Developing the World Leading Head Protection Using LS-DYNA

And part of the Mips Story

PETER HALLDIN

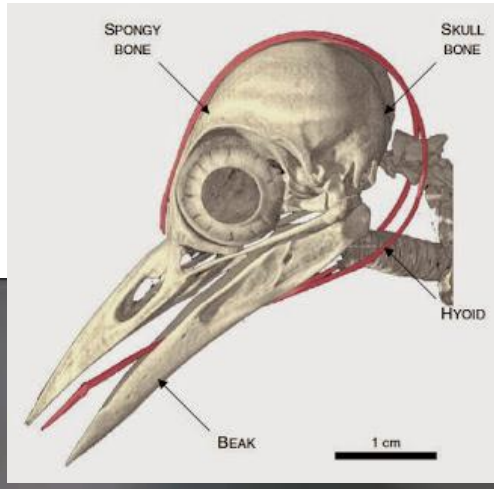
DIVISION OF NEURONIC ENGINEERING
ROYAL INSTITUTE OF TECHNOLOGY (KTH)
STOCKHOLM, SWEDEN

MIPS AB, STOCKHOLM SWEDEN

Daniel Lanner
Marcus Arnesen
Anna von Schantz
Isak Hampel Klang
Madelen Fahlstedt
Sofia Hedenstierna
Shiyang Meng

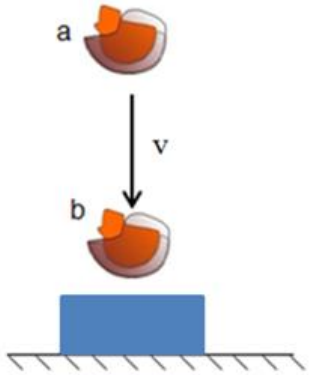
Why a woodpecker don’t get concussion ?

- Thousands impacts per day. Over 1000G per impact.
- Optimized energy absorption system
  - Cranium fixed with flexible joints
  - The tong surrounds the cranium and work as a damper
  - The lower beak is longer than the upper
  - No rotation of the head



How to design a helmet - Basic course I

Current test methods



< 250G = Pass

Table 13.3 Design requirement for cycle helmet

Function	Protective cycle helmet
Objective	Maximise energy absorption/unit volume
Constraints	Load on skull < damage-load

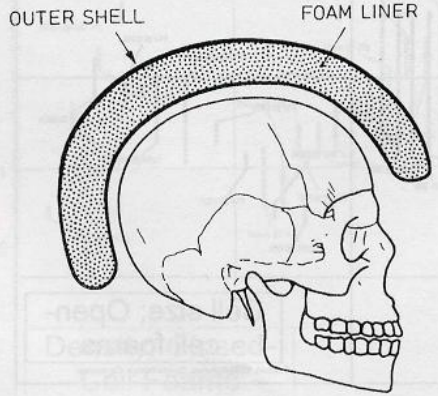
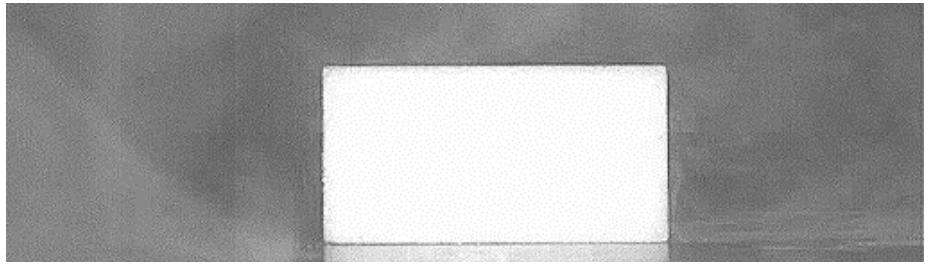


