Finite Element Human Computer Models in Vehicle Safety Applications

Dr Christophe Bastien¹, Dr Michel Behr², Prof Kambiz Kayvantash³, Dr Zahra Asgharpour⁴

¹ Coventry University
² IFSTTAR
³ CADLM
⁴ Automotive Safety Technology

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Research Collaboration Network

SIMulation technologies in the fields of BIO-Sciences and Multiphysics: BioMechanics, BioMaterials and BioMedicine
UNDERPINNING FOR THE USE OF HUMAN MODELS
Accident Fatality Landscape

- Plateau of number of fatalities since 2005
- Passive technology has reached its maximum capabilities
- Cost/ life benefit?
- Increased structural mass
- If 5 star EuroNCAP vehicles are safer (Folksham), many injuries still cannot be explained (PRISM, FP7)
- Active safety since 2014 will change the accident landscape

Why need Human Models?

- Crash events can be separated in 3 distinct phases
  - the vehicle impacting the barrier
  - the occupant impacting the restraint system and finally,
  - the organs impacting the occupant internal body cavity

- Require a predictive injury response and NOT a statistical risk of injury

- Current models are unidirectional and passive (new safety features will require active muscles)

- Future requires omnidirectional model with bio-fidelic response

- A Human is asymmetric
- Aging population
- Obesity (seatbelt, inertia)
- Gender
- Previous medical conditions

Correlation with crash test dummies is not injury causation in a real-life accidents
Comparison Hybrid III and THUMS

Kinematics is very different
PASSIVE HUMAN MODELS
HUMOS2 Human Model (Development)

- Sponsored by the European Community, the HUMOS project has involved several partners from automotive industry, research institutes, universities and software providers.
- The first phase of the project was initiated in 1997, the first HUMOS 1 FE model was released in 2001. The second phase started in 2002, the improved HUMOS 2 finite element model was released in 2006 together with an associated scaling and positioning tool.

Cadaver frozen and then sliced

MRI and CT scans of slices

Build of skeleton, muscles and organs
FE Human Models For Safety Assessment

- THUMS V3.0 model available in occupant and pedestrian (50th)
- Biofidelity of human geometry and mechanical properties
- Component parts of the bone, skin, ligaments.
- There are no internal organ modeling, In the abdomen area there are several layers of skin.
- Lungs modeled like a lumped masses, and abdomen also just a volume of the body representing the abdomen and lung.
- Detailed joint models of the lower extremity and the shoulder with ligaments, tendons, etc.

- Reasonable computational time for automotive crash analysis

Male
Height 175 cm
Age: 30-40 year old
Weight 77 kg
186 contacts
Elements: 145,000
FE Human Models For Safety Assessment

**THUMS 4.01**

**GHBM**

Organ and Muscle

MRI with pelvis and hip bone outline (red)

M50 Standing
Mostly Used Human Models

• THUMS 4.01 (40 year old)
  – 19 contacts (most contacts in head area)
  – 1 single contact for all organs
  – 1.8 million elements
  – 0.6 \( \mu \)s for a mass scaling of 2%
  – No failure criteria in material models
  – Stable model. Perfect energy curves

• GHBM (26 year old)
  – 450 contacts (more contacts in thorax area than THUMS 4.01)
  – Includes digestive system
  – Includes veins and aorta
  – 0.5 \( \mu \)s for a mass scaling of 2%
  – 2.0 million elements
  – Failure criteria in some material models
  – Stable but gives sometimes hourglassing in flesh area
Positioning Challenges

• THUMS 4.0 and GHBM models are difficult to position because of complex internal organs (not a mechanism)

• It is possible to position THUMS V3.0 in a pre-processor

• Positioning:
  – Rigidise ‘hard tissues’, i.e. bones (Java scripting in Primer)
  – Timestep increases to 1.6\(\mu\)s
  – Run for 2.0s to reduce inertial effects
  – Un-rigidise the bones
  – Re-map strains (flesh) for next run
  – 2.0s of event runtime in 4h (192 processors)

• Runtime in crash safety:
  – 160 processors
  – 10 hours of computation
  – 120ms event runtime
Scaling and Personalisation

- Commercial Algorithms from IFSTTAR and CADLM
- “PIPER” Position and Personalize Advanced Human Body Models for Injury Prediction
- The main objective of the PIPER project will be to develop new tools to position and personalize these advanced HBM.

