Helmet optimisation based on head-helmet modelling

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International Motorcycle Safety Confernce

The Human Element

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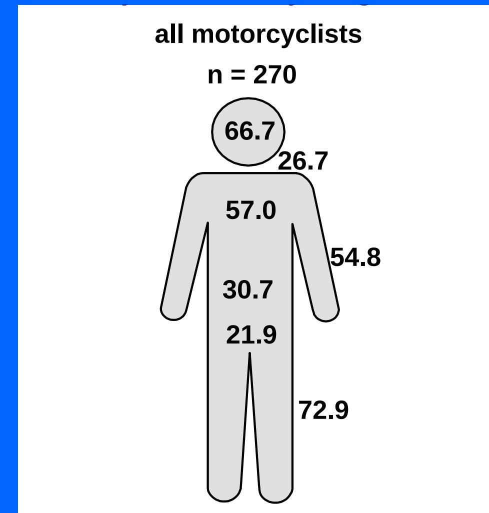
Presentation Overview

- **Introduction**
- **ULP-Strasbourg Head FE model Presentation**
- **Improved head injury criteria**
- **Helmet modeling and coupling with the head**
- **Helmet optimization**
- **Conclusion**

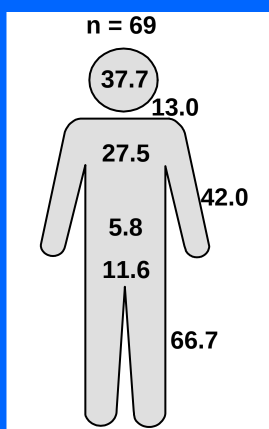
INTRODUCTION

- 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

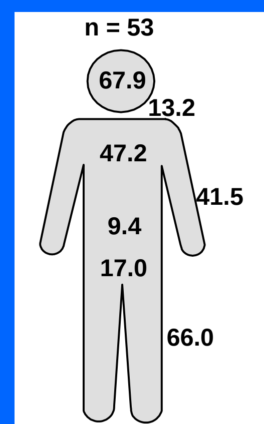
Importance of motorcyclist's head (from COST 327)



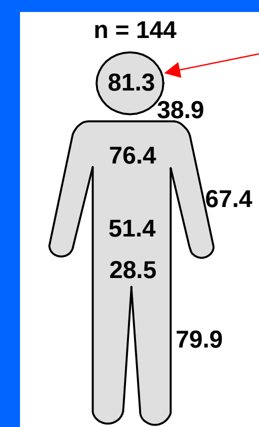
MAIS 1



MAIS 2



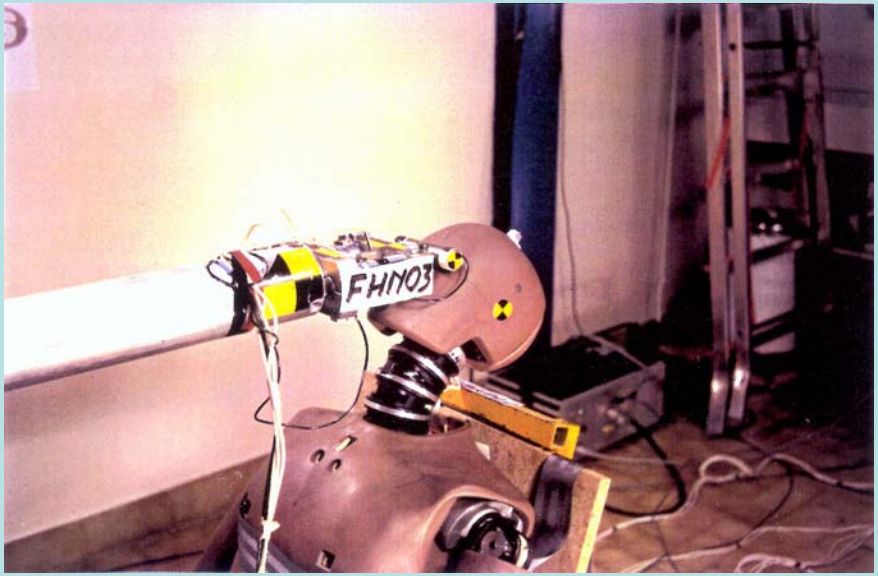
MAIS 3 +



80 %

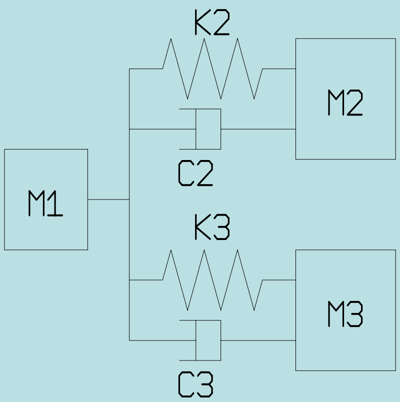
Hybrid III Head Model

M = 4.58 kg

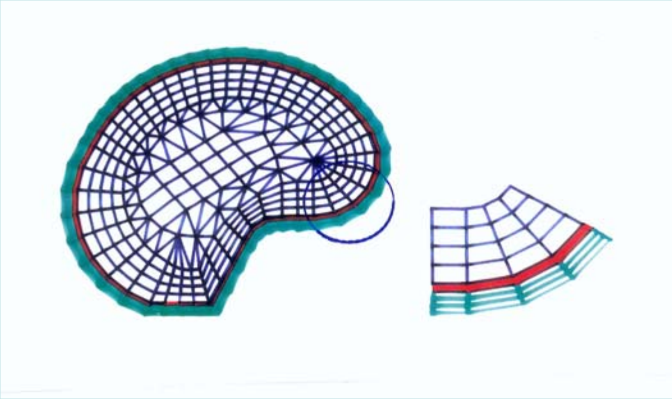


$$HIC = (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a\,dt\right]^{2.5}$$