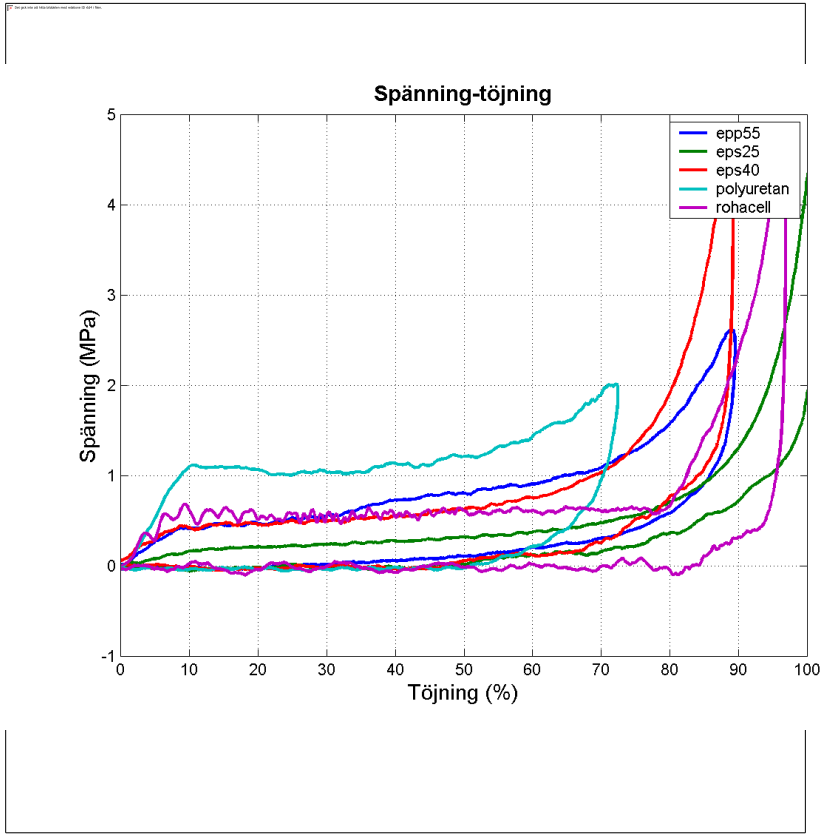
Figure 13.9 A cycle helmet. The liner must absorb as much energy per unit volume as possible without allowing the force on the skull to reach a damaging level.

Picture from Gibson and Ashby 1999

How to design a helmet – Basic course 1



20mm EPS will do it!



Outline

- Mips introduction (What, How, Why)
- 25 years of Mips & FE
  - Energy absorption in helmets with Mips
  - The effect of the human cervical spine in helmet testing
  - Virtual Test Lab
  - Other projects
    - CEN TC158- New rotational test standard
    - Safety helmets and initial rotation
    - Child helmets
    - Chin bar test
    - FE Head model evaluation

Our history

FROM RESEARCH TO COMMERCIAL SUCCESS

1995
Swedish neurosurgeon Hans von Holst contacts University to discuss solutions

1996-1998
Initial testing and seed funding, set up and patent filing costs

2000-2001
First scientific publication regarding Mips

2001-2007
In 2001 MIPS AB is founded, followed by a start-up phase including a Swedish launch of a helmet with Mips

