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H-Model™ Overview Description

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ABSTRACT

Owing to the lack of biofidelity, crash dummies can not adequately express crash injuries. Numerical human body modeling has strong potential to add biofidelity. Recently, a finite element human model (named and registered as H-Model™), which consists of outer skin and detailed internal components such as skeleton and soft tissues, has been developed. The outer skin is divided into 20 rigid segments, which are interconnected by the various joint types. Each segment incorporates all relevant dynamic properties such as mass, location of center of masses, inertias and joint resistances determined by using anthropometric data. A simple version is given by the "Human Articulated Rigid Body (HARB)" model. Detailed local models for important body parts (e.g. neck, thorax, pelvis, knee, etc.) are also developed. These local modules can be selectively added into the HARB model as needed. In practice, H-Model™ is an assembly of the HARB model and the local modules that are selected depending upon the purpose of the investigation of the moment. The HARB model can be used alone for evaluating global occupant behavior in crash situations. For elucidating individual injury mechanism such as bone fracture or soft tissue rupture, relevant local component module(s) should be added into the whole-body dummy model. The distinguishing feature of the present finite element human dummy model is omni-directionality. As opposed to currently available mechanical dummy models that cater to particular impact directions, the omni-directional H-Model™ can be utilized for all possible combinations of impact directions.

INTRODUCTION

This paper only gives an introductory summary of the structure of ESI Software's H-Model™. Interested readers are referred to the H-Model Reference Manuals (ESI Software/IPS-Intl.) for many more details. The basic model represents the 50-th percentile male human body and was conceived primarily to study injury mechanisms and to assess injuries of the human skeleton and organs which result from car accidents, including pedestrian injuries. The basic model permits in particular a fast and ongoing absorption of the nowadays rapidly growing biomechanical research results, the conception of improved crash protection measures and devices for the human driver (not the dummy), the omni-directional analysis of different impact directions (front, side, rollover with a single model with global and local responses to bags, belts, head restraints, knee bolsters, etc), the analysis of different body postures, the effect of muscle activity, and the reduction of the number of tests needed for the safe design of passenger cars.

Features.

Major features of the H-Model™ are given by a modular assembly of the deformable external and internal components into an underlying multi-body H-ARB (Human Articulated Rigid Body) model. Modularity permits to make zooms and study in detail each body part of interest, such as, for example, the head in head impacts, the neck in whiplash events, the thorax and abdomen for belt injuries, the lower extremity in knee impacts, the foot/ankle complex in toe panel intrusions and the upper extremity and shoulder complex in side impacts and airbag aggressions. Figure 1 shows an overall view of the model with skin and skeleton.

History.

The H-Model is a recent combination of two previous ESI Group biomechanical models of the human body, namely the "ROBBY" and the "H-Dummy" model families. The overall anthropometric properties of both models were mainly extracted from the report by D.H. Robbins *"Anthropometry of Motor Vehicle Occupants"*, Vols. 2-3, University of Michigan, UMTRI-83-53-2, 1983, after which the ROBBY family had been named. The new model family is now co-developed by the Seoul and Paris biomechanics teams of ESI Group.

Validation.

All listed models and sub-models have been validated with existing literature results. The basic validation tests and results are described in the H-Model Reference Manuals (ESI Software/IPS-Intl.)

Figure 1. H-Model with skin and skeleton

Figure 2. H-ARB version of H-Model

The H-ARB Human Articulated Rigid Body Model

The H-ARB version of the H-Model consists of articulated rigid body segments with flexible joints, after the Robbins Report (Robbins, D.H., 1983).. It represents the basic platform for the modular assembly of detailed skeleton components with soft tissues. It serves for the evaluation of the overall behavior kinematic and kinetic behavior of the occupant for omni-directional impacts. Figure 2 shows the H-ARB version of the H-Model with the joint tripods indicating the location and direction of the anatomical joints.