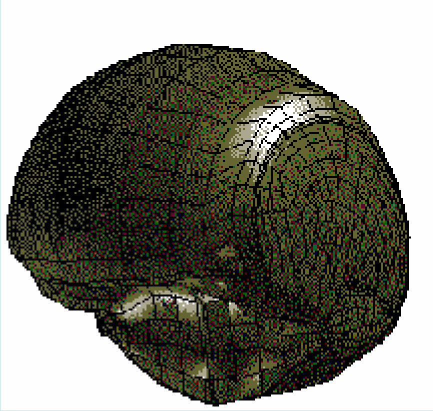
Human Head Modelling at ULP- Strasboug



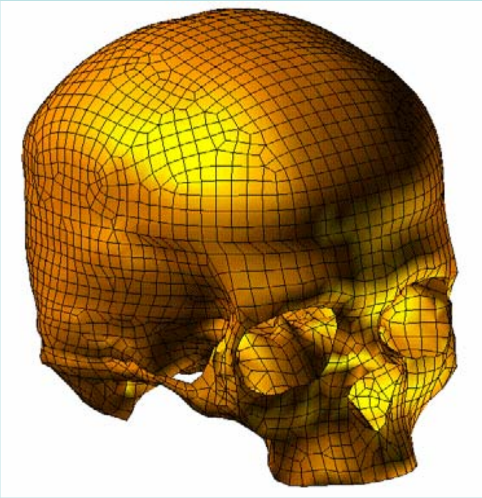
1990



1992

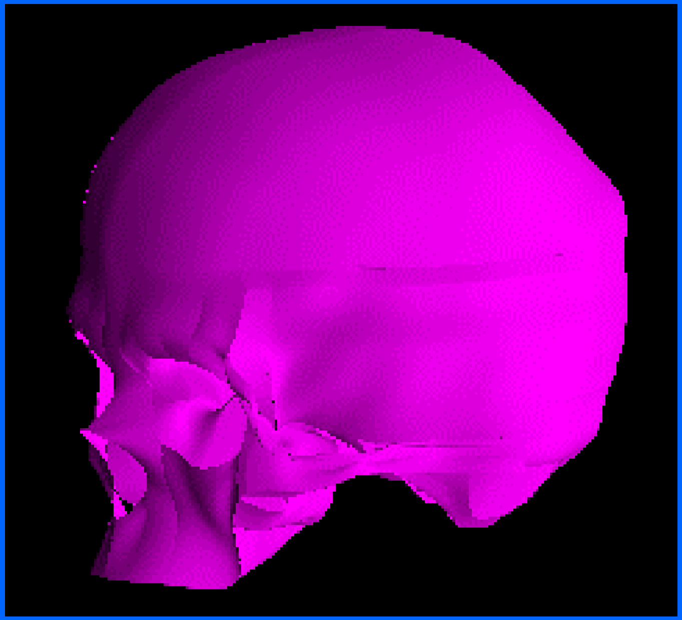


1994

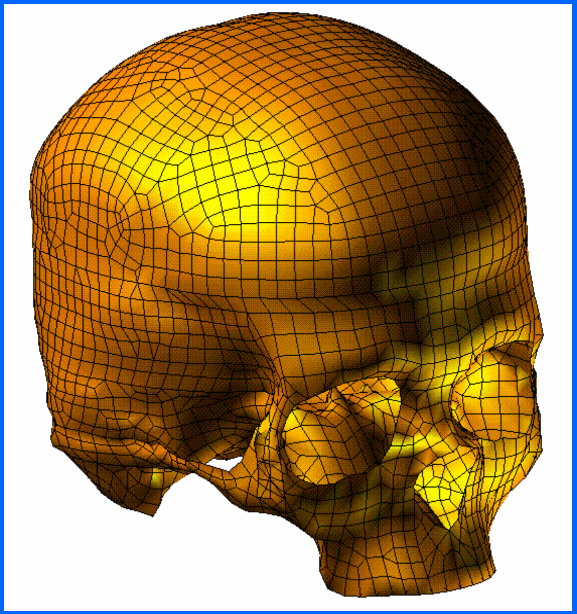


1998

FE MODEL BUILDING



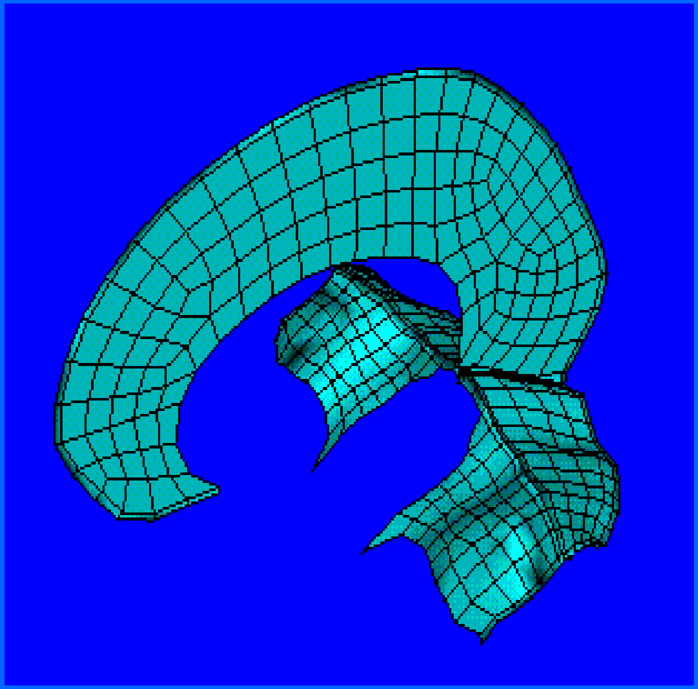
FE model building



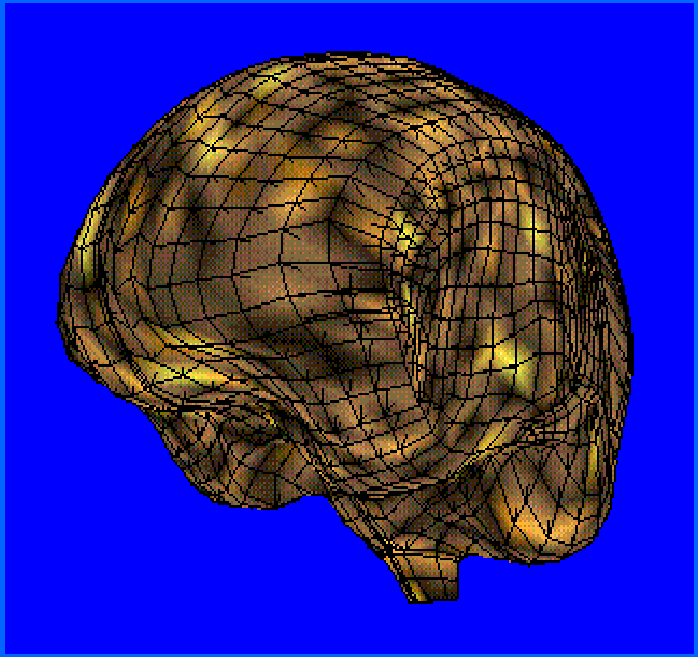
Rebuilt skull surfaces

Skull meshing

MEMBRANES AND BRAIN

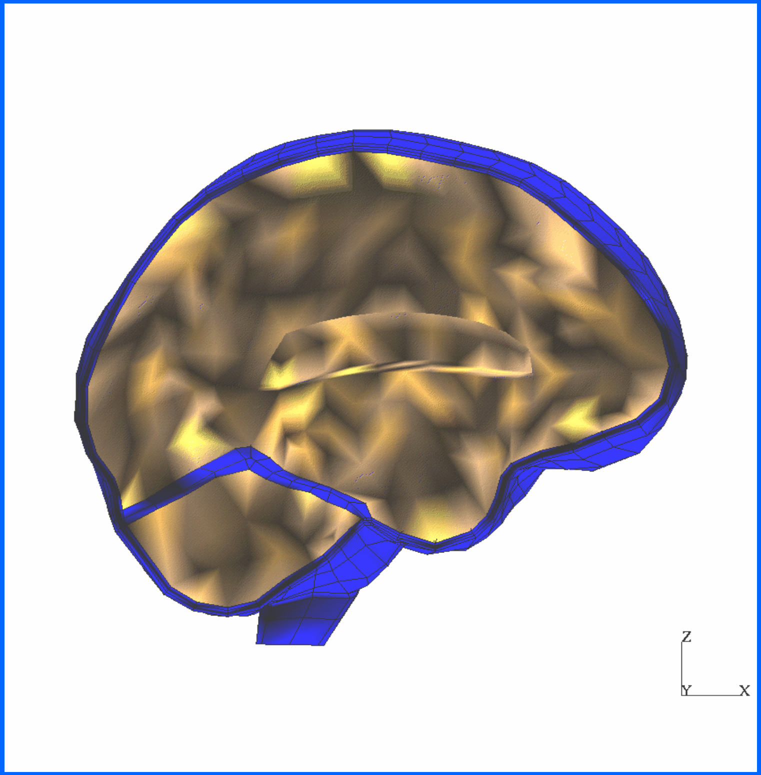


Faulx and tentorium

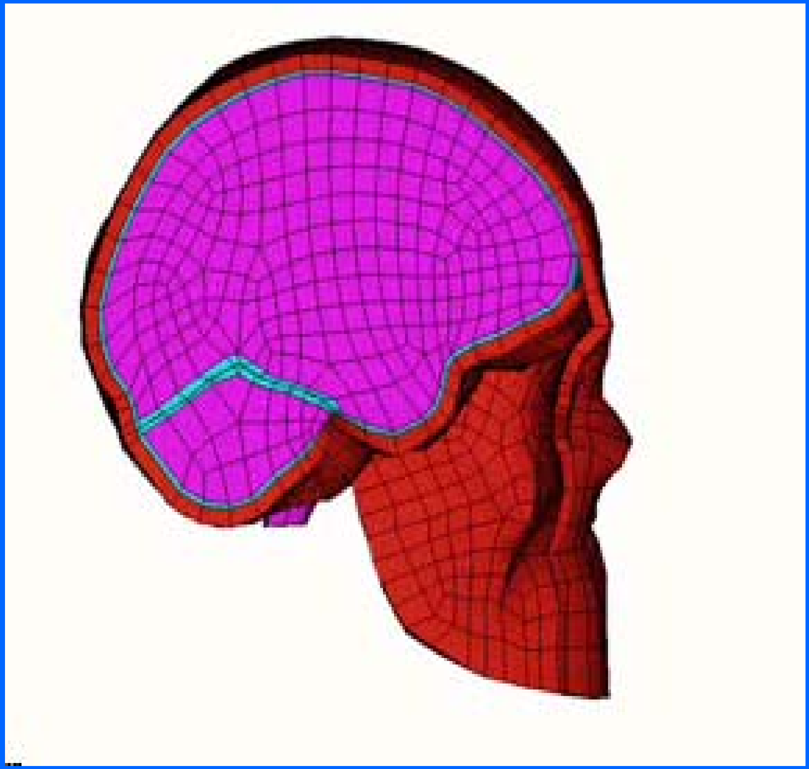


Meshing of the brain

CSF ANF FACE MODELLING



Brain and CSF



Face

MECHANICAL PROPERTIES OF FE MODEL COMPONENTS

structure	ρ [kg/m3]	E [Mpa]	ν	σ_t [Mpa]	σ_c [Mpa]	K [Mpa]	G_0 [Kpa]	G_{inf} [Kpa]	β [m/s]
cortical bone		15000	0,21	90	145				
spongy bone	1500	4500	0	35	35				
CSF	1040	0,012	0,49						
brain	1040					1125	49	16,7	0,14
skin	1200	16,7	0,42						
membranes	1140	31,5	0,23						

FE MODEL VALIDATION AGAINST DIFFERENT IMPACT CONFIGURATIONS

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

Brain motion validation agains Hardy's Impacts (2001)

Against Improved injury criteria

Atempts for new tolerance Limits

- FE head modelling and accident simulation

  Zhou et al. - 96, Kang et al. - 97, Newman et al. – 99

  King et al. 2003

- Experimental accident reconstruction

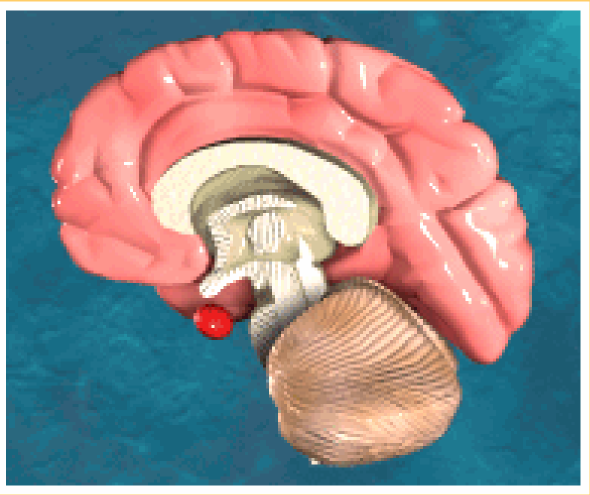
  Chinn et al. - 99, Willinger et al. - 2000

- Animal models

  Ommaya et al. - 67, Ruan et al. - 94, Zhou et al. - 94, Anderson et al. - 99

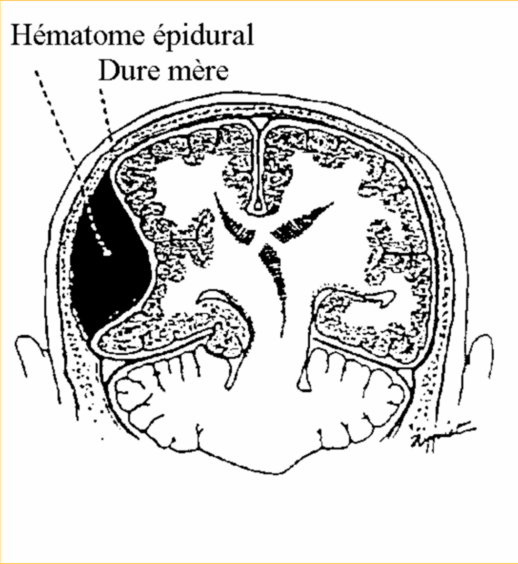
Head Injury Mechanisms

Brain



Contusion
DAI

Interface



SDH

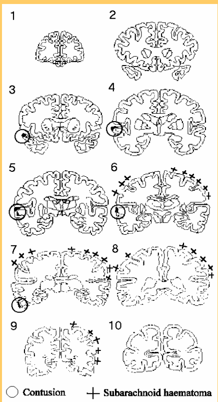
Skull

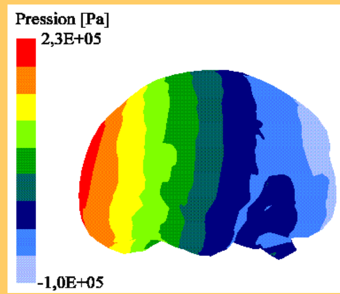
EDH
Fracture

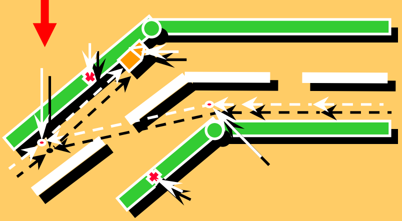
Injury mechanisms and mechanical parameters

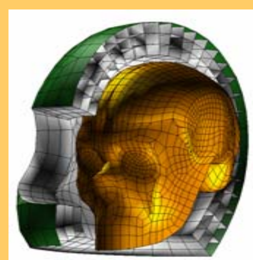
Skull fracture	→	Bone loading
Extradural Heamatoma	→	Bone loading
Subdural Heamatoma	→	Brain-skull relative motion
Focal brain Contusion	→	Local brain loading
Diffuse brain axonal or heamorragic injury	→	Brain loading

