquad i = x, y, z \qquad \textbf{(1).}$$

These factors were mainly used to scale the models geometry and geometry based parameters as mass and moment of inertia. Additional to that the following parameters were scaled as well:

- Joint characteristics (stiffness, friction, damping and hysteresis)
- Contact characteristics
- All other force models

Therefore, the set of scaling parameters was extended with a scaling factor λ_{xyz}. This factor is calculated as third power root of λ_x, λ_y, λ_z (Equation 2)

$$\lambda_{xyz} = \sqrt[3]{\lambda_x \lambda_y \lambda_z} \qquad \textbf{(2).}$$

The scaling rules that were applied are to a great extend similar to those used for normalization and scaling (IRWIN AND MERTZ, 1997, VAN RATINGEN, 1997, MERTZ ET AL., 1989), though no "response corridors" but model parameters were scaled. All material parameters were assumed to be invariant with subject size.

Table 1.
Anthropometry data set for scaling

No	**Value**
1	Weight
2	Standing height
3	Shoulder height
4	Armpit height
5	Waist height
6	Seated height
7	Head length
8	Head breadth
9	Head to chin height
10	Neck circumference
11	Shoulder breadth
12	Chest depth
13	Chest breath
14	Waist depth
15	Waist breadth
16	Buttock depth
17	Hip breath, standing
18	Shoulder to elbow length
19	Forearm – hand length
20	Biceps circumference
21	Elbow circumference
22	Forearm circumference
23	Wrist circumference
24	Knee height, seated
25	Thigh circumference
26	Upper leg circumference
27	Knee circumference
28	Calf circumference
29	Ankle circumference
30	Ankle height, outside
31	Foot breath
32	Foot length
33	Hand breadth
34	Hand length
35	Hand depth

Table 2.
Body sections into which the model is divided

No	*Body Region*
1	Pelvis
2	Lumbar spine
3	Abdomen
4	Thoracic spine
5	Ribcage
6	Neck
7	Head
8	Clavicles
9	Upper arm
10	Lower arm
11	Hand
12	Upper leg
13	Lower leg
14	Feet

Note, when using GEBOD, weight and height have to be specified in either kilograms (KG) and meters (M) or percentiles (%tile).For more detailed information on the scaling tool see MADYMO Utilities manual Release 6.3.1 (2006)

Creation of the parameterized model files

The parameterized files were created using the existing MADYMO 50^{th} and 5^{th} percentile human (DE LANGE ET AL., 2005). The models are put in upright standing position, with horizontal arms (parallel to the y – axis) to simplify the scaling process (see Figure 2).

In reference space, two planes in each direction located at ± 1.50 m from the models H-point were implemented. These planes were needed in order to control standing height, seated height and shoulder breadth. Five ellipsoids were implemented at the pelvis, at the top of the head, at the bottom of the heel and one at each side of the shoulder. By measuring the distance of these ellipsoids relative to the appropriate planes, standing and seated height as well as the shoulder breadth were calculated and controlled by the MADYMO / Scaler during the actual scaling process, which ran through an optimization routine.

The MADYMO / Scaler utility already allowed scaling various dummy models (HAPPEE ET AL., 1998) and a pedestrian human model (VAN HOOF ET AL., 2003) based on ellipsoid geometry. Scaling an ellipsoid model was relatively simple since every ellipsoid could be scaled in each dimension by applying an appropriate scaling factor. No irregularities would occur with a skin mesh in the resultant model. The distance between two adjacent ellipsoids is always determined by a joint that connects the bodies, the ellipsoids are attached to. Therefore, also the overall geometry of an ellipsoid dummy model could be easily modified towards a scaled model by scaling the distances determined by those joints.

For a facet model, in general scaling could be applied in a similar way. Scale factors for each body region of Table 2 were calculated according to Equation 1 and 2 and the scaling was performed as mentioned above. However, for a facet model the overall geometry is not determined by ellipsoids, but by an continuous FE mesh covering different body sections and consisting of rigid elements. This resulted in different parts of the mesh being scaled with different scale factors for each dimension. Therefore in a first approach problems occurred since the originally smooth mesh contained many rough edges wherever the scaling factors changed moving from one body region to another. As an example this is explained for the elbow region. Since the upper arm is likely to get a different scaling factor than the lower arm, the mesh in the elbow region will be badly shaped if not adapted (Figure 1).

