Helmet optimisation based on head-helmet modelling

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The Human Element

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Presentation Overview

• Introduction

• ULP-Strasbourg Head FE model Presentation

• Improved head injury criteria

• Helmet modeling and coupling with the head

• Helmet optimization

• Conclusion
INTRODUCTION

• One of the most frequent and severe injuring in almost all types of accidents
• Standards ? Upon criteria based on research performed more than 30 years ago
• Injury potential is assessed against HIC based on the linear acceleration of a single mass
• Helmet optimisation against biomechanical criteria is possible
Importance of motorcyclist’s head (from COST 327)

MAIS 1

MAIS 2

MAIS 3 +

80%
Hybrid III Head Model

$M = 4.58 \text{ kg}$

$$HIC = (t_f - t_i) \left[ \frac{1}{(t_f - t_i)} \int_{t_i}^{t_f} \ddot{a} \, dt \right]^{1.5}$$
Human Head Modelling at ULP- Strasbourg

1990

1992

1994

1998
FE MODEL BUILDING

Rebuilt skull surfaces

Skull meshing

FE model building
MEMBRANES AND BRAIN

Faulx and tentorium

Meshing of the brain
CSF ANF FACE MODELLING

Brain and CSF

Face
MECHANICAL PROPERTIES OF FE MODEL COMPONENTS

<table>
<thead>
<tr>
<th>structure</th>
<th>( \rho ) [kg/m³]</th>
<th>( E ) [Mpa]</th>
<th>( \nu )</th>
<th>( \sigma_t ) [Mpa]</th>
<th>( \sigma_c ) [Mpa]</th>
<th>( K ) [Mpa]</th>
<th>( G_0 ) [Kpa]</th>
<th>( G_{\text{inf}} ) [Kpa]</th>
<th>( \beta ) [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>cortical bone</td>
<td>15000</td>
<td>0,21</td>
<td>90</td>
<td>145</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>spongy bone</td>
<td>1500</td>
<td>4500</td>
<td>0</td>
<td>35</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSF</td>
<td>1040</td>
<td>0,012</td>
<td>0,49</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>brain</td>
<td>1040</td>
<td>1125</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>skin</td>
<td>1200</td>
<td>16,7</td>
<td>0,42</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>membranes</td>
<td>1140</td>
<td>31,5</td>
<td>0,23</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
# FE Model Validation Against Different Impact Configurations

<table>
<thead>
<tr>
<th>Test</th>
<th>Impact area</th>
<th>Impactor [kg]</th>
<th>Impactor velocity [m/s]</th>
<th>Force [N]</th>
<th>LA maxi [g]</th>
<th>RA maxi [rad/s²]</th>
<th>Duration [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nahum 1977</td>
<td>front</td>
<td>cylinder with padding [5,6]</td>
<td>6,3</td>
<td>6900</td>
<td>198</td>
<td>6,5</td>
<td></td>
</tr>
<tr>
<td>Trosseille 1992 MS 428_2</td>
<td>face</td>
<td>steering wheel [23,4]</td>
<td>7</td>
<td>102</td>
<td>7602</td>
<td>15,8</td>
<td></td>
</tr>
<tr>
<td>Yogonandan 1994</td>
<td>vertex</td>
<td>rigid sphere [1,213]</td>
<td>7,3</td>
<td>10500</td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Brain motion validation against Hardy’s Impacts (2001)
Against Improved injury criteria
Attempts for new tolerance Limits

• FE head modelling and accident simulation
  King et al. 2003

• Experimental accident reconstruction
  Chinn et al. - 99, Willinger et al. - 2000

• Animal models
Head Injury Mechanisms

Brain
- Contusion
- DAI

Interface
- SDH

Skull
- EDH
- Fracture
Injury mechanisms and mechanical parameters

Skull fracture ———> Bone loading

Extradural Hematoma ———> Bone loading

Subdural Hematoma ———> Brain-skull relative motion

Focal brain Contusion ———> Local brain loading

Diffuse brain axonal or hemorrhagic injury ———> Brain loading
ACCIDENT RECONSTRUCTION

Real world head impact simulation

- Motorcyclist accident (13)
- Sport accidents (22)
- Pedestrian accidents (29)
COST 327 ACCIDENT DATA
WORKING GROUP

Indeep analyses of accidents

Detailed medical reports
Experimental accident replication

Model inputs – Helmeted american footballers

Experimental accident replication

Validation parameters

Measured dummy head acceleration field

Rigid skull applied velocity field
Analytical accident replication

Model inputs – Knocked down pedestrians

Analytical accident replication

Validation parameters

Accident data
- Windscreen damages
- Head superficial wounds

Initial relative angular position and velocity between the head and the windshield
NUMERICAL RESULTS (2) - CASE G174