ACCIDENT RECONSTRUCTION





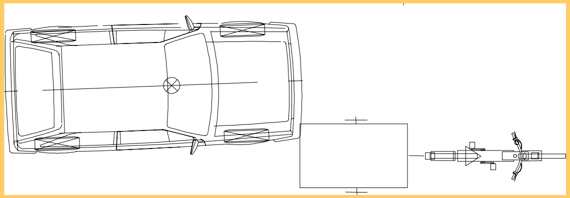


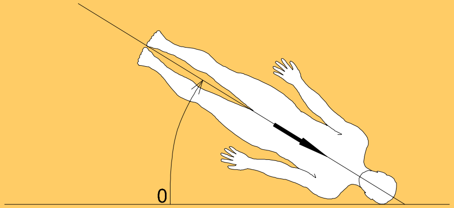


Real world head impact simulation

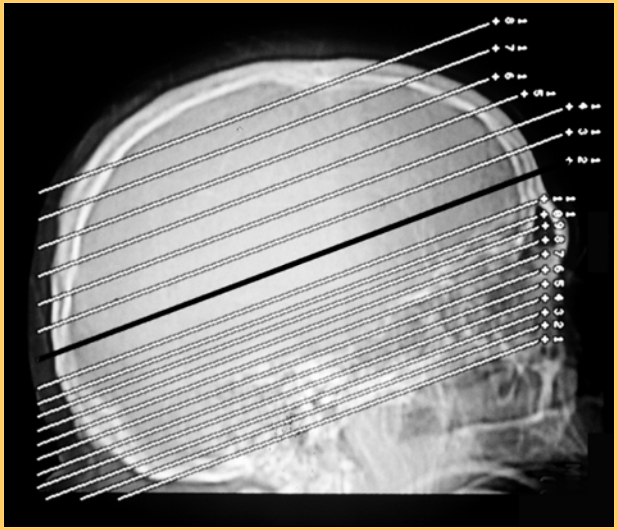
- Motorcyclist accident (13)
- Sport accidents (22)
- Pedestrian accidents (29)

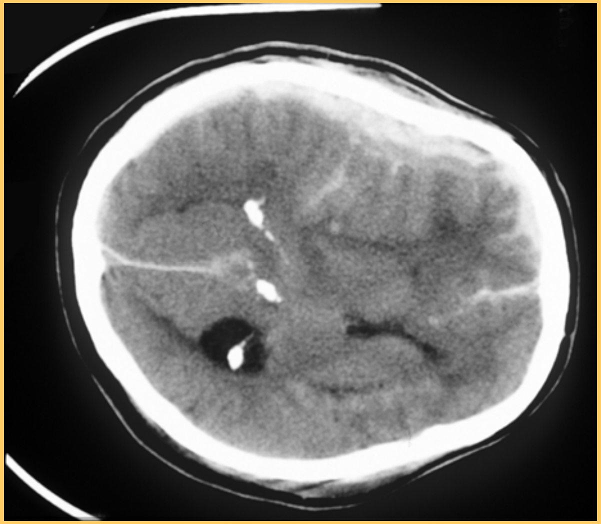
COST 327 ACCIDENT DATA WORKING GROUP





Indeep analyses of accidents





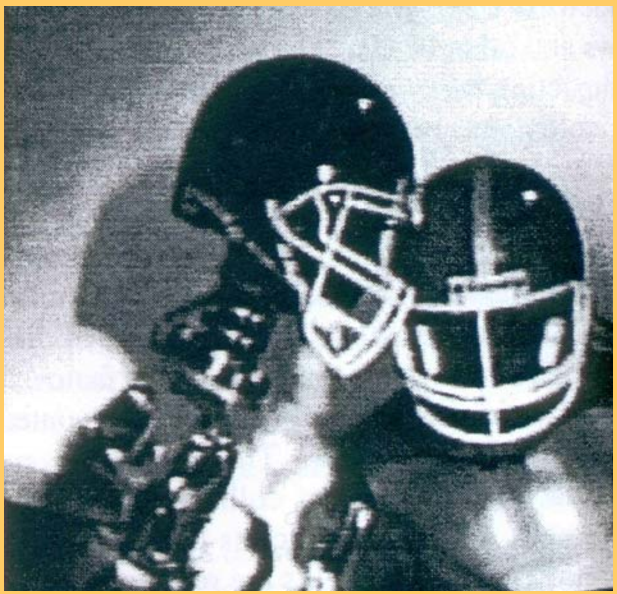
Detailed medical reports

Experimental accident replication

Model inputs – Helmeted american footballers

Experimental accident replication

Validation parameters



Measured dummy head acceleration field

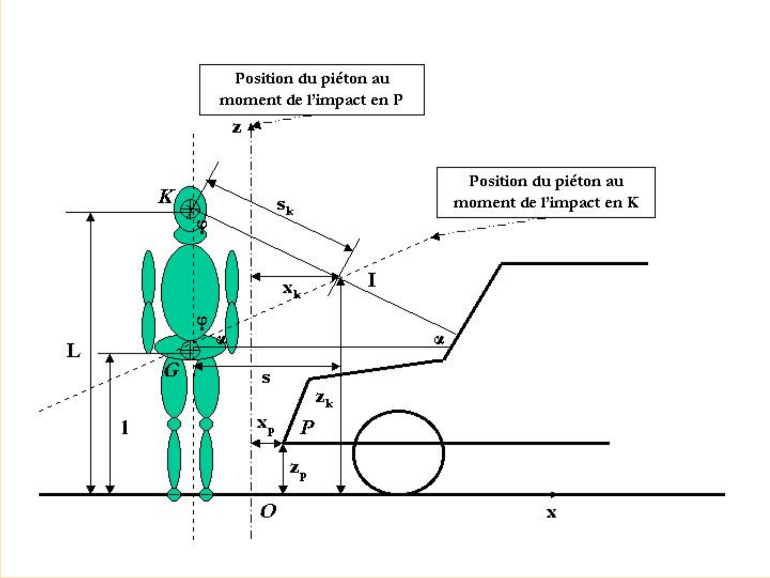
Rigid skull applied velocity field

Analytical accident replication

Model inputs – Knocked down pedestrians

Analytical accident replication

Validation parameters

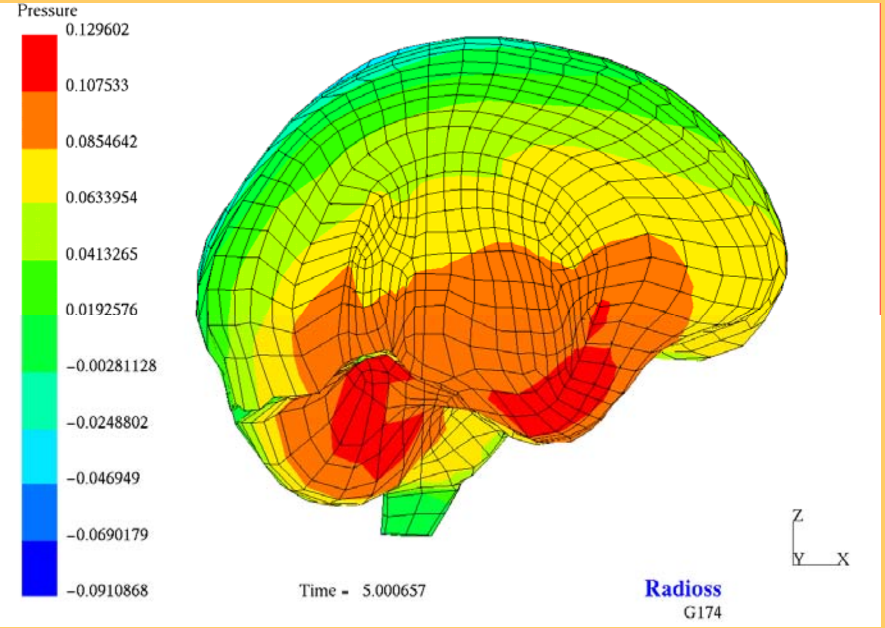


Accident data

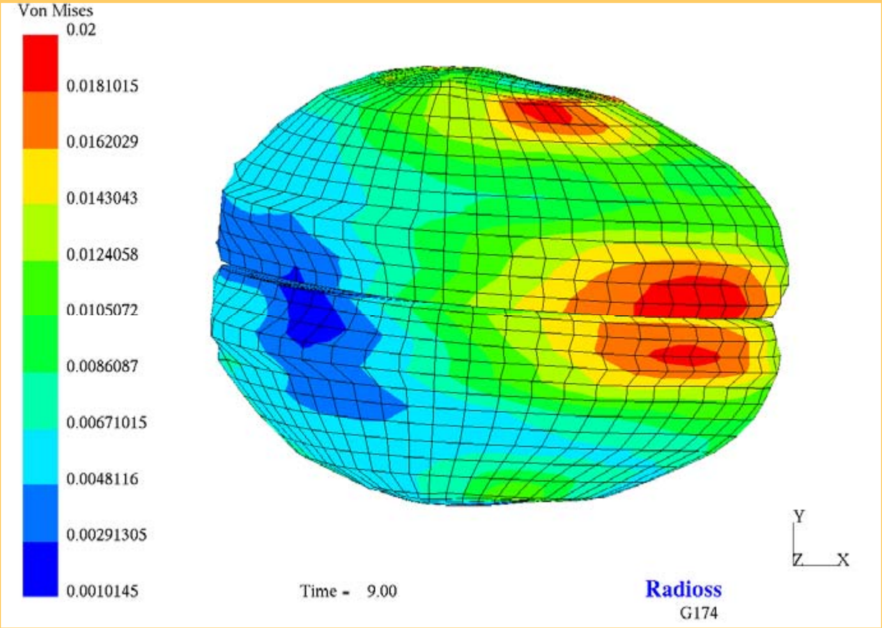
- *Windscreen damages*
- *Head superficial wounds*

Initial relative angular position and velocity between the head and the windscreen

