Development of a Chinese 5th Percentile Female Active Human Body Model

Atul Mishra, Pronoy Ghosh, Ravikiran Chitteti, Christian Mayer

I. INTRODUCTION

The increasing market penetration and number of functions from PRE-SAFE® and driver assist systems makes capturing the occupant kinematics in a pre-crash phase and evaluating its influence on a crash result increasingly important. During PRE-SAFE® or/and assist system actions, for example braking or evasive steering, the occupant position may change depending on the occurring low *g* loading condition. Active Human Body Models (Active HBMs) are capable of capturing human kinematics in low *g* loading scenarios that make up the pre-crash phase.

Integrated safety analysis toolchain for which an Active HBM is a pre-requisite was demonstrated in [1]. Previous researchers [2-5] have discussed development of Active HBMs of 50th %ile male anthropometry and numerical muscle controllers. THUMS v6 model family, comprising of 5th %ile female, 50th %ile male and 95th %ile male, have been developed based on the Visible Human Project data [6]. However, a generic method for creating "Active" HBMs of different anthropometries is not yet available.

The current work aims to develop a generic method for creation of "Active" Human Body Models and this is demonstrated through the creation of a Chinese anthropometry 5th %ile female Active HBM in LS-DYNA™. The generic method focuses on estimation of muscle parameters for different anthropometries.

II. METHODS

The current work consists of four major steps:

1. Development of *classical* THUMS-D F05 CNIS HBM-

THUMS-D F05 (Mercedes-Benz AG internal model representing Western 5th %ile female anthropometry) [7], based on **T**otal **HU**man **M**odel for **S**afety (THUMS) v3, was morphed to a Chinese 5th %ile female anthropometry based on China National Institute of Standardization (CNIS) [8] data resulting in *classical* THUMS-D F05 CNIS. This model represents a 5th %ile Chinese female with a height of 1,484 mm and weight of 55 kg.

2. Relaxation of *classical* THUMS-D F05 CNIS HBM-

Previous research [9] has identified the need to "*relax"* the classical HBMs before the subsequent development of an Active HBM. The previous work did underline the importance of flesh material on the high passive stiffness of the classical HBM. Literature survey suggested that a hyper-elastic material is more suitable for representing the soft tissues. Hence, the flesh of torso, pelvis, thighs, lower leg, upper arm and forearm in THUMS-D F05 CNIS HBM were modeled using hyper-elastic material model (MAT_181 in [10]) with soft tissue tensile material properties from a previous research [11]. Furthermore, the skin in the torso region was overly stiff and was relaxed by reducing the elastic modulus. These modifications resulted in *Relaxed* THUMS-D F05 CNIS HBM.

3. Muscle Implementation

Muscles were implemented based on a 50th %ile male Active HBM, A-THUMS-D M50 shown in [1], which represents a mid-size male (Western anthropometry) with height of 1,750 mm and weight of 73.5 kg in LS-DYNA. The model consists of a total of 552 muscle strands, both point to point and routed, represented by 1D truss elements assigned with MAT_156 (MAT_MUSCLE) [10], which were implemented in "Relaxed" THUMS-D F05 CNIS HBM in the current work to develop "Active" THUMS-D F05 CNIS HBM (A-THUMS-D F05 CNIS). The parameters in LS-DYNA MAT_156 are normalised and therefore directly transferable from one model to another.

On the other hand, the Physiological Cross Sectional Area (PCSA) parameter, which is representative of the muscle size and is related to the force (F) generated by a Finite Element (FE) muscle (Eq .(1) [10]), differs between different anthropometries and different genders.

A. Mishra (e-mail: atul.mishra@daimler.com; tel: +91 8061496433) is Project Engineer, P. Ghosh is Project Engineer and R. Chitteti is Senior Program Manager in Human Body Modeling at Mercedes-Benz Research & Development, India. C. Mayer is Program Coordinator with Mercedes-Benz AG, Germany.

$$F = \sigma * PCSA \tag{1}$$

PCSAs for A-THUMS-D M50 50th %ile male Active HBM taken from [12-16] had to be converted to A-THUMS-D F05 CNIS Chinese 5th %ile female Active HBM. The conversion was done at body region level rather than individual muscle group level, to keep the method generic and easy to implement. Scaling factors for different body regions were derived from [6] and [12] for *gender transformation* of muscle PCSAs. In addition, the subjects in [6] and [12] were not of the same anthropometry as either A-THUMS-D M50 or A-THUMS-D F05 CNIS, therefore size normalisation became necessary.