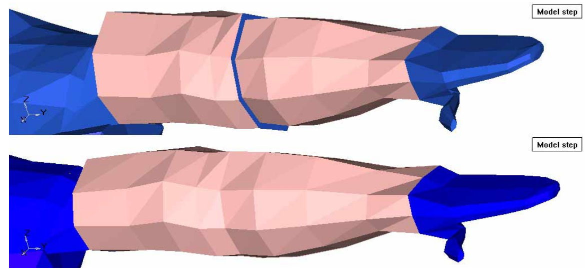

Figure 1. Scaled arm with (bottom) and without (top) mesh smoothing

The transition nodes of the lower arm were then not congruent any more with the transition nodes of the upper arm. To avoid this unwished effect, linear mesh smoothing functions were applied in these intersection areas.

Creation of a scaled model

In order to create a scaled human model, the three procedures mentioned before can be used:

- GEBOD
- User Defined (anthropometry data set)
- Fixed Scale Factors

In case most measures of the anthropometry of the target model are known, most reasonable results can be obtained using method two. If only weight and height of the target model are of interest, GEBOD can be used as well. Nevertheless, the anthropometry of models based on GEBOD should always be checked carefully since they often turned out to be unrealistic in some body parts like shoulder and upper leg. If so, the model could easily be corrected by a second scaling using the retrieved anthropometry data of the GEBOD model and correcting unrealistic scaling factors towards realistic ones.

It is not only possible, to scale the parameterized models towards adults, but also towards child anthropometry. As a base model, the male model can be scaled using a self defined anthropometry set. GEBOD is not suitable in this case, since it was often found to result in highly unsuitable models, especially when scaling towards very young children. This is exemplified in Figure 2 where both, a model of a three year old child created with GEBOD (left) and created with a self defined anthropometry data set based on the CANDAT database (right) (TWISK ET AL., 1993) is provided.

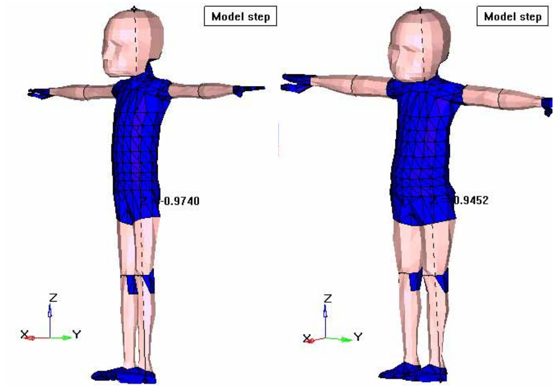

Figure 2. Child model resulting from GEBOD anthropometry (left) and from CANDAT anthropometry

In general, it is advised to use the female model only to scale towards adult females or teenage females that have reached puberty (app. age 13). The male model should only be used for male and child models. No appropriate outer geometry will be obtained otherwise due to too significant differences between male and female body shape, the latter which is absent with young children.

FRONTAL IMPACT SIMULATION

So far no validation of the mechanical impact behavior has been performed with the scaled models. To indicate the benefit of this work a frontal impact simulation was performed using two scaled models as well as the standard 50th percentile human occupant model.

Simulation model set up

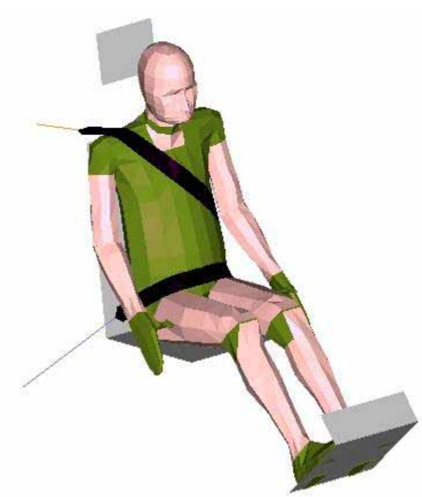

Figure 3. Simulation model set-up including the original 50th percentile human occupant