NUMERICAL RESULTS (2) - CASE G174



Brain pressure field at 5 ms

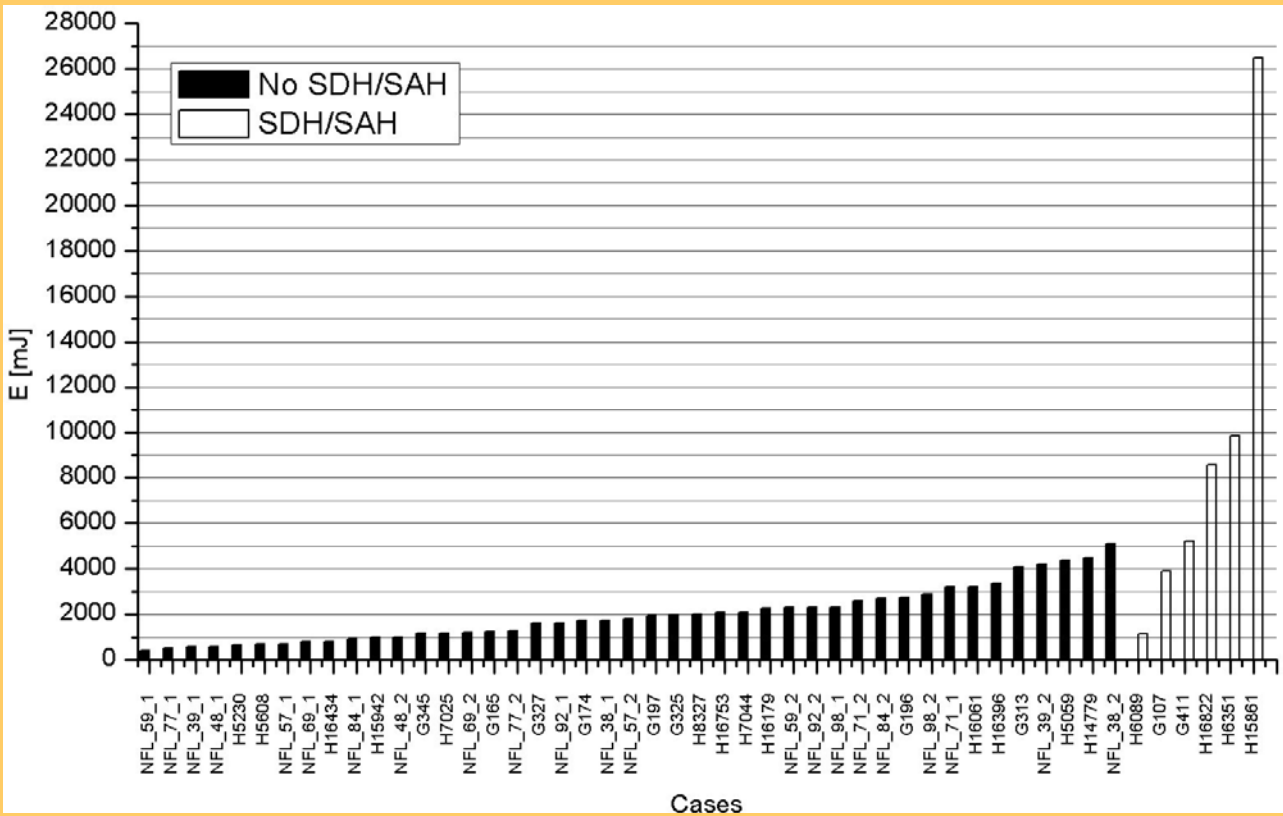


Brain Von mises stress field at 9 ms

ULP injury prediction Assesment

Sub-dural and sub-arachnoidal haematoma – Histograms

Global strain energy of the sub-arachnoidal space

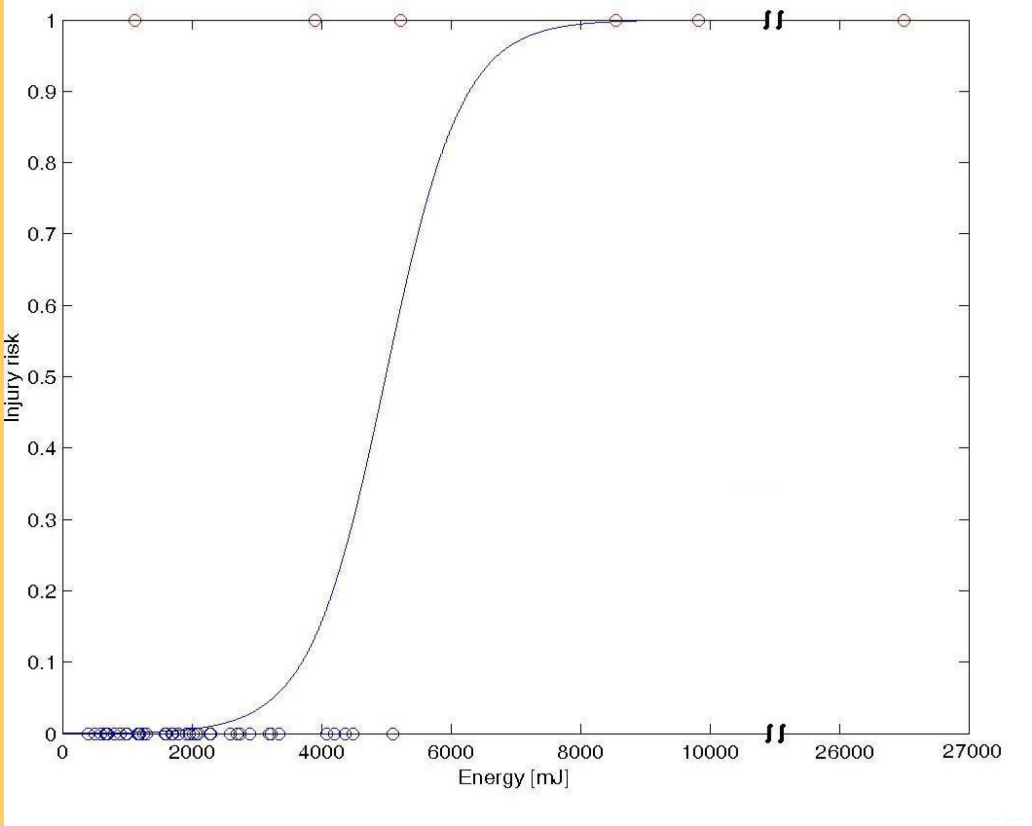


Threshold → ~ 5000 mJ

ULP injury prediction Assesment

Sub-dural and subarachnoidal haematoma – Risk curve

Global strain energy of the sub-arachnoidal space



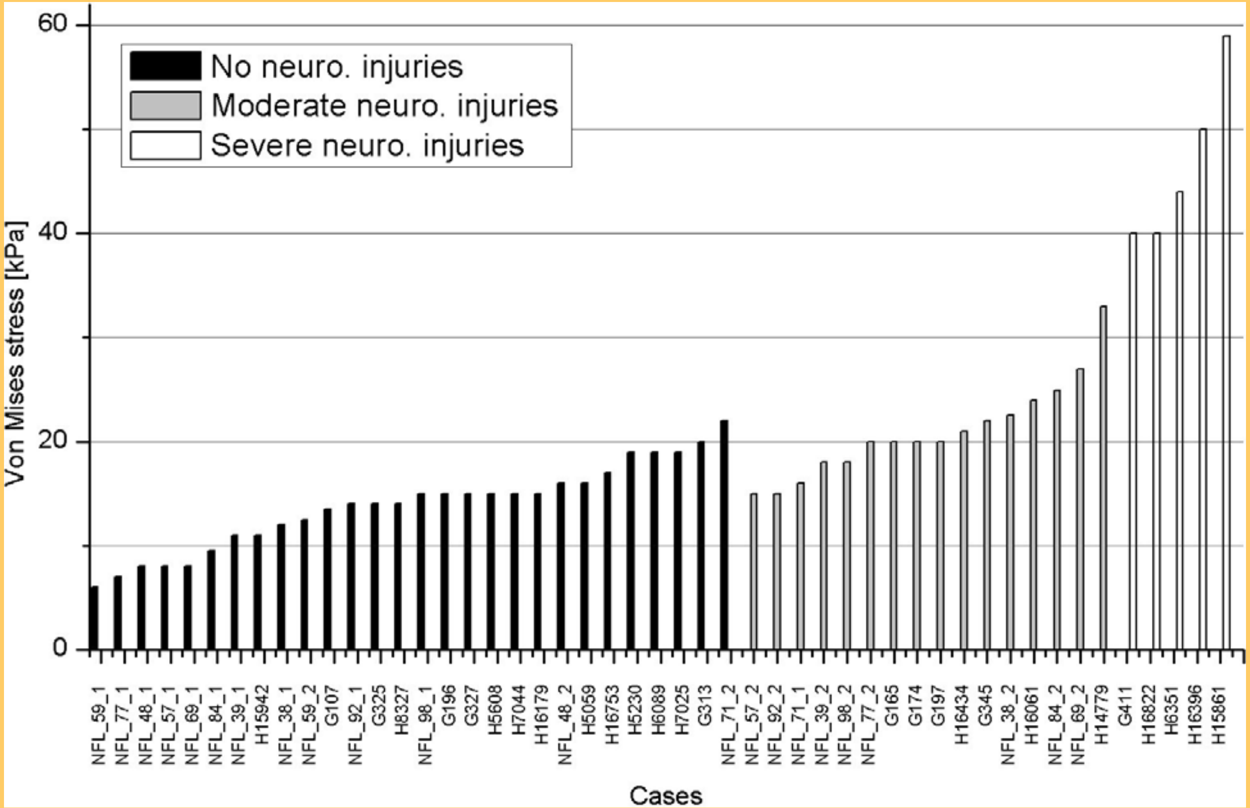
Risk 50 %

~ 4995 mJ

ULP injury prediction Assesment

Moderate neurological injuries – Histograms

Intra-cerebral Von Mises stress

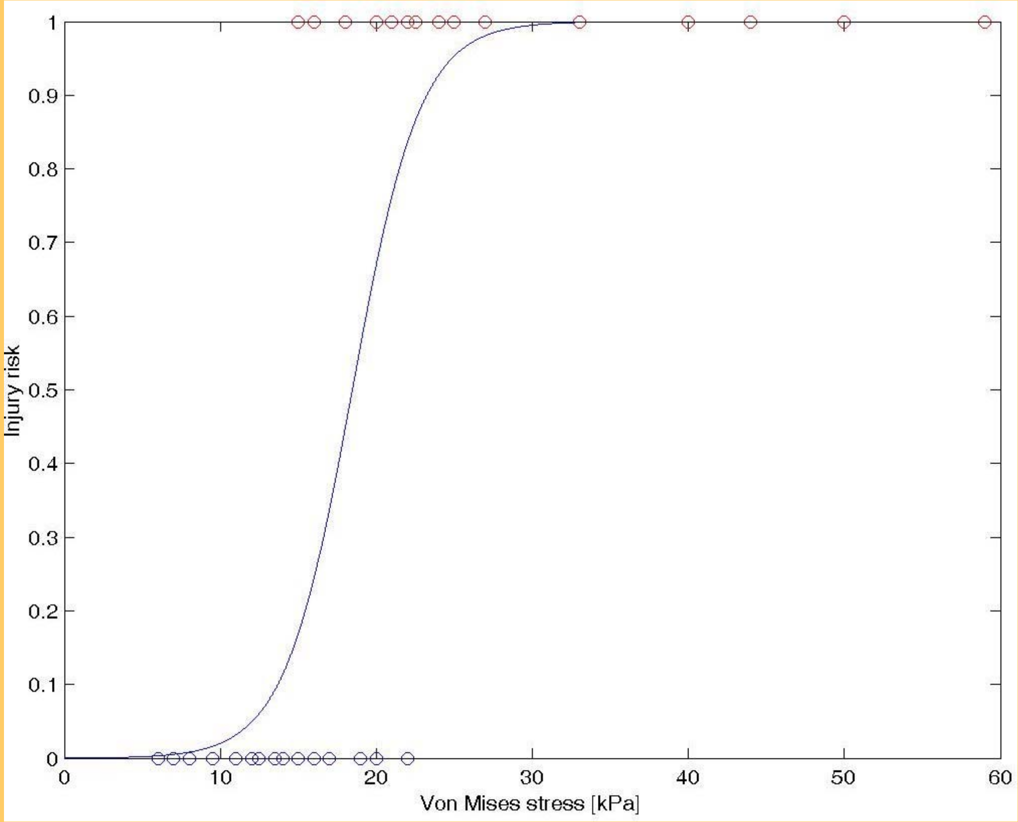


Threshold → ~ 20 kPa

ULP injury prediction Assesment

Moderate neurological injuries – Risk curve

Intra-cerebral Von Mises stress