The PCSAs for muscles were converted in three steps:

1. ***Size normalisation*** of A-THUMS-D muscles to male subject in [6][12] using [17]:

$$A^{M\_Sub} = A^{M50} * \frac{W^{M\_sub}}{W^{M50}} * \frac{l_{MT}^{M50}}{l_{MT}^{M\_sub}} \tag{2}$$

Since length values for each muscle are not available and subject heights are similar to A-THUMS-D height, assuming $l_{MT}^{M50} = l_{MT}^{M\_sub}$ we get:

$$A^{M\_Sub} = A^{M50} * \frac{W^{M\_sub}}{W^{M50}} \tag{3}$$

2. ***Gender transformation*** of PCSA values from male subject to female subject using [6][12]:

$$A_i^{F\_Sub} = f_i * A^{M\_Sub} \tag{4}$$

3. ***Size normalisation*** to A-THUMS-D F05 CNIS from female subject in [6][12] using [17]:

$$A_i^{F05} = A_i^{F\_Sub} * \frac{W^{F\_05}}{W^{F\_Sub}} \tag{5}$$

Summarising the above equations and simplifying:

$$A_i^{F05} = A^{M50} * \frac{W^{M_{sub}}}{W^{M50}} * f_i * \frac{W^{F\_05}}{W^{F\_Sub}} \tag{6}$$

$$A_i^{F05} = A^{M50} * F_i \tag{7}$$

TABLE I
LIST OF THE PARAMETERS AND CORRESPONDING SYMBOLS USED

Symbol	Parameter Definition	Source/Value
σ	Total stress generated in a muscle element	[10]
A^{M_Sub}	PCSA of any muscle for male subject	[6][12]
A^{M50}	PCSA of any muscle in A-THUMS-D M50	A-THUMS-D M50
W^{M_sub}	Male subject weight	[6][12]
W^{M50}	A-THUMS-D M50 weight	73.5 kg
l_{MT}^{M50}	Muscle Tendon Unit (MTU) length of a muscle in A-THUMS-D M50	A-THUMS-D M50
$l_{MT}^{M\_sub}$	MTU length of a muscle for male subject	NA
i	Index of body region	
$A_i^{F\_Sub}$	PCSA of a muscle in body region *i* for female subject	[6][12]
f_i	Scaling factor for converting PCSA from male to female subject	[6][12]
A_i^{F05}	PCSA of any muscle in body region *i* for A-THUMS-D F05 CNIS	Calculated
W^{F_05}	A-THUMS-D F05 CNIS Weight	55 kg
W^{F_Sub}	Female subject weight	[6][12]
F_i	Combined muscle scaling factor	Calculated

TABLE II
F_i VALUES (EQ. (8)) IN DIFFERENT BODY REGIONS

Body Region	Calculated Value	Source
Neck	0.613	[12][17]
Shoulder and Chest	0.773	[6][17]
Arms	0.519	[6][17]
Hip	1.037	[6][17]
Upper Legs	0.893	[6][17]

4. Controller Implementation

The neural control model used in this study is the hybrid equilibrium point controller as described in [2], which is a form of intermittent control and based on the assumption that the central nervous system governs the controlled motion through shifting between particular states of the musculoskeletal system – so-called equilibrium points.

Finally, the above steps resulted in an A-THUMS-D F05 CNIS Active HBM. The model was validated with OM4IS phase 1 data [18] as a first step. Model with active muscles and with inactivated muscles is referred to as A-THUMS-D F05 CNIS and *Relaxed* A-THUMS-D F05 CNIS respectively in the following text.

III. INITIAL FINDINGS

The model was seated on a simplified sled model representative of OM4IS phase 1 environment [17], lap belt was modelled and 1 *g* braking pulse (vehicle speed 12 km/h) from [18] was introduced. Gravity loading was applied. Feet were positioned flat on the floor and arms were not repositioned in the current study, but settling of arms was seen during course of the simulation due to gravity loading. The simulation setup is shown in Fig. 1.

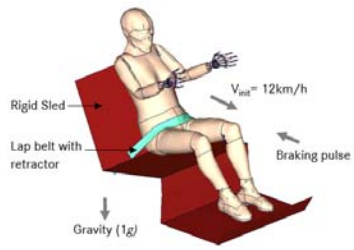

Fig. 1. A-THUMS-D F05 CNIS in OM4IS Phase 1 Environment [17].