Figure 3 represents the overall response of the H-ARB model in a frontal car crash sled test scenario, while Figure 4 shows the overall response of this model in an arbitrary out-of-position (OOP) scenario of a car passenger.

Figure 3. Sled test with H-Model/H-ARB

Figure. 4. OOP passenger airbag with H-Model/H-ARB

Zooms.

For detailed studies ("zooms") of the impact response of the individual body parts, it is possible to substitute their detailed finite element models into the H-ARB version of H-Model. The following sections outline such detailed models. This modular approach saves CPU time while the overall model response correctly represents the kinematics of the body to generate the dynamic boundary conditions for the required zoom.

H-Head: Skull and Brain

The detailed FE head model (H-Head) of the H-Model mainly consists of deformable bone and brain components. The cerebro-spinal fluid (CSF) is presently modeled with the Murnaghan equation of state, ($p=p_0+B((\rho/\rho_0)^{\gamma-1})$, where p is the hydrostatic pressure, ρ, is the mass density and B and γ are material constants. For the modeling of the vacuum cavity that can develop at the interface between the skull and brain from negative countercoup pressures, ideal gas equations are used. The model is fully compatible with the H-Neck spinal cord model.

Figure 5 shows the head and brain model in cutaway views and the head model in the position of a simulated pendulum impact. Figure 6 shows contours of the pressure at the surface of the brain matter as they develop at several times after the pendulum impact.

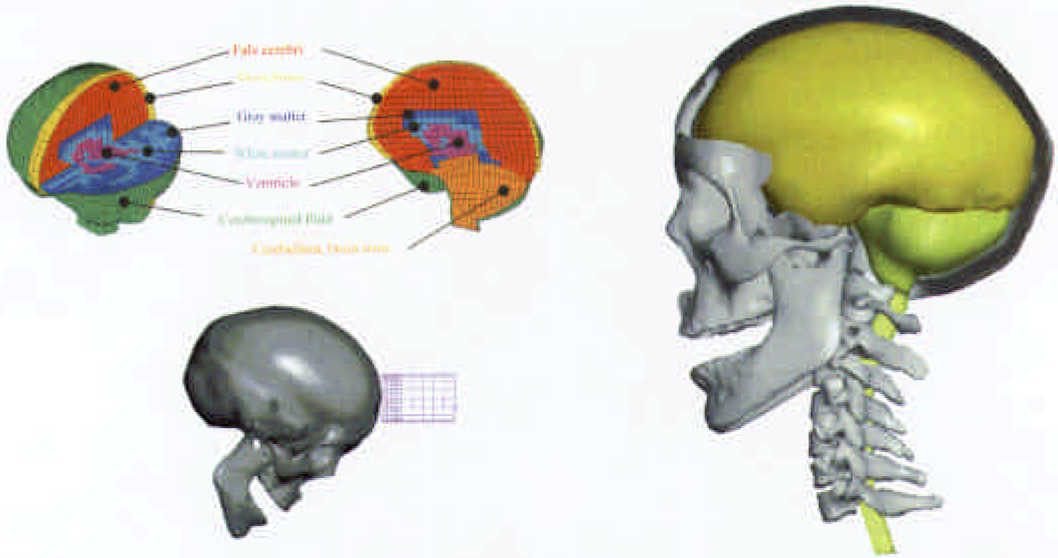

Figure 5. H-Head model and impact pendulum

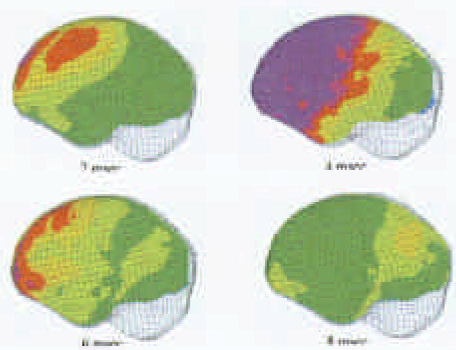

Figure 6. H-Head pressure response of brain to pendulum impact

H-Neck: Cervical Spine with active muscles

The H-Model is equipped with a cervical spine model (H-Neck) with rigid vertebrae and deformable ligaments and discs, that is stabilized with muscle bars. The muscle forces obey the well known active and passive Hill muscle law. The H-Neck model is fully compatible and interfaced with the H-Head model. The muscle bars are curved in space and can change curvature with the increasing flexure deformation of the cervical spine, assuring a correct introduction of the muscle forces. Figure 7 shows the assembled H-Head/H-Neck model.