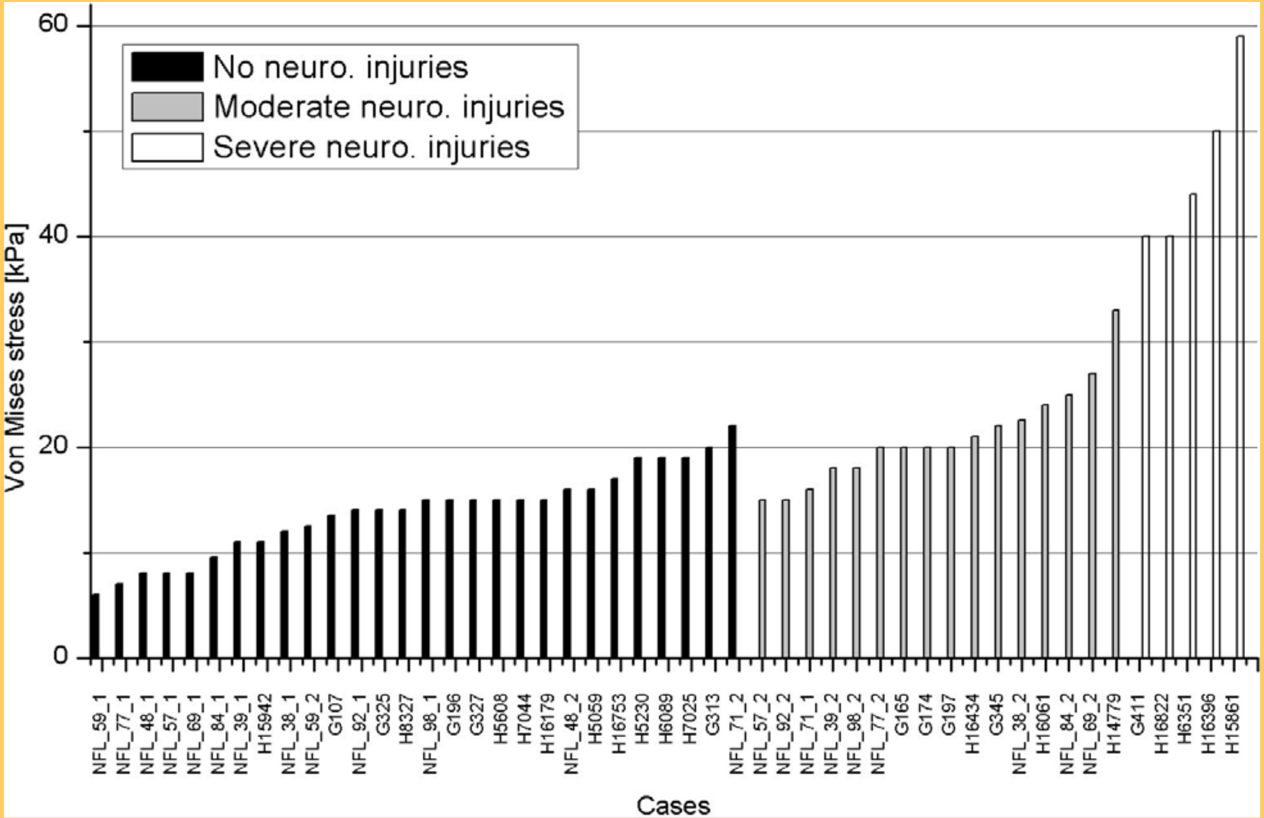


Risk 50 % → ~ 18.5 kPa

ULP injury prediction Assesment

Severe neurological injuries – Histograms

Intra-cerebral Von Mises stress

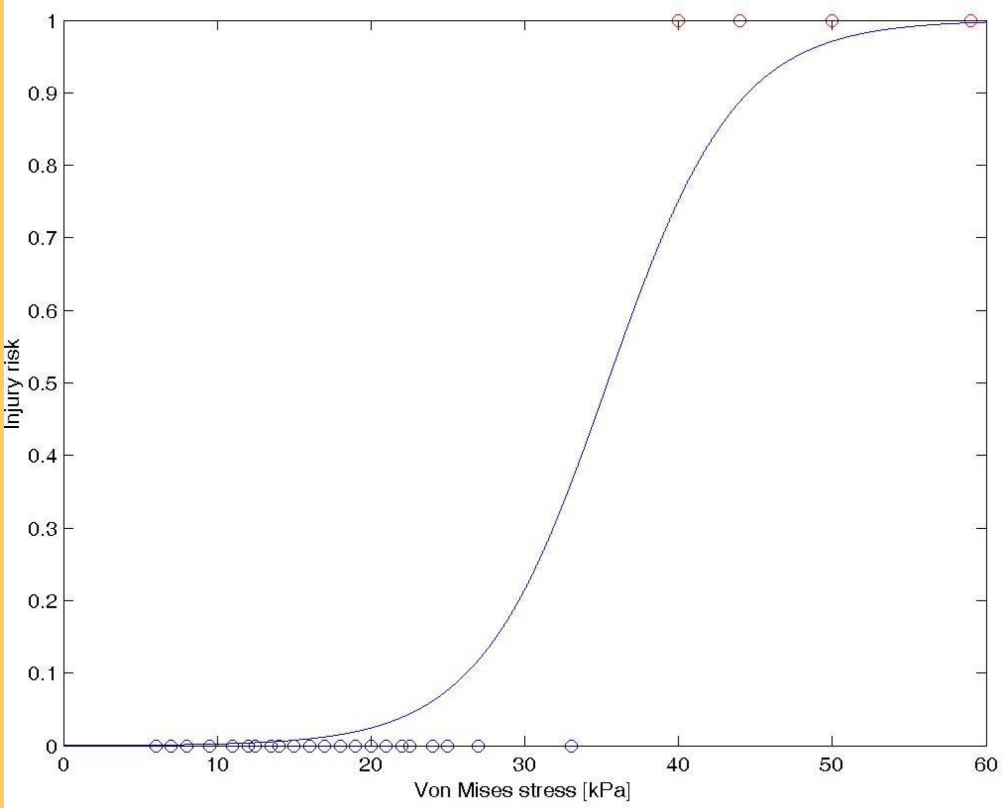


Threshold → ~ 40 kPa

ULP injury prediction Assesment

Severe neurological injuries – Risk curve

Intra-cerebral Von Mises stress

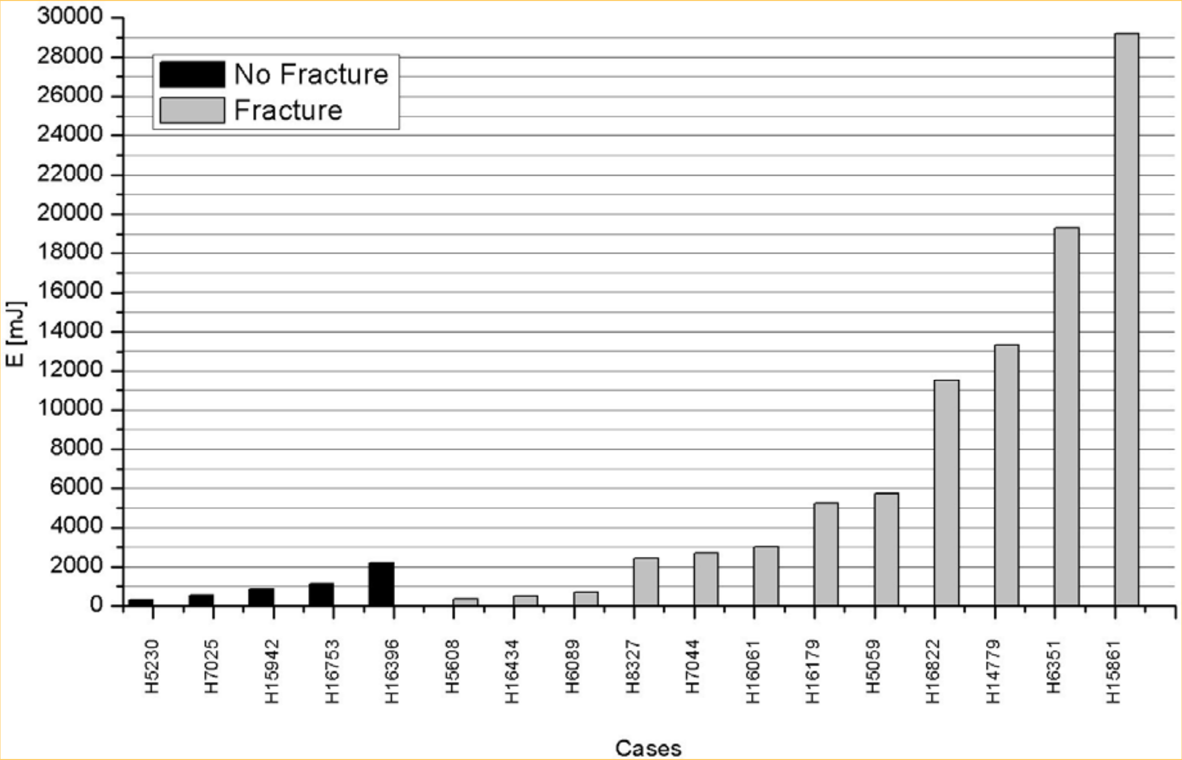


Risk 50 % → ~ 35.4 kPa

ULP injury prediction Assesment

Skull bones fractures – Histograms

Global strain energy of the skull

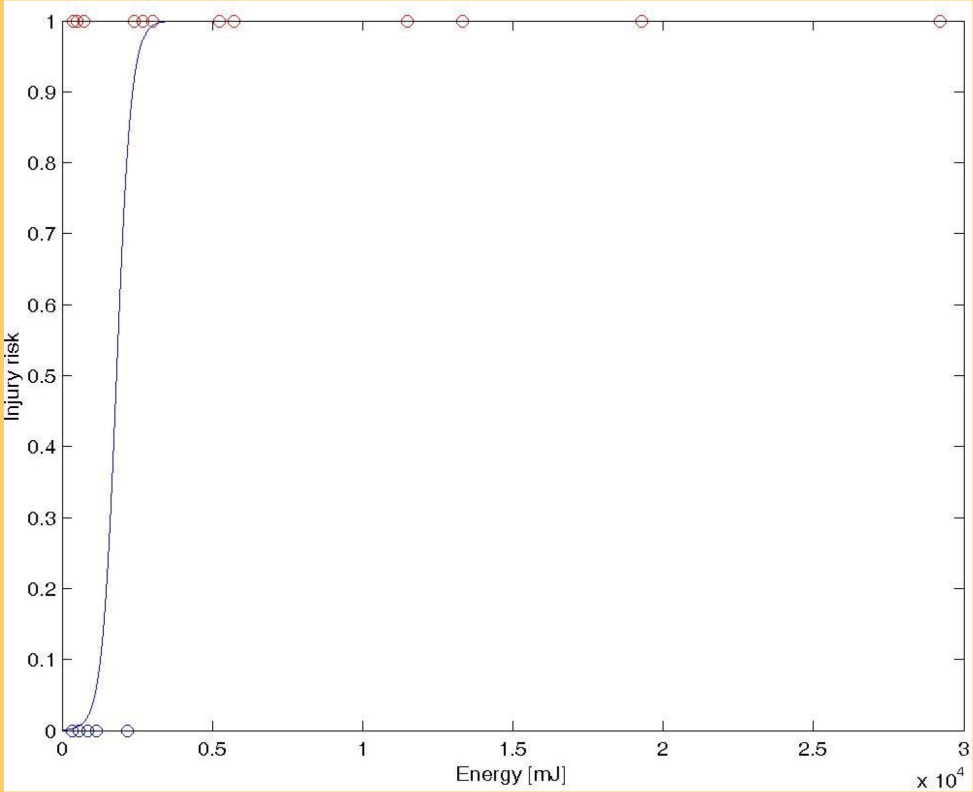


Threshold → ~ 2500 mJ

ULP injury prediction Assesment

Skull bones fractures – Risk curve

Global strain energy of the skull



Risk 50 % → ~ 2531 mJ

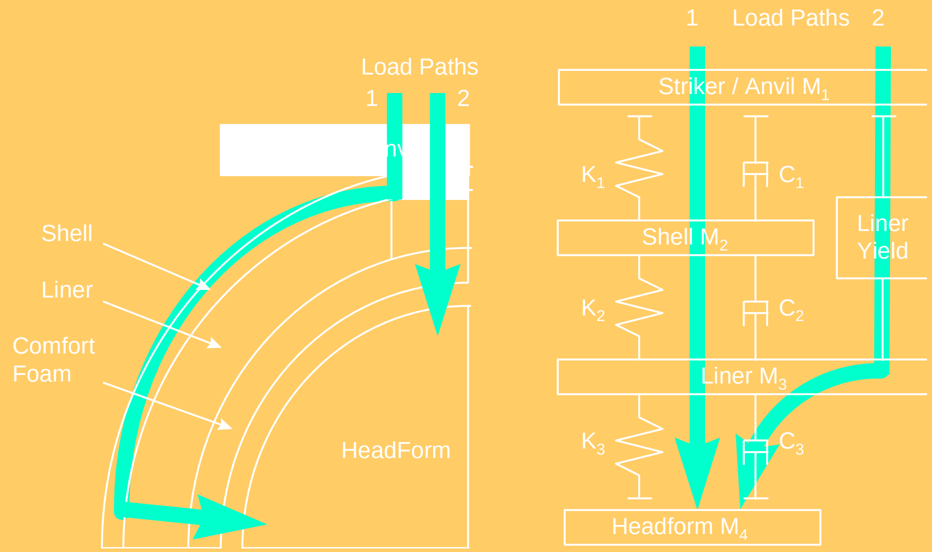
Recall ULP Criteria

New head injurie 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)

