OPTIMISATION OF VEHICLE PASSIVE SAFETY FOR OCCUPANTS WITH VARYING ANTHROPOMETRY

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Paper Number 98-S9-O-03

ABSTRACT

A method has been developed to generate models representing subjects of varying anthropometry. This method has been applied to crash-dummy models, and will in the future also be applied to human body models. The first step of the method is to generate a set of target anthropometry parameters from a relevant population. The second step is to scale an existing model towards the desired anthropometry. Different scaling factors are being applied for the different body parts and dimensions. These factors are used to derive body dimensions, mass and inertia properties, joint resistance and contact resistance parameters. For this study on adult subjects it has been assumed that material properties are invariant with subject size. Quasi-static simulations were performed to confirm that the resulting stiffness of complete body parts obey the scaling rules applied to the model components.

The design of a vehicle has been evaluated with respect to passive safety for a wide range of occupant sizes. Starting point was a set of validated frontal impact simulations including Hybrid III dummies. These simulations were repeated with occupant models of varying size and weight. The model setup for the frontal impact simulation was similar the model used in the study of Michaelsen, 1997. The frontal impact simulations have shown a wide range of results for the different types of ccupant. Due to different seat positions and body proportions the injury parameters exceed the range of results found for standard dummies.

INTRODUCTION

In the area of vehicle crash-safety design limited attention is being paid to variations of body size. For adults, current regulations only prescribe testing with dummies representing a "50th percentile male". For frontal impact two other versions are available of the Hybrid III dummy (Mertz et al., 1989). These dummies represent respectively a small female (5th percentile) and a large male (95th percentile). A small female dummy for side impact has recently been introduced (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. The current dummy sizes do represent variations in length but do not cover variations in corpulence and other body proportions. Mathematical human body models developed for ergonomic design do describe such variations in body proportions (Fig 1).

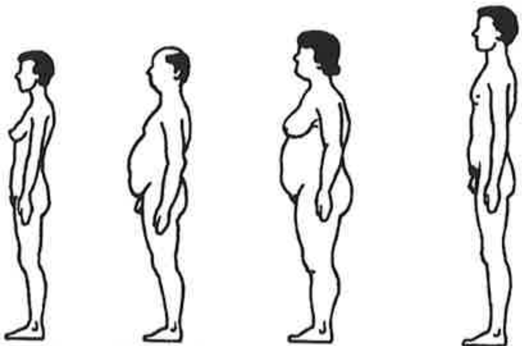

Fig. 1. Variability in Bodyproportion and -height (Pictures from Flügel, 1986)

These models are based on extensive anthropometric measurements on various populations (e.g. Flügel, 1986; Geuβ, 1984; Ramsis, 1998). The current paper describes a method to generate models representing subjects of varying anthropometry. Crash dummy models with varying body size and body proportions are generated using scaling techniques. These models are used to evaluate occupant protection in frontal impact.

METHODS

Occupant model scaling

A method has been developed to generate models representing subjects of varying anthropometry (MADYMO, 1998). This method has been applied to crash-dummy models, and will in the future also be applied to human body models. The first step of the method is to generate a set of target anthropometry parameters from a relevant population. The second step is to scale an existing model towards the desired anthropometry.

Scaling procedures have been used widely in the field of crash safety. The design of the Hybrid III small female and large male dummies is partly based on scaling (Mertz et al. 1989). Available biofidelity requirements for adults have been used to estimate requirements for children. Scaling was applied for the design of the TNO P1½ dummy (see Thunnissen et al., 1994), the TNO Q3 dummy (van Ratingen, 1997), and child Hybrid III and CRABI dummies (Irwin and Mertz, 1997).

Scaling is relatively simple if all length dimensions scale with the same factor. Such simple scaling is called *geometric scaling*. In our study a more advanced scaling method is applied. Different scaling factors are specified for x, y, and z dimensions. Furthermore different scaling factors are applied for different body parts. Thus the model geometry can be adapted freely to the desired anthropometry parameters.