The vertebrae of the H-Neck model are interconnected by the neck ligaments, modeled as bars or membranes. The inter-vertebral contacts are modeled with sliding interfaces. Figure 8 shows the extension response of the H-Neck model in a rear passenger car impact, while Figure 9 represents the flexion response for a frontal crash.

Figure 10 shows the response of the H-Neck model mounted on the H-ARB version of the H-Model in a rear impact sled test simulation with a headrest, while in the simulation of Figure 11 such a headrest was absent.

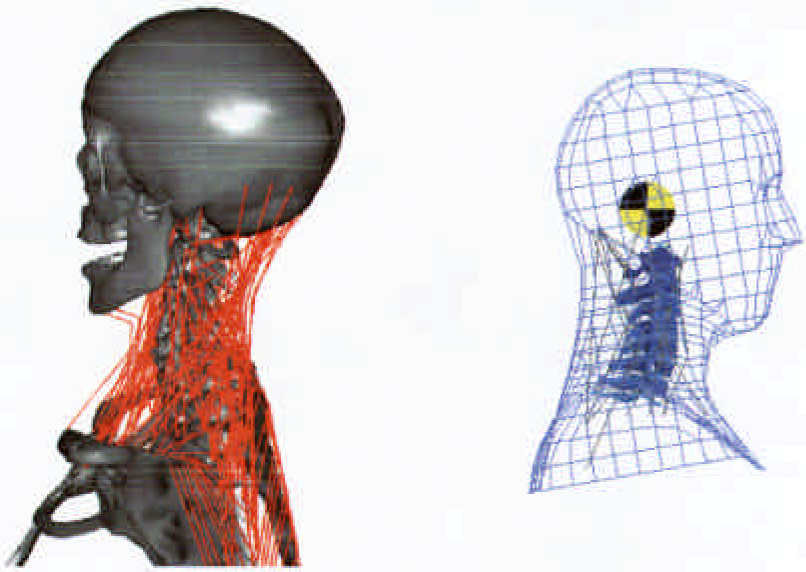

Figure 7. Assembled H-Head/H-Neck model

H-MODEL™ OVERVIEW DESCRIPTION

Figure 8. H-Neck extension due to rear-end collision

Figure 9. H-Neck flexion due to frontal impact

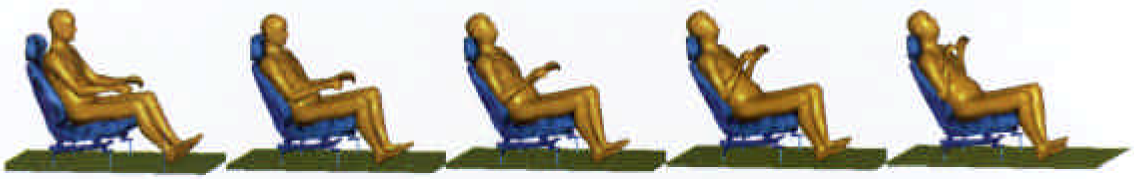

Figure 10. H-Model/H-Neck rear impact sled simulation with headrest

Figure 11. H-Model/H-Neck rear impact sled simulation without headrest

H-Thorax: Rib Cage and thoracic organs

The thorax of the H-Model (H-Thorax) mainly consists in deformable and damageable rib and spine bones and the thoracic organs and great vessels with internal air and blood modeling, Figure 12. The blood-filled vessels are simulated with their incompressible fluid, while the lungs can compress like airbags. Both models can leak out fluid or compressible air ("bio-bags").