Brain pressure field at 5 ms

Brain Von mises stress field at 9 ms
ULP injury prediction Assessment

Sub-dural and sub-arachnoidal haematoma – Histograms

Global strain energy of the sub-arachnoidal space

Threshold $\approx 5000$ mJ
ULP injury prediction Assessment

Sub-dural and subarachnoidal haematoma – Risk curve

Global strain energy of the sub-arachnoidal space

Risk 50% ~ 4995 mJ
ULP injury prediction Assessment

Moderate neurological injuries – Histograms

Intra-cerebral Von Mises stress

Threshold ~ 20 kPa
ULP injury prediction Assessment

Moderate neurological injuries – Risk curve

Intra-cerebral Von Mises stress

Risk 50 % ~ 18.5 kPa
ULP injury prediction Assessment

Severe neurological injuries – Histograms

Intra-cerebral Von Mises stress

Threshold ~ 40 kPa
ULP injury prediction Assessment

Severe neurological injuries – Risk curve

Intra-cerebral Von Mises stress

Risk 50% $\approx 35.4$ kPa
ULP injury prediction Assessment

Skull bones fractures – Histograms

Global strain energy of the skull

Threshold ~ 2500 mJ
ULP injury prediction Assessment

Skull bones fractures – Risk curve

Global strain energy of the skull

Risk 50 % \( \sim 2531 \text{ mJ} \)
Recall ULP Criteria

New head injury criteria to specific injury mechanisms

- **Sub-arachnoidal haematoma**
  - Global strain energy of the sub-arachnoidal space $> 5$ J

- **Moderate neurological injuries**
  - Intra-cerebral Von Mises stress $> 18$ kPa

- **Severe neurological injuries**
  - Intra-cerebral Von Mises stress $> 38$ kPa

- **skull fractures**
  - Global strain energy of the skull $> 2.5$ J
HELMET MODELLING
Literature review

Mills et al. (1988)
Guimberteau et al. (1998)
Yetram et al. (1994)
Vetter et al. (1987)
Brands et al. (1996)
External surface of the Helmet

Outer Shell
(524 Shell elements)
Thickness 4mm

Foam
(1675 Brick elements)
Thickness 40 mm
Mechanical properties

Foam compression tests

\[ \varepsilon_{t+1} = \varepsilon_t + \left[ \frac{(v_{t+1} + v_t) \times 1}{2 \times e} \right] \]

\[ \sigma_t = \frac{m \gamma_t}{s} \]
## Mechanical properties

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Model</th>
<th>$E$ [GPa]</th>
<th>$\nu$</th>
<th>$\rho$ [kg/m$^3$]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer shell</td>
<td>Thermo-plastic</td>
<td>linear-elastic</td>
<td>1.5</td>
<td>0.35</td>
<td>1055</td>
<td>Thickness = 4mm</td>
</tr>
<tr>
<td>Protective padding</td>
<td>Expanded polystyrene</td>
<td>elastoplastic</td>
<td>1.5e-3</td>
<td>0.05</td>
<td>25</td>
<td>Thickness = 40mm, Yield stress = 0.35MPa</td>
</tr>
<tr>
<td>Headform</td>
<td>aluminium</td>
<td>rigid</td>
<td>27</td>
<td>0.3</td>
<td>_</td>
<td>Mass = 4.27 kG</td>
</tr>
</tbody>
</table>
Model Validation (1)

Headform (2208 nodes ; 1652 elements)

\[ HIC = \left( \frac{t_2 - t_1}{t_2 - t_1} \right) \left[ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} adt \right]^{2.5} < 2400 \]

Front impact

\[ V = 7.5 \text{ m/s} \]

Head acceleration < 270g
Model Validation (2)

V = 7.5 m/s
Validation at P Point

SIMULATION DU CHOC EN P CASQUE-HEADFORM

Time = 0.000000

HEADFORM (4.27 Kg)

VITESSE D'IMPACT 7.5 m/s

MUR RIGIDE
Coupling of the helmet with the human head model.
Human head model coupled to the helmet FE model

Front Impact
Regulation ECE R022

Impact speed 7.5 m/s
Results in terms of intra-cerebral parameters

Pressure

Von Mises

➢ Tolerance ➢ limite

Coup : 350 Kpa
Contre-coup : -90 KPa

Maximum Von Mises : 31 KPa
Parametric study
Parametric study

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Young modulus of the foam</td>
<td>1.05 MPa, 1.95 MPa</td>
</tr>
<tr>
<td>B  Shell thickness</td>
<td>2.8 mm, 5.2 mm</td>
</tr>
<tr>
<td>C  Young modulus of the shell</td>
<td>10.5 GPa, 19.5 GPa</td>
</tr>
<tr>
<td>D  Foam elastic limit</td>
<td>0.21 MPa, 0.455 MPa</td>
</tr>
</tbody>
</table>

Mechanical characteristics of the 16 virtual helmets: +/- represents ±30% of reference value.
Results in terms of HIC and Max Acc

- All virtual helmets present HIC < 2400
- Max Acceleration < 270g
- Foam yield stress
- HIC
Results in terms of pressure and shearing

- Correlation between P et VM
- Foam yield stress and Young modulus
- A number of solution
Conclusions

- Presentation of a state of the art head FE model
- Proposal for new head injury criteria
- Development of a full face helmet model
- HIC is linked to foam yield stress
- Intra-cerebral pressure and shearing highly correlated
  Foam yield stress and Young modulus of high importance in the optimisation process
- HIC optimisation is different then P and VM optimisation
  Optimiser / P et VM
Thank you for your attention

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