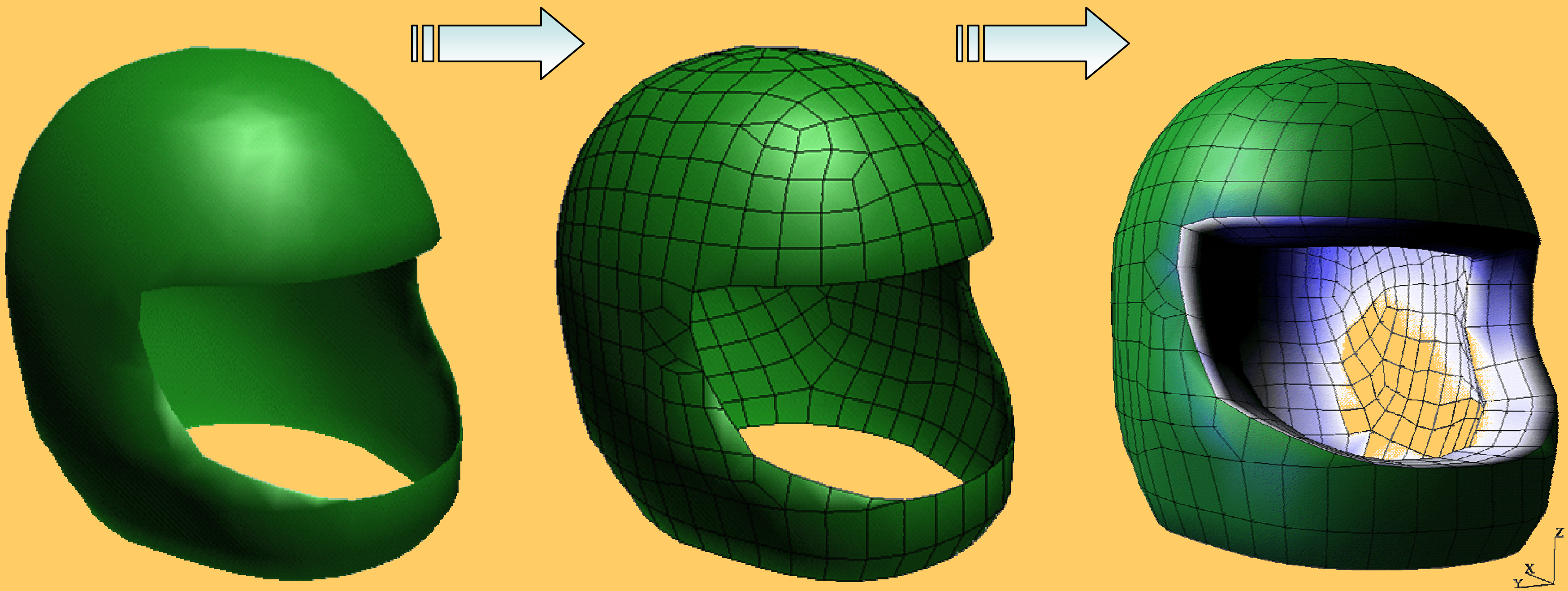
Guimberteau et al. (1998)

Yetram et al. (1994)

Vetter et al. (1987)

Brands et al. (1996)

Meshing   Extrusion for foam modelling



External surface of the Helmet

Outer Shell (524 Shell elements) Thickness 4mm

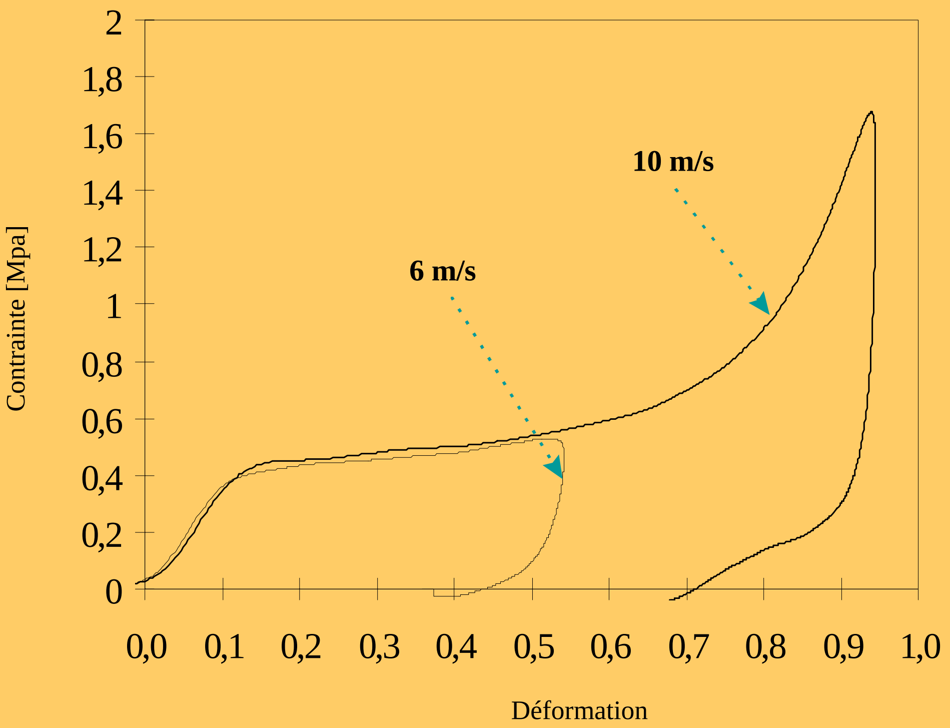
Foam (1675 Brick elements) Thickness 40 mm

Mechanical properties

Foam compression tests

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

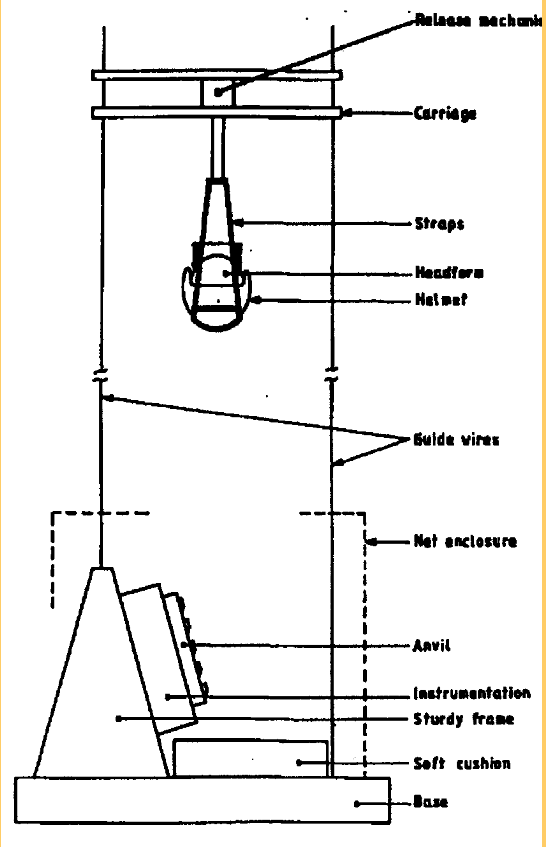
$$\sigma_t = \frac{m\gamma_t}{s}$$



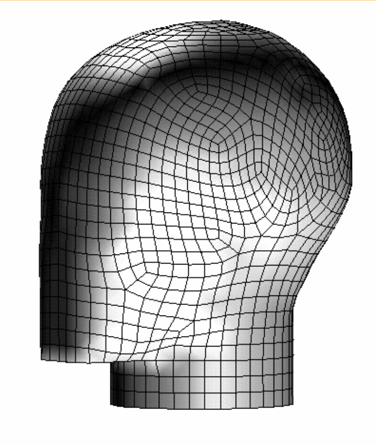
Mechanical properties

Component	Material	Model	E [GPa]	ν	ρ [kg/m3]	Comment
Outer shell	Thermo-plastic	linear-elastic	1,5	0,35	1055	Thickness = 4mm
Protective padding	Expanded polystyrene	elasto-plastic	1,5.e-3	0,05	25	Thickness = 40mm Yield stress = 0,35MPa
Headform	aluminium	rigid	27	0,3	_	Mass = 4,27 kG