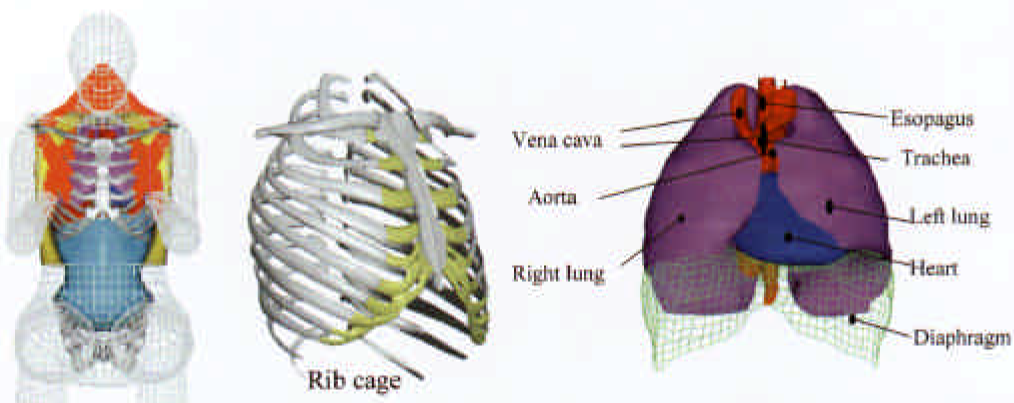

Figure 12. H-Thorax model with rib cage and internal organs

The abdominal cavity is represented as an incompressible bio-bag. Figure 13 shows the global response of the H-Thorax model under a frontal pendulum impact after the cadaver tests done by Kroell. Figure 14 represents the local response in a transverse section of the same simulation, with the deformations of the heart, lungs and cut vessels visible.

Figure 13. H-Thorax response in frontal pendulum impact simulation

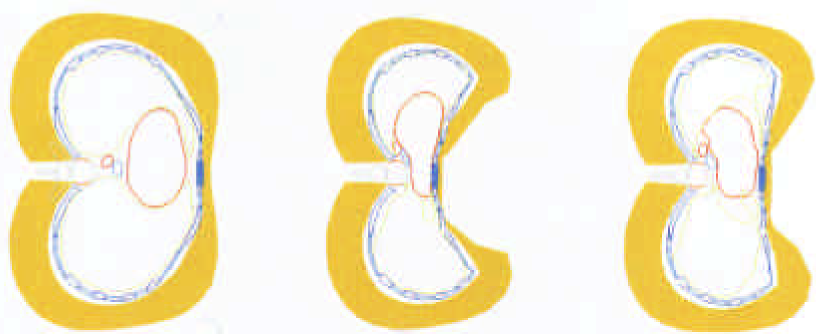

Figure 14. H-Thorax response in frontal pendulum impact simulation (sections)

H-UE: Shoulder and arms

The upper extremity (H-UE) of the H-Model mainly consists of deformable and damageable bones and flesh padding. Active and passive muscle forces are modeled with bar elements using the Hill muscle model.Nonlinear contact interfaces model the cartilage layers on shoulder and elbow joints. Figure 15 shows the H-UE model in its context, while Figure 16 shows the skeleton and the attached muscle bars.

Figure 15. H-UE model

Figure 16. H-UE model with shoulder muscles

Figure 17 indicates details about the shoulder and elbow ligaments, which are modeled with nonlinear bars. Figure 18, finally, shows the simulation of a three point bending test including bone fracture of the humerus bone.