As simulation set up, the frontal impact application that is provided with MADYMO v6.3.1 was chosen. This model consists of a simple seat and a three point passenger belt system. The following human models were used within this application:

1. 50th percentile human occupant of 1.74 m standing height and 75.86 kg weight
2. Low mass model: Same size as 50th percentile human occupant, but 10 kg lighter
3. High mass model: Same size as 50th percentile human occupant, but 10 kg heavier

The models were created following the procedure described before. The scaling has been performed using the GEBOD anthropometry database and afterwards the models were corrected towards shoulder breath, upper leg length and circumference, neck circumference as well as chest depth. The simulation set up including the 50th percentile human occupant is shown in Figure 3, a side view of all 3 models in standing position is provided in Figure 4. For a better overview in all following pictures that contain all three models, the low mass model (pink) is shown on the left, the original 50th percentile human occupant model (green) in the middle and the high mass model (blue) on the right.

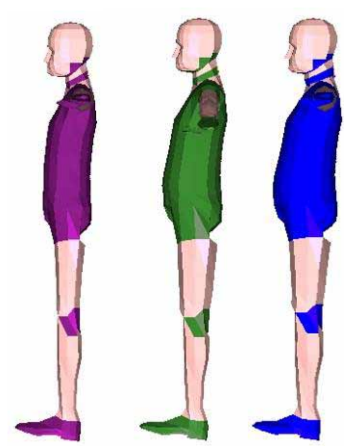

Figure 4. Side view: low mass (left), original (middle) and high mass human model (right) of 1.74 m standing height

All models are first settled into the seat and a separate belt fit is performed as presimulation to the actual impact simulation. The crash pulse represents a zero degrees full frontal impact of a mid-sized passenger car, as provided with the application. The initial position of the low mass and the high mass model in the seat with fitted belts is provided in Figure 5.

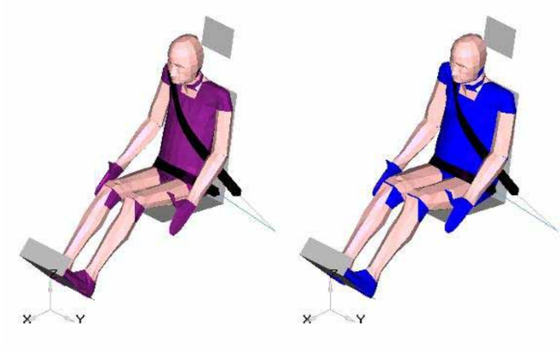

Figure 5. Initial position of the low mass (left) and high mass (right) human occupant model

Results

When looking at the kinetics, it can be seen, that during the impact simulation the low mass model rotated more and the high mass model less around the z axis than the original 50th percentile human occupant. Pictures of all three models at the end of the impact from different views are provided in Figure 6 to Figure 8.

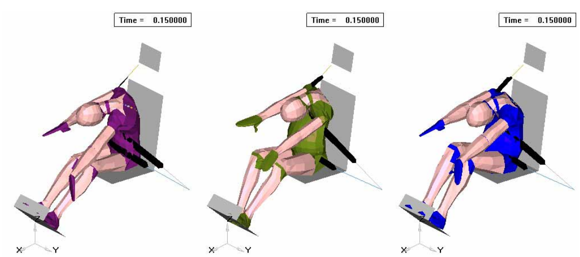

Figure 6. Isometric view of all three models at the end of the impact simulation (low mass model at the left, original model in the middle and high mass model at the right)

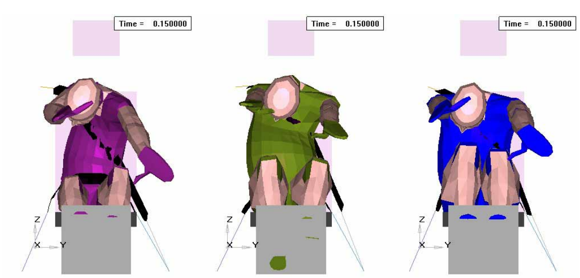

Figure 7. Frontal view of all three models at the end of the impact simulation (low mass model at the left, original model in the middle and high mass model at the right)