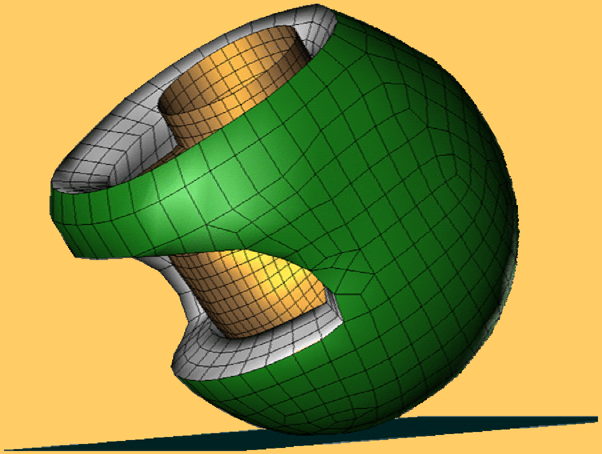
Model Validation (1)



V=7.5 m/s



Headform (2208 nodes ; 1652 elements)

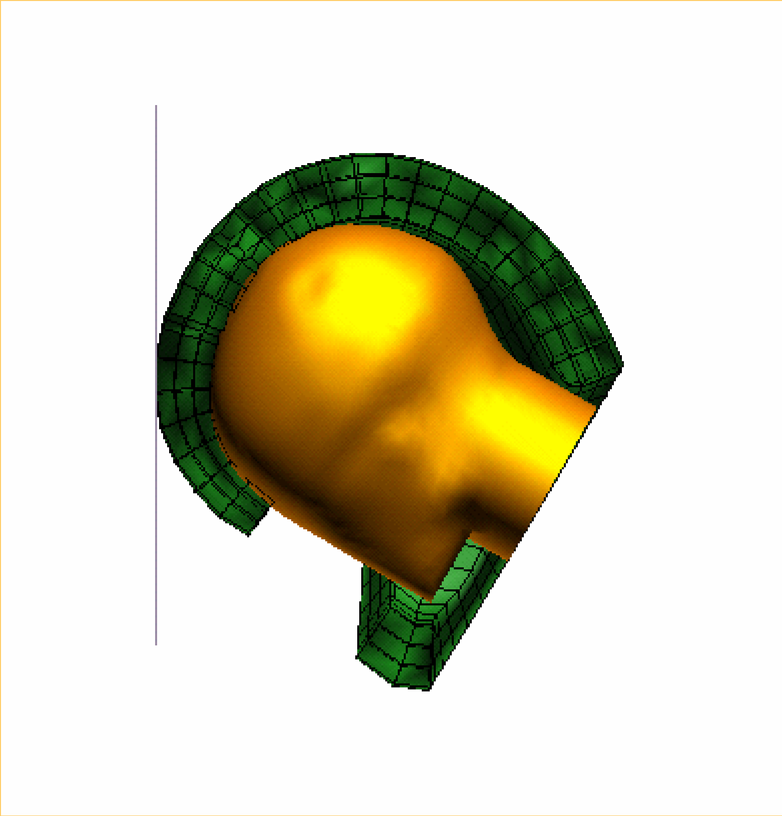


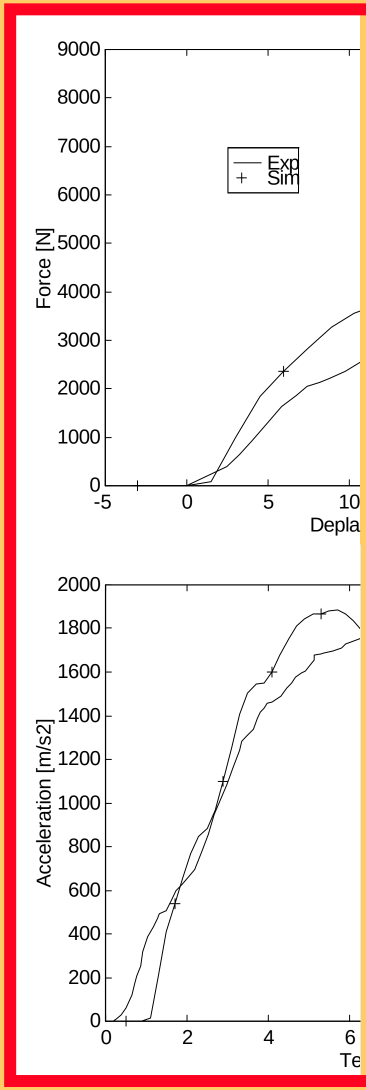
Front impact

Head acceleration < 270g

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

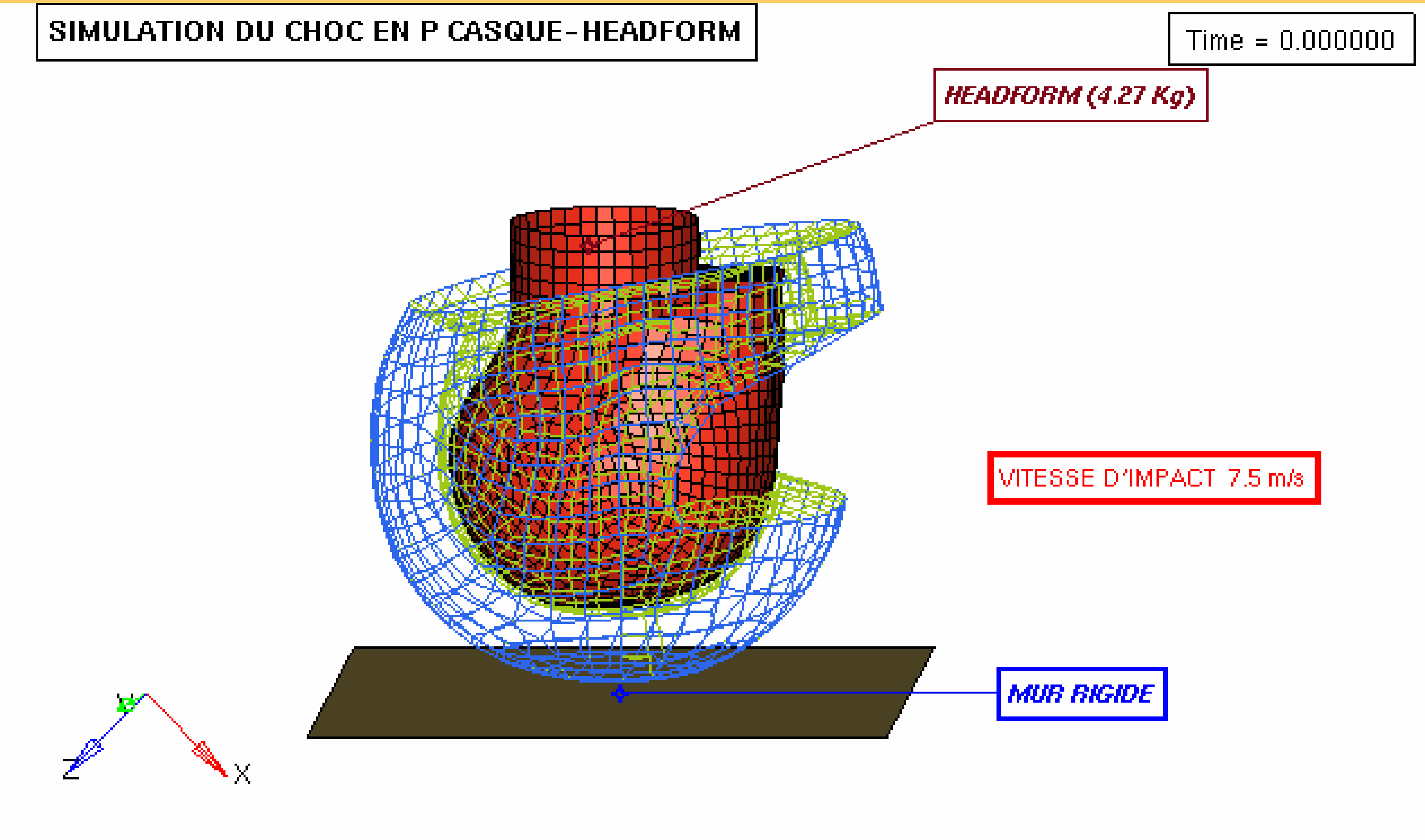
Model Validation (2)