- By facilitating the generation of population and subject-specific HBM and their usage in production environments, the tools will enable new applications in industrial R&D for the design of restraint systems as well as new research applications.
Frontal Pendulum Impact (2.5m/s)

Frontal Impact Force Response vs. Kroel PMHS Tests

GHBM Human Model

DvT

FvD

FvT
Frontal Pendulum Impact (4.3m/s)

Frontal Impact Force Response vs. Kroel PMHS Tests

DvT

FvD

FvT
Frontal Pendulum Impact (6.7m/s)

Frontal Impact Force Response vs. Kroel PMHS Tests

DvT

FvD

FvT
Oblique Pendulum (2.5m/s)

Oblique response vs Shaw PMHS Tests

GHBM Human Model

FvD

DvT

FvT
Oblique Pendulum (4.3m/s)

Oblique response vs Shaw PMHS Tests

FvD

Graph showing force (N) vs deflection (mm) with various lines representing average, upper, lower, and model.
Table Top Test (Single Belt)

M1 + M2 - State 1 at time 0.000000
Belted Sled Test

Belted Sled Tests (Shaw 2009)
PASSIVE PREGNANT HUMAN MODEL
Pregnant Human Model

- **Objective:** Reduce the risk of adverse fetal outcome resulting from road accidents (leading cause of fetal loss resulting from trauma)

  - Placenta
  - Amniotic fluid (FSI formulation)
  - Uterine wall
  - Fetus

- Develop a biofidelic pregnant woman model in the LS-DYNA environment
Pregnant Human Model

- Frontal crash at 40km/h
- Large strain at the Utero Placenta Interface (UPI)
- Adverse fetal outcome predictor based on strain distribution at the UPI area
- UPI loading mainly due to inertial effect
- Develop and assess the effectiveness of safety devices specific to pregnant woman morphology
SEAT PRESSURE MAPPING
Seating Human Thigh Pressure Maps

- Pressure distribution
- Contact area
- Deformed cushion profile
- Comfort indication (pressure distribution related)
ACTIVE HUMAN MODEL
Active Muscles Algorithm

- Sensory and motor loops modelling at the scale of an articulated musculoskeletal segment

In order to get our control loop, Stellar (CADLM) communicates with several computer programs:

- The LS-DYNA Model
- Internal Python scripts
- External softwares

Central activation from CNS
- Update activation in LS-DYNA Model
- LS-DYNA calculation
- Get muscle fibre length
- Get average fibre length per muscle
- Apply fibre length for each muscle in a muscle spindle model
- Use results from muscles spindles to update muscle force
Active Muscles Algorithms

- The muscle activation contains 5 steps:
  1. Impact of the hammer (black ring) on the biceps brachial tendon
  2. Stretch of sensors which are part of the muscles
  3. Delay of 40 ms
  4. Muscle contraction of the agonist muscles (biceps brachial and brachialis)
  5. Elbow flexion
Active THUMS (development)

Ejima reflex test (2009)  Development of Active THUMS 5.0 (2014)

How does it compare with real-life occupant behaviour?
OM4IS Reflex Test

• Occupant requested to hold a virtual steering wheel and to tense (reflex)
• Kinematics is less pronounced than Ejima’s test used for THUMS’ reflex validation…
• What should be the REFERENCE test to validate Human models for low deceleration scenarios?
• The discussions have started…
Conclusions

• Only Finite Element Human Models will improve further vehicle safety in the future over the use of crash test dummies, which are non-biofidelic and passive
• Correlation is not causation
• Finite Element Human Models are omnidirectional, hence 1 model does it all in passive safety (as 2015)
• Organ injuries assessment are now strain related (no injury criteria are coded)
• Force displacements responses are correlated to cadaver tests, BUT no information has been extracted about internal organ damages
• More work is needed to address link between human computer models and real-life AIS
Conclusions

• Active models are being worked on but look few years away
• Active models need a reflex feature as well as a cognitive loop in order to replicate active safety scenarios and driver behaviours in the future
• Improvements in material characterisation and muscle activation are still needed
• Positioning and personalising tools are still needed (PIPER)
• THUMS and GHBM have been created through an incredible effort by scientists and analyst and are both promising models to assess trauma in a predictive manner (non statistical)
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