Input for the scaling is a set of target anthropometry parameters (see Table 1). The corresponding parameters have also been evaluated for the standard models which are to be scaled. Initial scaling factors are simply derived as the ratio of target length divided by standard length. Thus various scaling factors are derived for different body parts and for x, y and z dimensions. The resulting scaling factors are then applied to the standard model. Finally the mass and the main dimensions of the resulting model are checked. The mass is only an indirect result of the scaling process and therefore normally deviates slightly from the specifications. Therefore a second phase of the scaling, the so-called correction is performed. The model is simulated repeatedly to optimise the prediction of mass, erect standing height, seated height and shoulder width. In this correction phase only the geometry scaling factors are optimised. No variation of the assumed body tissue density is performed. The orientations of the segments will not be changed, which means that the models will have the same (initial) posture as the standard model, used as starting-point.

Table 1. Anthropometry parameters used for generation of scaled dummy models.

Anthropomety parameter	Remarks
weight	
standing height	without shoes
seated height	
head length	
head breadth	
head to chin height	
neck circumference	derived using ramsis skin points
shoulder breadth	
chest depth	
chest breadth	
waist depth	derived using ramsis skin points
waist breadth	derived using ramsis skin points
buttock depth	derived using ramsis skin points
hip breadth,standing	
shoulder to elbow length	
forearm-hand length	
knee height,seated	without shoes
ankle height,outside	without shoes
foot breadth	without shoes

In addition to the geometry, all other model parameters are scaled, so there is scaling of:

- Geometry
- Sensor locations
- Reference length for the V*C criterion
- Mass and Moments of Inertia
- All joint characteristics (stiffness, friction, damping and hysteresis)
- Ellipsoids and contact characteristics
- All other force models

The scaling rules applied are largely equivalent to those used for scaling and normalization (Mertz et al. 1989, va Ratingen, 1997, Irwin and Mertz, 1997). Here it should be noted that we applied scaling to model parameters where others mostly scale "response corridors" (see Thunnissen et al., 1994 for discussion). Scaling is performed assuming that material properties are invariant with subject size. Biomechanically this seems to be an acceptable approach for adult subjects. For scaling towards children, or to simulate elderly persons the variation of material properties should be included. The assumption of equal density leads to analytical scaling rules for mass, centre of gravity and rotational inertia. For the scaling of stiffness and damping the assumption of identical material parameters leads to simple scaling rules. For instance when scaling the force deflection behaviour of an ellipsoid, deflection scales with the representative length and force scales with surface and thereby with length to the second power. Quasi-static simulations were performed to confirm that the resulting stiffness of complete body parts obey the scaling rules applied to the parameters of model components.

Occupant population

Models were generated representing typologies from the Ramsis anthropometric database (Flügel, 1986; Geuβ, 1984; Ramsis, 1998). Table 2 lists the selected options. The parameter *proportion* describes the relative length of torso and legs. All models were based on the 1984 German population, age group 18-70 year. The selected occupant population is summarized in Table 3. Here models number 0-12 represent standard typologies whereas numbers 13 and 14 represent extreme body sizes generated with the Ramsis Body Builder (Ramsis, 1998). For the extreme male models a maximal length has been obtained by defining 99th percentile for age group 18-29 year in reference year 2010. Maximal corpulence was selected as 99th percentile. For the extreme females a minimal length was obtained by defining 1th percentile for age group 18-70 year in reference year 1984. For the population from Table 2, target anthropometric parameters from Table 1 were generated. Most of these parameters were standard output, but some parameters had to be reconstructed using "skin point" positions in the default posture. These parameters were applied to scale the dummy models. For all male models the 50th percentile male Hybrid III model was scaled whereas for all female models the 5th percentile female model was scaled. For a number of scaled dummy models the geometry was verified by comparison to the Ramsis skin and joint positions. Figure 2 illustrates that for the external dimensions a generally good correspondence was obtained but the dummy models have a somewhat reduced shoulder height.