V=7.5 m/s

Validation at P Point

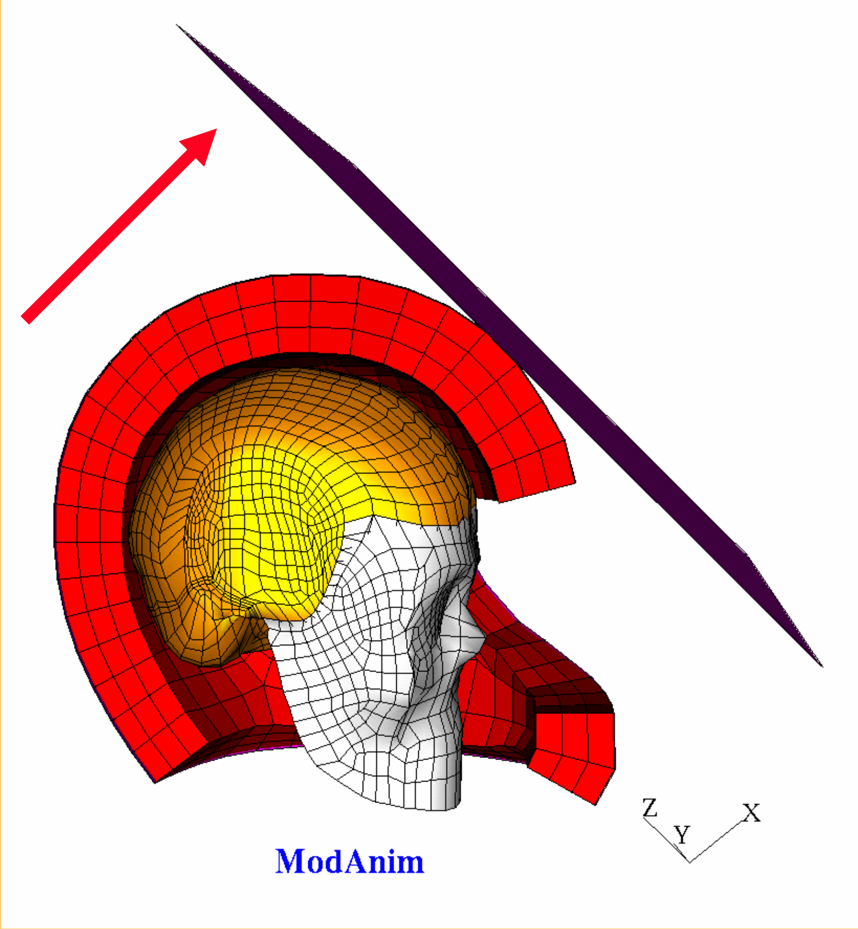


Coupling of the helmet

with

the human head model

Human head model coupled to the helmet FE model

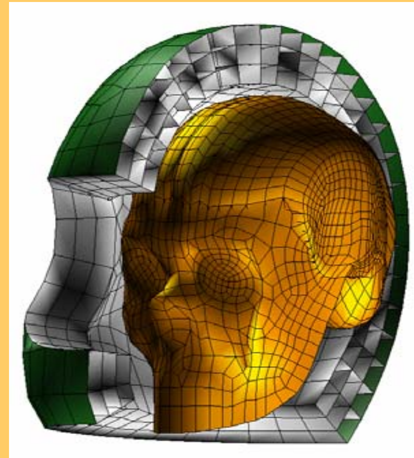


Front Impact

Regulation ECE R022

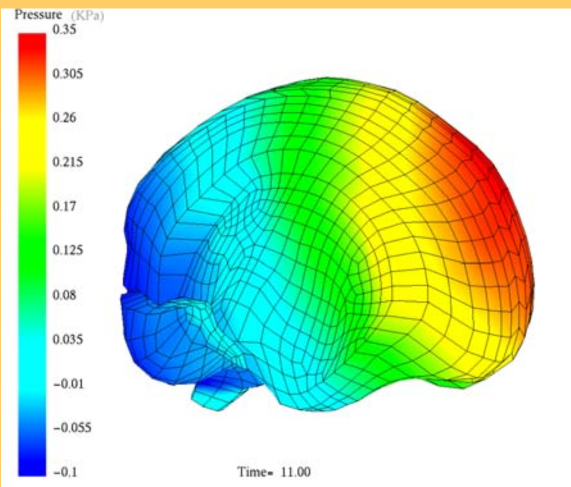
Impact speed 7.5 m/s

Results in terms of intra-cerebral parameters

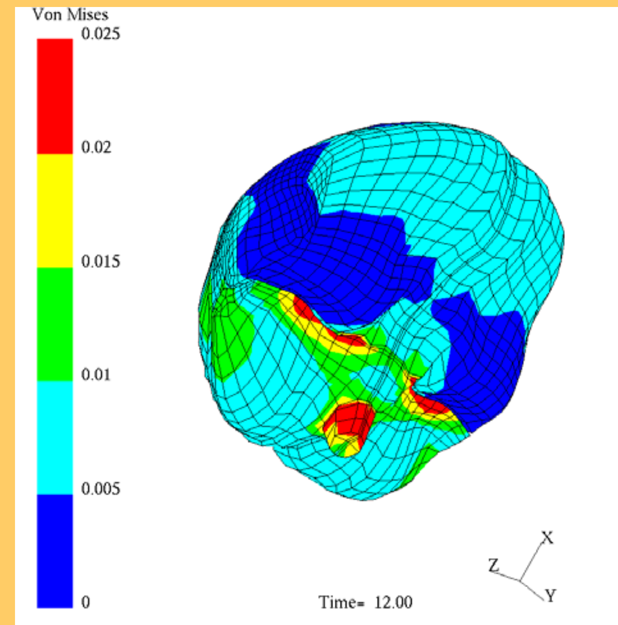


Pressure

Von Mises



- Tolerance
- limite



Coup : 350 Kpa
Contre-coup : -90 KPa

Maximum Von Mises : 31 KPa

Parametric study

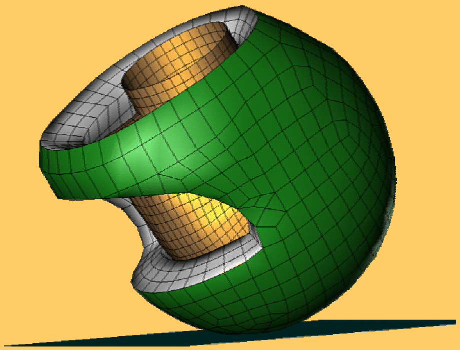
Parametric study

Parameters	Values -	Values +
A Young modulus of the foam	1.05 MPa	1.95 MPa
B Shell thickness	2.8 mm	5.2 mm
C Young modulus of the shell	10.5 GPa	19.5 GPa
D Foam elastic limit	0.21 MPa	0.455 MPa

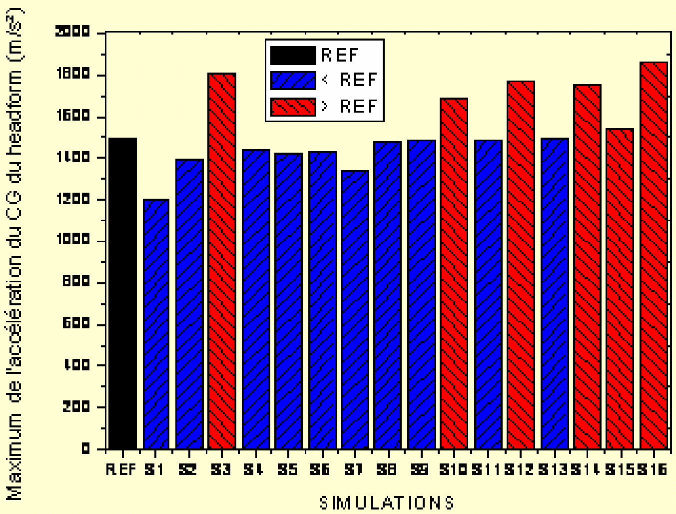
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
A	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+
B	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+
C	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+
D	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+

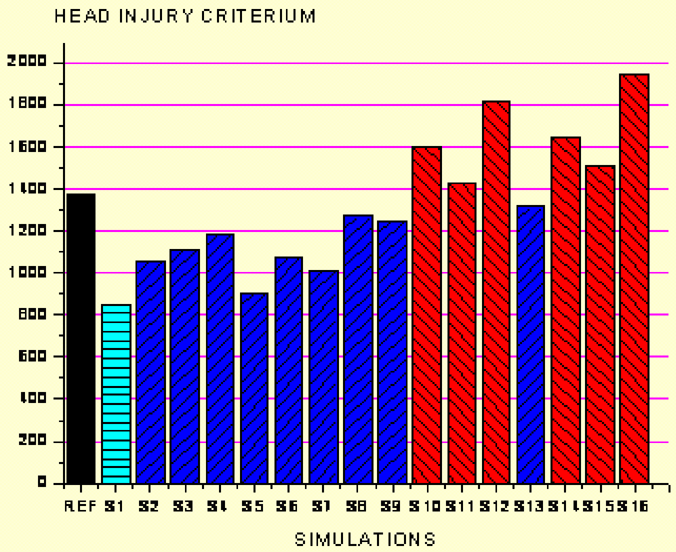
Mechanical characteristics of the 16 virtual helmets : +/- represents ±30% of reference value.

Results in terms of HIC and Max Acc

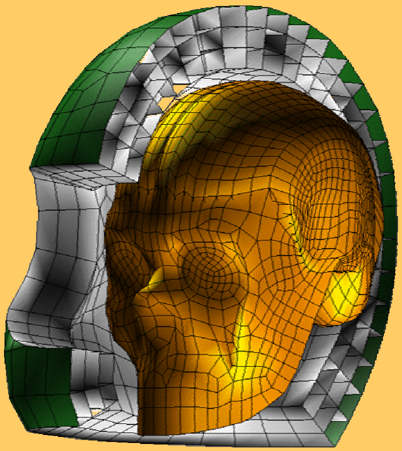


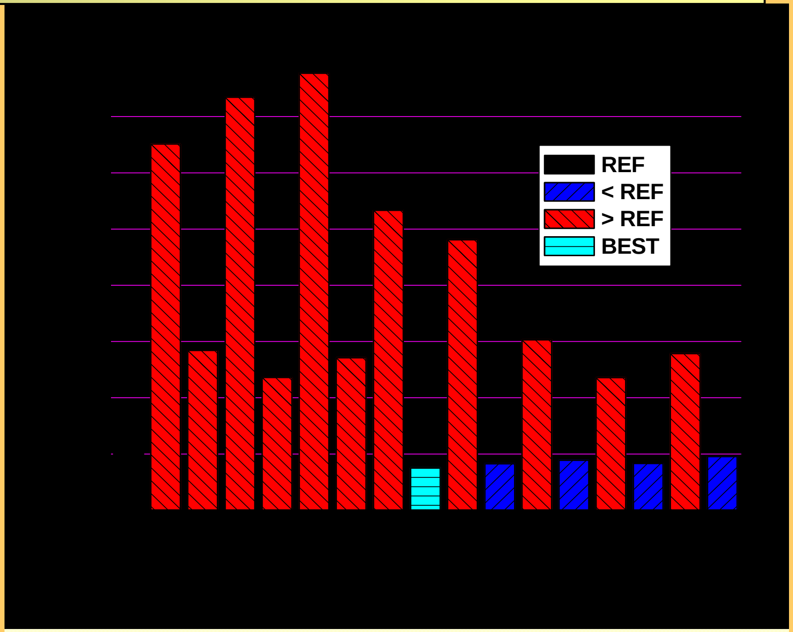
- All virtual helmets present HIC < 2400
- Max Acceleration < 270g
- ↑ foam yield stress
  ↑ HIC

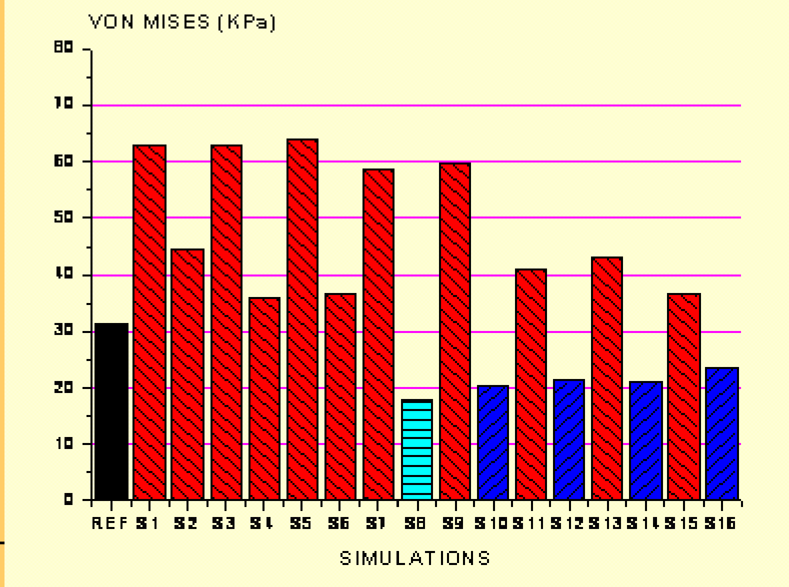




Results in terms of pressure and shearing







- 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
- Devlopment 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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