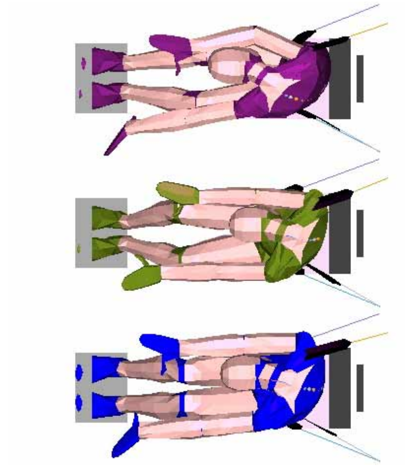

Figure 8. Top view of all three models at the end of the impact simulation (low mass model at the top, original model in the middle and high mass model at the bottom)

This is behavior is considered logic, since a low mass model has more space to move and less contact area with the belt than a high mass model because its less wide in lateral direction. As can be seen in Figure 8 the pelvis belt is also able to pull the low mass model most and the high mass model least back into the seat due to their masses. This also leads to more rotation of the model itself for a light human model.

Differences can as well be found when looking at the time history signals. In Figure 9 and Figure 10 an overview on some of the corresponding results is provided.

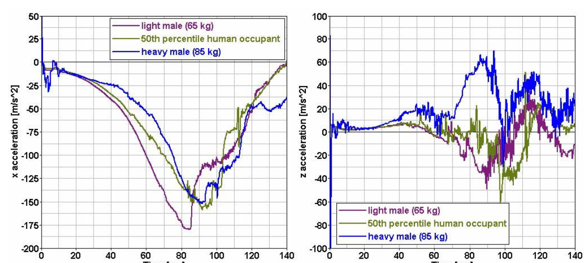

Figure 9. Pelvis x- and z- acceleration

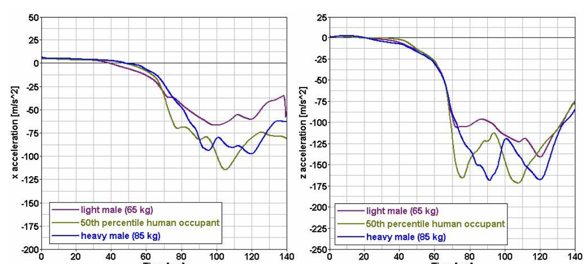

Figure 10. Head CG x- and z- acceleration

It can be stated, that in general the progression of the curves are comparable. The peak values are in the same range, but differ as expected according to the models mass.

Note, that the chosen application is very general and only a first indication on the usefulness of the scale-able models. The created models are not based on actual anthropometry data but out of GEBOD models that were corrected towards values that seamed feasible.

DISCUSSION

Recapitulating it can be stated that the created scalable models are suitable to obtain models that are not representing the available standard human occupants (5^{th} percentile female, 50^{th} and 95^{th} percentile male). In a basic frontal impact application differences could be found in the response of the scaled models and the original 50^{th} percentile human occupant. This indicates that scaled models are able to predict the response of occupants different from the standard models available in a better way. The main difference with respect to previous scalable models lies in the fact that now also models based on facet geometry can be obtained with scaling. Before, scaling was only possible for ellipsoid based models.

The main limitation of the models is that no age based material dependency is taken into account during the scaling. As a result, for example the response of created child models will not be completely biofidelic. Furthermore, the impact behavior of all models (injuries, range of motion, etc.) is not yet validated but only investigated briefly with 2 scaled models. In order to investigate whether scalable models are able to predict the behavior of an actual occupant more precisely than the standard models, two options could be taken into account:

- Comparison to PMHS sled tests
- Real accident reconstruction with known anthropometry data of the actual occupant

In order to investigate the influence of different parameters as neck circumference, neck to chin height or mass on the injury outcome, it might also be useful to perform model studies. Therefore, models could be created that only differ in certain parameters, investigated under one specific loading condition and their behaviors could be compared to the outcome of actual performed tests that can be found in literature.

However, it is assumed that future work with scalable human models will prove the benefit of this work for protection of non average sized occupants.

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