Table 2. Standard typologies selected for model generation.

parameter	selected options		
gender	male	female	
length (standing)	very short	medium	very tall
corpulence	slim waist	medium waist	large waist
proportion	short torso	medium torso	long torso

Table 3. Population defined.

number	length	corpulence/ waist	torso	length [m]		mass [kg]	
				male	female	male	female
0	medium	medium	medium	1.7425	1.6227	75.697	62.575
1	v.short	slim	short	1.6264	1.5249	54.959	48.036
2	v.short	slim	long	1.6049	1.5213	57.645	48.082
3	medium	slim	short	1.75	1.6337	62.82	54.002
4	medium	slim	long	1.737	1.6123	64.129	53.932
5	v.tall	slim	short	1.8713	1.7302	70.491	60.011
6	v.tall	slim	long	1.8472	1.7149	71.643	59.951
7	v.short	large	short	1.6272	1.5251	81.46	71.788
8	v.short	large	long	1.6131	1.515	83.392	73.861
9	medium	large	short	1.7515	1.627	89.125	76.929
10	medium	large	long	1.7256	1.6124	89.371	77.695
11	v.tall	large	short	1.8551	1.7277	92.415	80.704
12	v.tall	large	long	1.8557	1.7186	94.828	81.813
13m	xx.tall	medium	medium	1.98	---	89.003	---
14m	xx.tall	xx.large	medium	1.98	---	102.769	---
13f	xx.short	medium	medium	---	1.4774	---	55.513
14f	xx.short	slim	medium	---	1.478	---	41.681
standard MADYMO Hybrid III dummy models							
P5	v. small				1.52		48
P50	medium			1.72		77	
P95	v. tall			1.85		101	

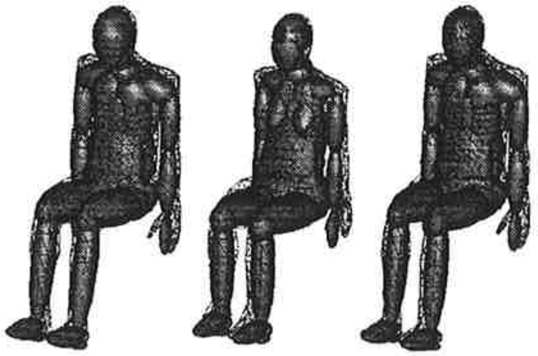

Fig. 2. Comparison of scaled dummy models (ellipsoids) to Ramsis surface (mesh).

FRONTAL IMPACT SIMULATION

Simulation model setup

The frontal impact simulations were done with MADYMO V5.2. The driver side model represents an European middle class car. The restraint system contains a driver airbag of 60ltr. and a belt with a retractor loadlimiter (loadlevel: 4kN). The simulation model was also equipped with a deformable steering column (loadlevel: 5kN, max. deformation: 80mm).
The airbag was optimized for an unbelted 50th%ile Hybrid III Dummy in a FMVSS 208 crashtest. The frontal impact simulations were done with belted occupants. The occupants were positioned in such a way, that they could reach the pedals and the steering wheel. The pelvis angle was set to 25°. Due to the different body sizes the H-point positions of the scaled dummies differ up to 280mm.
For the frontal impact simulations the following 3 different crashpulses were used:

- NCAP
- Offset 55km/h
- 50km/h 0°

Fig. 3 shows the very small/thick and the very tall/slim male occupant in the carmodel.

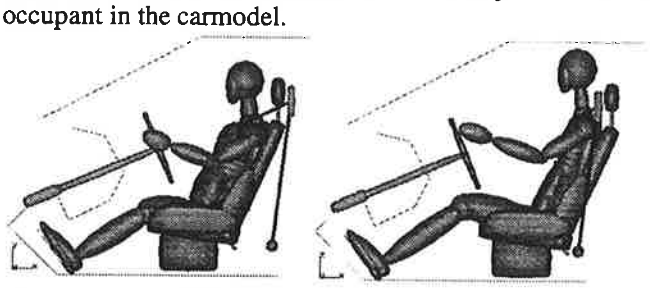

Fig. 3. Very small/thick/long torso male (left) and very tall/slim/long torso male occupant (right)

Occupant simulation results

The following consideration of the simulation results focusses on the stiff (NCAP), medium (50km/h 0°), and smooth (Offset 55km/h) crashpulse.
The kinematics of a very tall/slim male occupant with long torso is shown in Fig. 4.