2009
The first third party helmet with Mips is launched

2010
Mips becomes a true ingredient brand offering a global solution

2014
Establishment of the BRG and Mips collaboration

2015
Mips achieves profitability

2016
The first street motorcycle helmet model with Mips is launched

2017
March 23, MIPS IPO on Nasdaq Stockholm

2018
Major legal disputes settled proven strong patent portfolio

2019
More than 20 MOTO brands using Mips

RESEARCH | START-UP PHASE | GROWTH | SCALE UP / CONT. GROWTH

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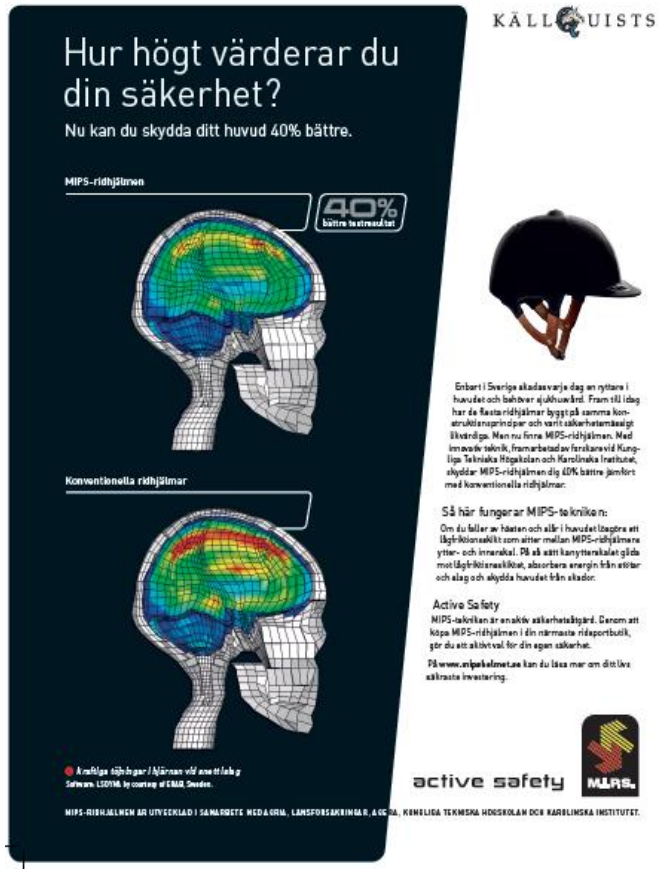
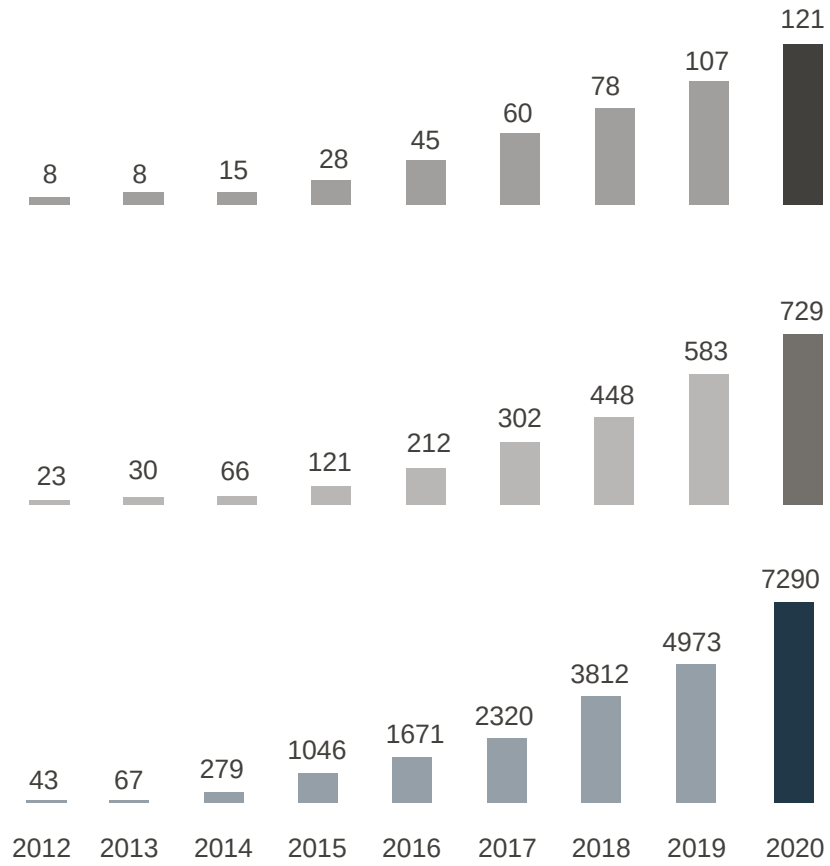
2007… - Research at KTH and KI has resulted in a 40% Safer equestrian helmet!



Gothenbourg Horse Show 2007

A world leading brand in helmet safety



121
ACTIVE BRANDS

729
MODELS

7.3M
UNITS SOLD

- ESTABLISHED IN THREE MAIN CATEGORIES:
- Sports (Bike, Snow, EQ, Hockey and Mountaineering)
- Moto (Road motorcycle and MX)
- Safety (Industry and LEAF)
- 70 people in Täby and 20 in China

+120 Helmet Brands Worldwide Have Adopted the Mips safety system in Their Best Helmets

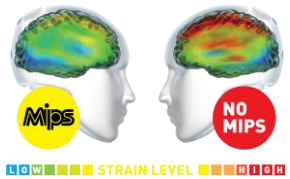
Mips today

25

Years of research at the Royal Institute of Technology and the Karolinska Institute.

4

Thesis and multiple research papers in international scientific publications.



World renowned Finite Element (FE) Model of the human brain.

60.000

State of the art test facility for all helmet categories.

Reconstructions from real life accidents.

External validation by 3rd party in US, Canada and Sweden.