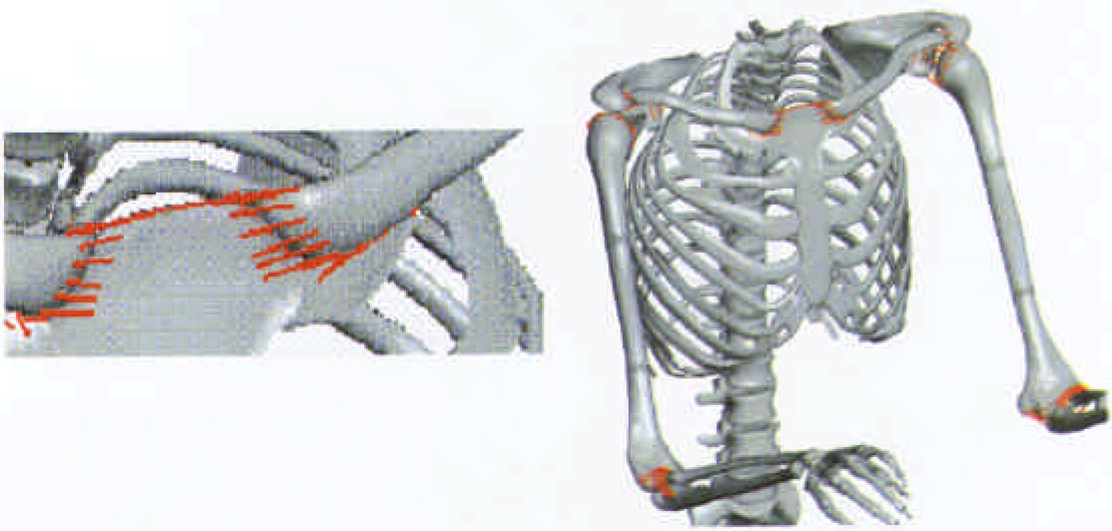

Figure 17. H-UE shoulder and elbow ligaments

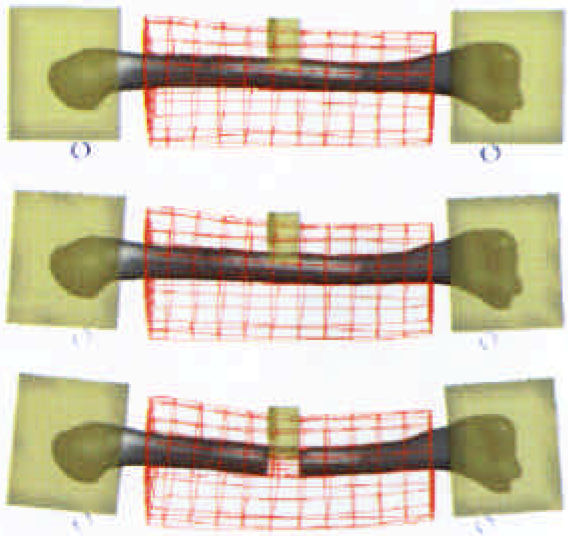

Figure 18. H-UE three point bending simulation of humerus

H-LE: Knee-Thigh-Hip complex

The lower extremity (H-LE) of the H-Model mainly consists of deformable and damageable bone models with flesh padding and muscle bars. Nonlinear contact interfaces model the cartilage layers of the hip and knee joints. Figure 19 depicts the H-LE model in its context.

Figure 19. H-LE model

Figures 20 to 22 result from the study of the influence of the stiffness of the knee bolster padding material on the type of injury to the upper leg in a frontal car crash. While a soft padding (Figure 20) can lead to "condyle splitting" (distal femur fracture), a soft padding (Figure 21) to hip dislocation, an intermediate stiff padding (Figure 22) can lead to the relatively benign shaft fracture of the femur.