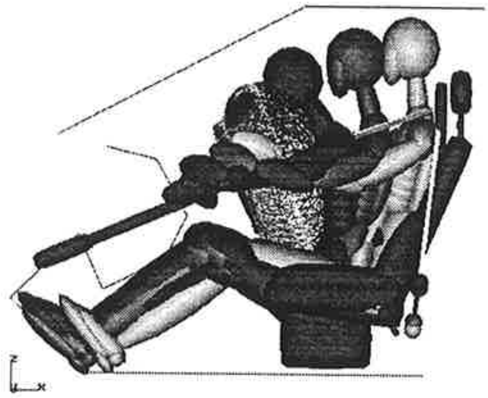

Fig. 4. Kinematics of a very tall/slim/long torso male occupant (time states: 0, 60, 80, 120ms)

The injury parameters of the occupant simulation have shown a large bandwidth of results. The following figures show the deviation of the injury parameters in percent relative to the 50th%ile male Hybrid III model. That means, that the results of the 50th%ile male are set to 0% deviation. The results of the three standard dummies are marked with little boxes in the following figures.

Fig. 5 shows the 3ms-head acceleration versus the H-Point position relative to the vehicle for the NCAP-Crashpulse. The results of the scaled dummies exceed the bandwidth of the three standard dummies results. Some higher 3ms-head accelerations (>60%) are caused by contact between head and upper steering rim. This occurs for large occupants, where the head moves over the airbag and impacts on tl steering rim. The extreme small/slim occupants are sitting very close to the steering wheel, which causes „mild OOP" for the NCAP crashpulse. Apparently identical H-Point positions can cause a wide range of results.

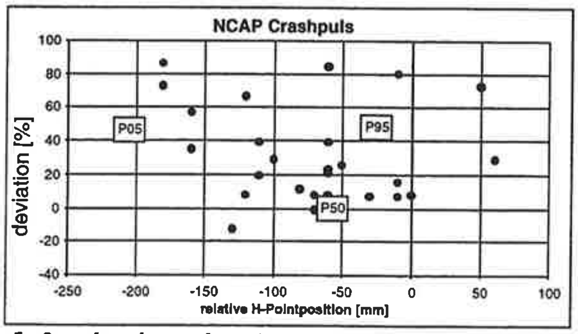

Fig. 5. 3ms-head acceleration against the relative H-Point-position for the NCAP crashpulse

The same observations for the range of results can be made for the 3ms-chest acceleration (Fig. 6) and the chest deflection (Fig. 7). Here the chest deflection is given relative to a scaled reference length representing chest depth.

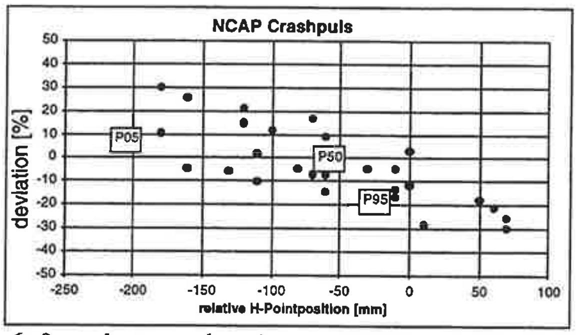

Fig. 6. 3ms-chest acceleration against the relative H-Point-position for the NCAP crashpulse

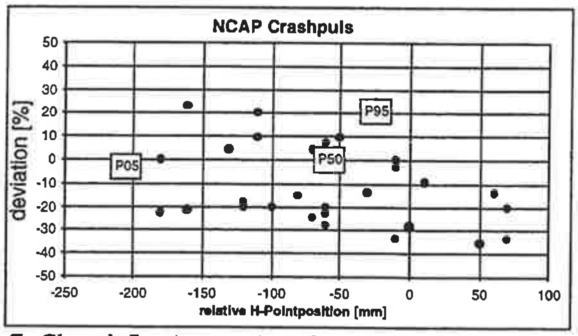

Fig. 7. Chestdeflection against the relative H-Point-position for the NCAP crashpulse

The relationship between the 3ms-chest acceleration and the weight of the occupant can be seen in Fig. 8. The higher weight causes a lower chest acceleration for the NCAP crashpulse.

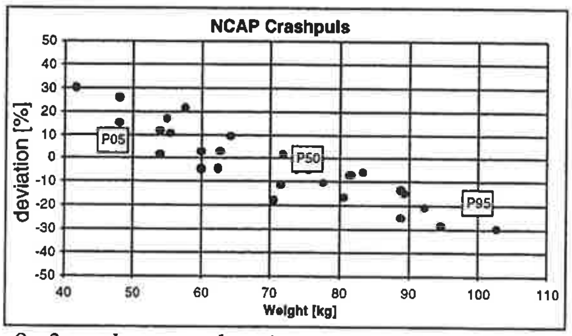

Fig. 8. 3ms-chest acceleration against the weight for the NCAP crashpulse

The other crashpulses have shown similar results as for the NCAP crashpulse. The following figures show the 3ms-chest acceleration for the Offset 55km/h (Fig. 9) and the 50km/h 0° crashpulse (Fig. 10).