IP

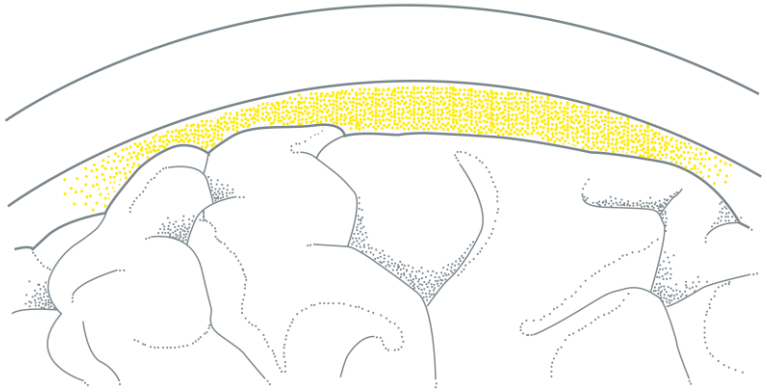
36 patent families

Multi-directional Impact Protection System

The cerebrospinal fluid is our natural protection system that allows the brain to move relative to the skull.

→ Mips =

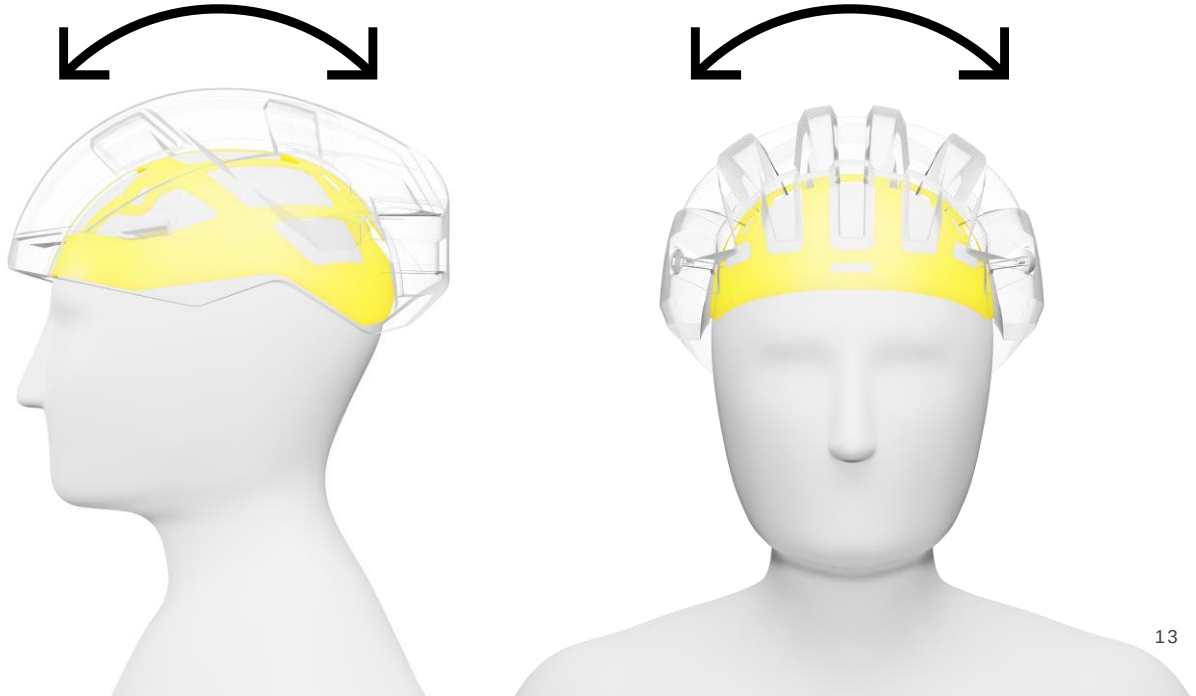
10–15 millimeter
Omnidirectional
Full coverage