Excursion corridors for occupant movement relative to the vehicle for different manoeuvres were developed in OM4IS project, with volunteers close to 50th %ile male anthropometry [18]. These corridors formed the basis for examining A-THUMS-D F05 CNIS kinematics in the sled environment.

In absence of muscle activity, the HBM upper body rotates as a passive system about the restrained pelvis. Therefore, the corridors were scaled by the factor of 0.895 based on the sitting height (Table III) for *Relaxed* A-THUMS-D F05 CNIS HBM. However, excursions of A-THUMS-D F05 CNIS were compared with original corridors.

In the absence of muscle activity, *Relaxed* A-THUMS-D F05 CNIS showed higher excursions compared to the scaled corridors and original corridors as reported in [18], which is indicative of model being relaxed.

In presence of muscle activity, A-THUMS-D F05 CNIS showed significantly lowered excursions. Peak head excursion and peak torso excursion reduced by about 150 mm. The HBM responses are illustrated in Fig. 2.

TABLE III
SITTING HEIGHT VALUES FROM [19]

Mid-Size Male	907 mm
Small Female	812 mm

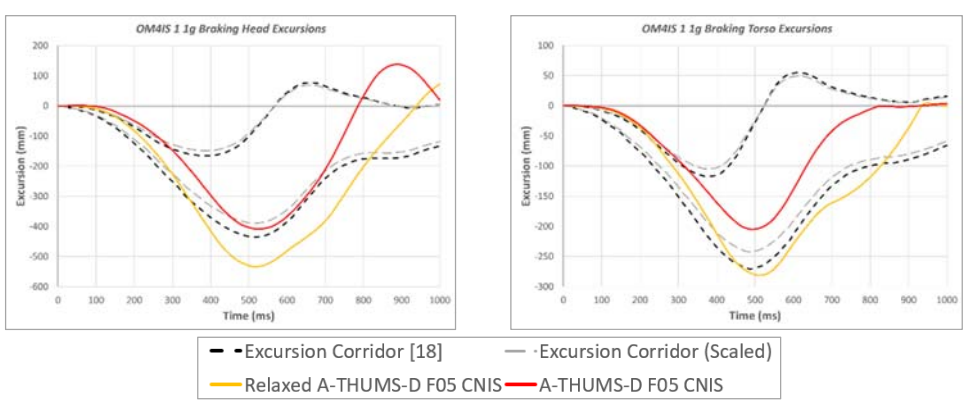

Fig. 2. Excursions recorded with A-THUMS-D F05 CNIS Active HBM in 1 *g* Braking.

IV. DISCUSSION

Active HBMs are developed to capture human responses in low *g* loading scenarios, which are characteristic of the pre-crash phase. The priority at present is to create methods that allow the creation of Active HBMs of different anthropometries to address the topic of integrated safety for all vehicle occupants.

This work is a step in that direction, where a method to transfer muscle PCSA values from A-THUMS-D M50 50th %ile male Active HBM to A-THUMS-D F05 CNIS Chinese 5th %ile female Active HBM was developed based on data available in literature and easily measurable physical quantities, making this method applicable to other anthropometries as well, for example, child models. The A-THUMS-D F05 CNIS without muscle activation showed higher excursions as compared to volunteer corridors from [18] and thus the model was *relaxed.* A-THUMS-D F05 CNIS showed reduced excursions in the presence of muscle activity, which is the expected outcome. This paves way for further validation of the model and subsequent improvements.

There are certain limitations to this study. Current work assumed body region level scaling factors for muscle transfer between male and female HBM for simplicity. However, different muscle groups, in the same body region, may have different proportions between male and female subjects, and using scaling factors for each muscle group will result in a more realistic transfer of PCSAs. In addition, the excursion corridors from OM4IS Phase 1 [18] are derived from tests conducted with volunteers of 50th %ile male anthropometry which may not be directly applicable for validation of the 5th %ile Chinese Female Active HBM developed in the current study. Methods to adapt existing kinematic corridors for validation of Active HBMs to make them suitable for other anthropometries are required as linear scaling based on body size is not appropriate.

The model created in this study A-THUMS-D F05 CNIS needs to be validated further before application in predicting pre-crash occupant responses and use in integrated safety toolchain. The model created would be subsequently used in OSCCAR China project in an integrated safety toolchain as a pre-crash HBM in conjunction with crash HBMs morphed to Chinese anthropometry. Harmonised methods to compare independently morphed HBMs will be created in OSCCAR China project (Tsinghua University, China) along with adaptation of novel virtual safety assessment methods created in OSCCAR Europe project.

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