

## Integration of the Open-Source Extended Hill-type Muscle Material into THUMSv5

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### I. INTRODUCTION

Active Human Body Models (AHBMs) are gaining more and more significance in the design process of new vehicles due to their capabilities of active human motion simulation. Such simulations are often used in pre-crash and passive safety systems development as well as for virtual testing and proof of concept of new interior designs for autonomously driving cars.

There are several AHBMs available on the market for professional use, with Total Human Model for Safety (THUMSv5) [1] currently being one of the most popular among them. The main difference between AHBMs and generic passive Human Body Models (HBMs), used for in-crash simulations, are additional model structures. AHBMs use truss/seatbelt elements to model the human muscular system and sophisticated controller code to govern the muscle activation. As was shown in previous publications [2-3], both of these model structures could be improved in order to get more physiological valid results or to reduce the simulation runtime.

This study aims to implement the extended Hill-type material (EHTM) with an integrated physiological controller proposed in [2-3] into THUMS AM50 Occupant Academic Version 5.02.1 and validate it with an example taken from the THUMS model validation catalogue.

### II. METHODS

#### Experimental Data

To validate the model's behaviour with the newly inserted EHTM muscle elements, experimental data from [4] were used. In this study, a series of volunteer sled tests were conducted to investigate occupant kinematics under a brake deceleration of 0.8 G. The normalised electromyography (EMG) of 24 muscles was recorded and used as an activation level input for the respective muscles. Data for the muscles without corresponding measurements were estimated by a method described in [1]. As a result, the THUMS model is supplied with included files containing two activation conditions: a sleeping driver without activation (*Relaxed*) and a braced driver based on EMG data (*Braced*). A third *Tensed* activation state was obtained from the *Braced* driver state by activating the muscles just enough to hold a seated posture under the gravitational load. The initial position of the model during simulations is shown in Fig. 2.

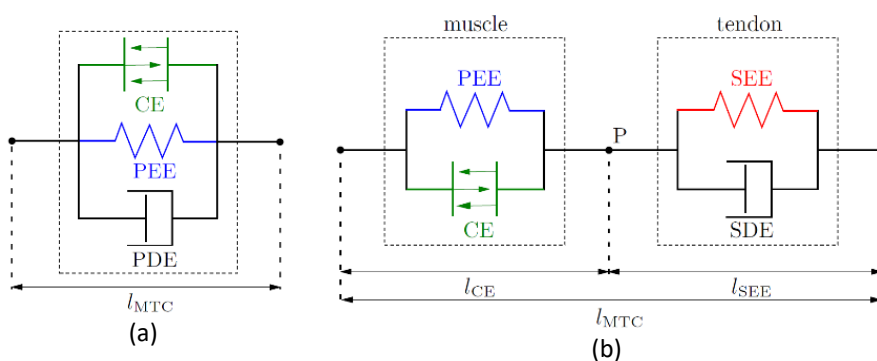


Fig. 1. Element structure of the LS-DYNA MAT\_156 (a) and Extended Hill-type models (b).



Fig. 2. THUMSv5.02 AM50 OC Academic in the initial position.

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### Computational Modelling

The muscular system in the original THUMSv5.02 is modelled using truss elements with an assigned Hill-type muscle model (MAT\_MUSCLE, MAT\_156 in LS-DYNA, Fig. 1 (a)). All material parameters of MAT\_156 were converted to respective parameters of EHTM with missing data taken from anatomy literature sources. For some muscles of the limbs, these elements were combined with additional elements. Seatbelt/slip ring elements were included to model long tendons and their routing over the joints, while shell elements were used to model tendons which have a broader contact area to adjacent bones, thus making joints more stable during movements. In contrast to MAT\_156, EHTM has the advantage of including the tendon as an element of the Hill-type muscle model itself Fig. 1 (b). Thereby, the combination of EHTM with the seatbelt/slip ring elements is no longer needed. Muscles with long tendons could be modelled by several elements with EHTM material, routed with the PART\_AVARAGED keyword when needed, providing more stability to the model. Shell elements were kept intact, as the required joint stability could not be achieved by only using truss elements.

### III. INITIAL FINDINGS

Six simulations were conducted covering three different muscle activation states for two models, original THUMS v5.02 and the newly created THUMSv5.02-EHTM. Initial results for Head and T8 centres of gravity (COG) displacements in a relative coordinate system are presented in Fig. 3. As seen, both models deliver comparable kinematics results for all cases, with the displacements being more pronounced for THUMSv5.02-EHTM.

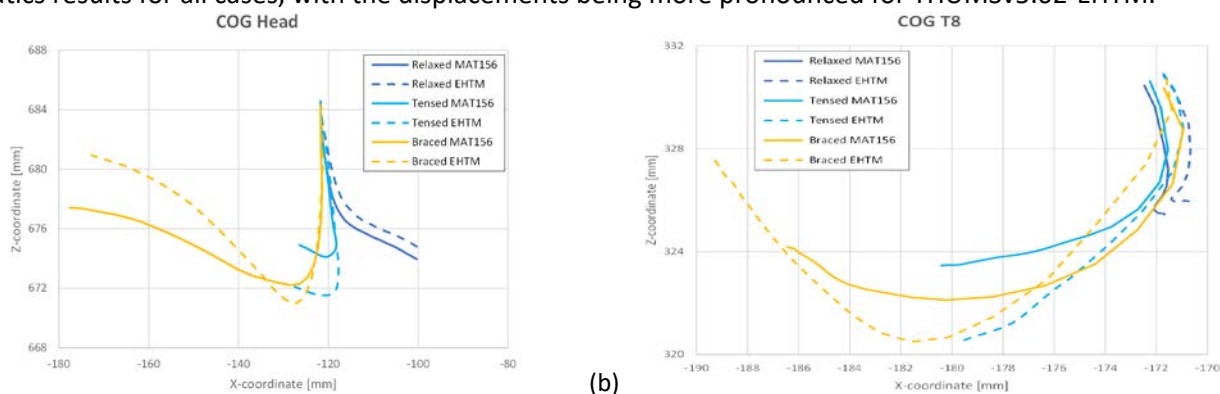


Fig. 3. Displacements of Head (a) and T8 (b) COGs for six different simulation cases.

### IV. DISCUSSION

Simulation results show that the THUMSv5.02-EHTM model is more compliant compared to the original one. This fact could be explained by the structure of the physiological elements of Hill-type models (Fig. 1 (a) and (b)). According to the model scheme, MAT\_156 is stiffer, because all of its three elements are connected in parallel, so that the parallel elastic element (PEE) and the parallel damping element (PDE) are producing forces in different muscle states. As for the EHTM, PEE force is dependent on the contractile element (CE) force, which means it produces less additional force when muscle is extending under the external load comparing to MAT\_156. Therefore, insertion of the EHTM improved the overall THUMSv5.02 properties, because HBMs tend to be too stiff when compared to living humans, as was shown in [5].

In the future, the model should be validated with other experimental data in different loading scenarios.

### V. ACKNOWLEDGEMENTS

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### VI. REFERENCES

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