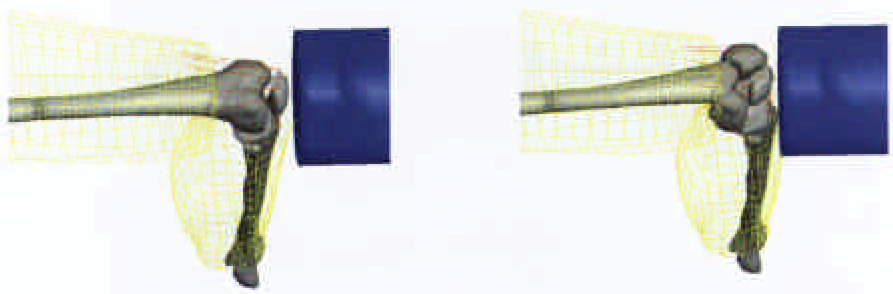

Figure 20. H-LE condyle split with hard padding

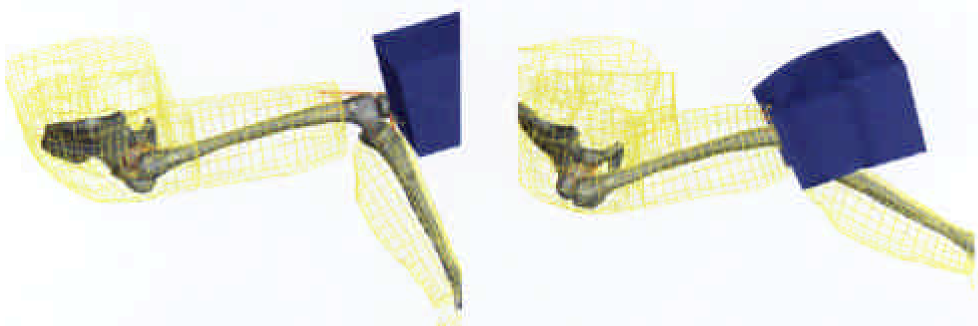

Figure 21. H-LE hip dislocation with soft padding

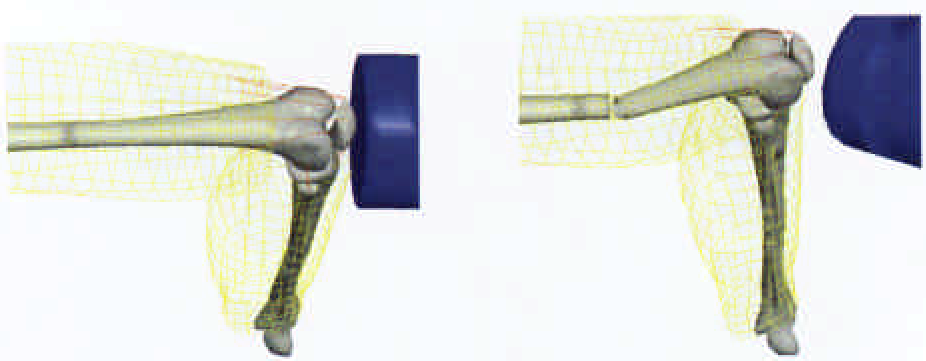

Figure 22. H-LE shaft fracture with intermediate padding

H-Ankle&Foot

The H-Ankel&Foot model mainly consists of deformable and damageable bone models, joint elements for foot bone articulations and sliding interfaces for the major articular surfaces, see Figure 23. Figure 24 shows the model with its plantar muscles and tendons.


Figure 23. H-Foot&Ankle model overview

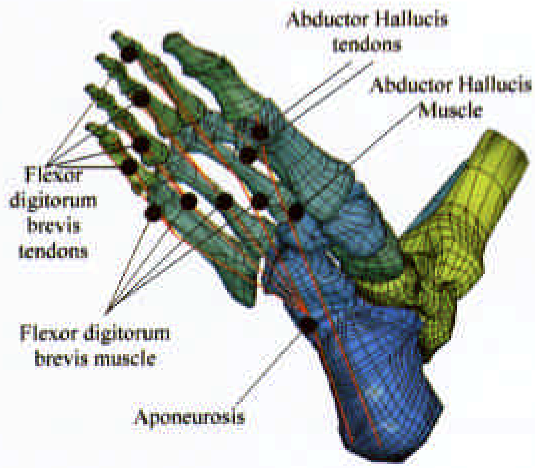

Figure 24. H-Foot&Ankle model with plantar muscles

Figures 25 to 27 are H-Foot&Ankle simulation responses to plantar loads, leading to dorsiflexion, inversion and eversion of the foot/ankle complex.