Fig. 9 shows the „smooth“ Crashpulse (Offset 55km/h), where the 3ms-chest acceleration hardly correlates with body weight. This is due to the smaller influence of the airbag in this crash type. The belt takes most of the occupant energy in this case.

The results for the „medium“ crashpulse in Fig. 10 also show a strong correlation between the 3ms-chest acceleration and the weight of the occupants.

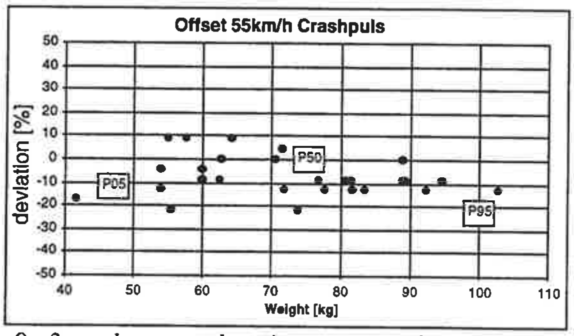

Fig. 9. 3ms-chest acceleration against the weight for the Offset 55km/h crashpulse

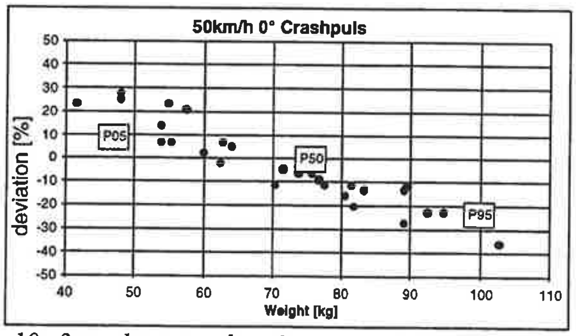

Fig. 10. 3ms-chest acceleration against the weight for the 50km/h 0° crashpulse

DISCUSSION

Scaleable crash-dummy models can be used for the design of safer vehicles and restraint systems. With such models the safety of vehicles can be evaluated for subjects with an anthropometry not represented by available dummies. This is relevant, in particular for the design of "smart restraint systems". For accident reconstructions it is considered important to have a model that describes the anthropometry of the subject involved with sufficient accuracy. In many cases the size and weight of accident subjects deviates considerably from any available dummy. Here sometimes models with an extreme anthropometry are required.

The scaled dummy models are based on scaling methods similar to those used in the design of small and large dummies. We thereby feel that the scaled models have a biofidelity comparable to these small and large dummies. A next step will be to apply the scaling methods for human body modelling. Only a validation on biological specimens of varying anthropometry can really validate such scaling methods. Here it is expected that for the simulation of children or elderly persons variation of properties of biological tissues will have to be considered.

The frontal impact simulations with the new scaled dummy models have shown, that the current standard dummies (5th%ile, 50th%ile, 95th%ile) provide only a limited representation of the real world occupant population. The range of results for the scaled dummies is significantly larger than for the standard dummies. This is partly due to the variation of corpulence and proportion (torso/leg length) which is not considered with standard dummies. This is also partly due to the larger range considered for length and mass. The population studied includes body masses of 42-103 kg where Hybrid III dummies range from 48-101 kg. The population studied includes lengths ranging from 1.48-1.98 m where Hybrid III ranges from 1.52 to only 1.85 m (see Table 1). The results also have shown, that the injury parameters could be largely different for occupants on the same seat position. This has to be taken into account for the development of adaptive restraint systems.

The robustness of restraint systems can be evaluated and improved with the scaled dummy models. The current simulation models have CPU of only 3 minutes on a SGI Origin200 workstation. This made it feasible to analyze 34 occupant sizes for different crash conditions in a limited time. A next step will be to *optimize* a design for different occupants sizes. Here it is presumably recommended to optimize a somewhat more limited population and number of crash conditions.

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