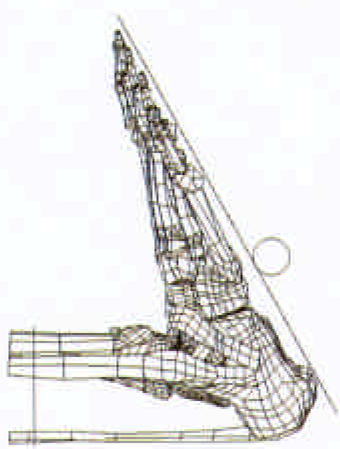
Figure 25. H-Foot&Ankle dorsi flexion

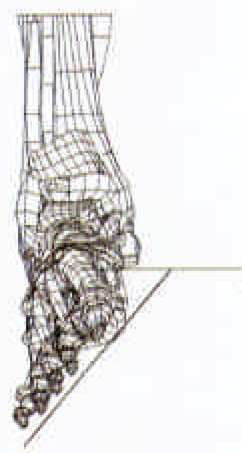
Figure 26. H-Foot&Ankle inversion

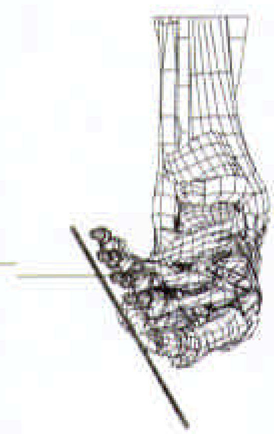
Figure 27. H-Foot&Ankle eversion

CONCLUSIONS

This document presents a short overview on ESI Group's H-Model of the human body, that was developed mainly for crash and impact studies in passenger car accidents. The latest model and its Reference Manuals become available in Fall 2000. The model is part of a greater emerging library of compute models ("BioLib"), which will contain models of the human body that are conceived and validated mainly for ergonomics and biomedical applications. All models benefit from the synergy created from their different fields of application.

ACKNOWLEDGMENTS

The material in this document was edited by Eberhard Haug (Scientific Director, ESI Software, 99 rue des Solets, Silic 303, 94588 Rungis Cedex, eh@esi.fr). The ESI Group biomechanics developments are carried out jointly by the following persons and their staff at different institutions: Hyung-Yun Choi (Associate Professor, Hongik University ME Dept., http://safety.hongik.ac.kr/), Inhoek Lee, (Engineer, IPS-Intl., Seoul, Korea), Muriel Beaugonin, (Leader of the Biomechanics Safety Group, ESI Software, 20 rue Saarinen, Silic 303, 94588 Rungis Cedex, mb@esi.fr).

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H-Model Reference Manuals. ESI Software/IPS-Intl.

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DISCUSSION

PAPER: **H-Model Overview and Description**

PRESENTER: ***Eberhard Haug, ESI group***

QUESTION: *Guy Nusholtz, Daimler Chrysler*
Did I hear you correct this is a Frankenstein model? You've taken models from all over the place and kind of glued them together?

ANSWER: Not quite. We have three different families of models, an old one, the ROBBY model family, a newer one which is the H-model family which has been built from scratch, all new where the data came from the ViewPoint Datalab Catalog, the VisibleHuman Project,the Robbins report and so on. The third model family is the HUMOS project model that has been brought about in a three year European project which is by now finished and that might continue in a second three year period. So these are three different model families. Only the first one (ROBBY) is sort of a Frankenstein model where we have inputs from Wayne State university and our own inputs.

Q: So it's just the first one, the rest were developed from scratch?

A: Right

Q: Okay. Thank you.