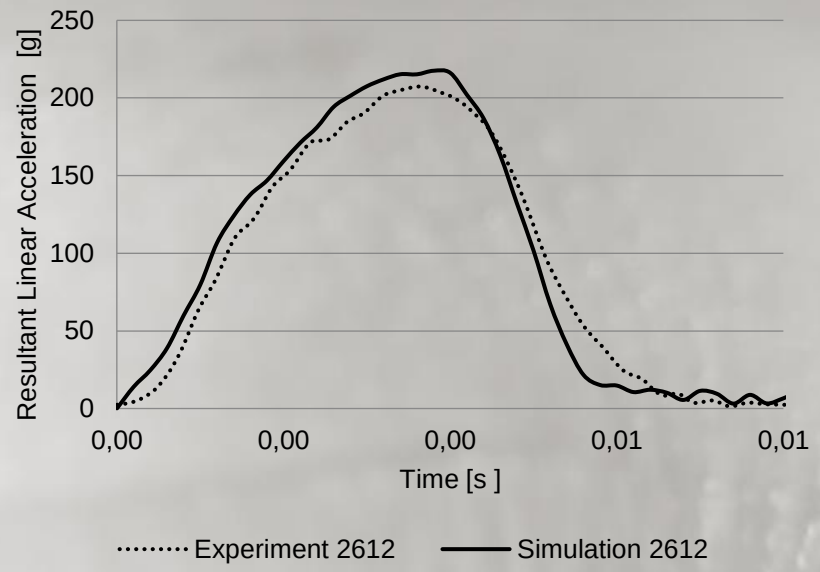


Skull

Cerebrospin

Brain

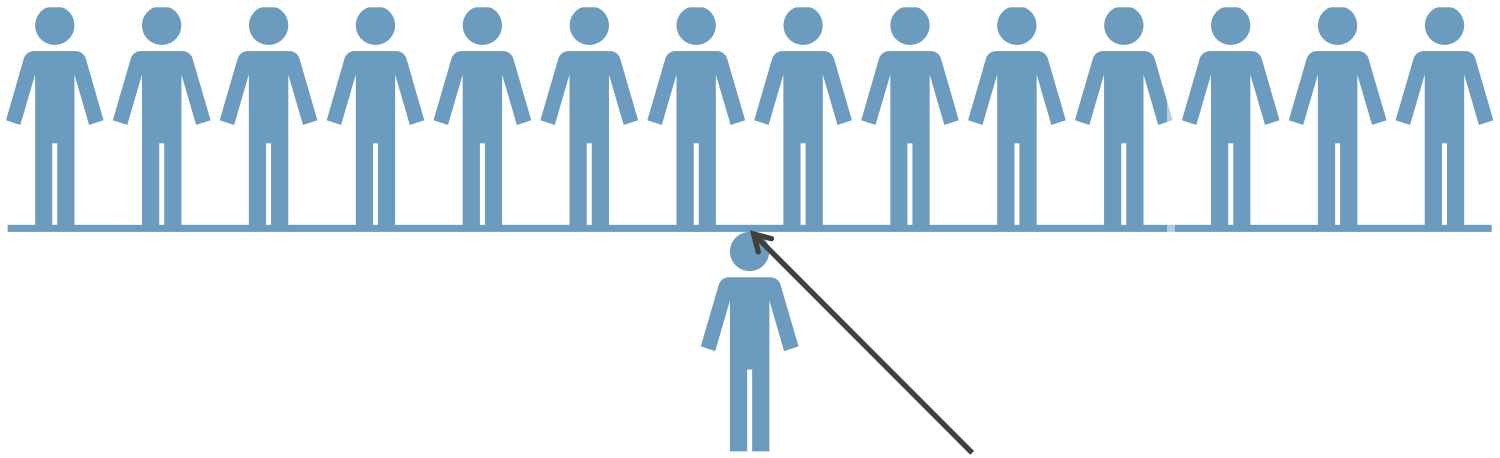




In the critical 5 - 10 milliseconds of an impact ...

A blink of an eye lasts 100 milliseconds.

WHILE UNDER SIGNIFICANT POINT LOADING

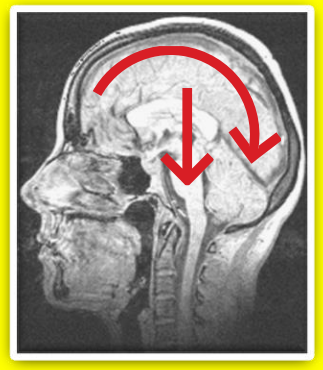


750 kg

At the moment of impact, the point load on the the head and the helmet is approximately 750 kg.

Why do we need Mips?

Type of Injury dependent on Impact

	Linear	Rotational (Angled & Tangential)
IMPACT DIRECTION:	↓	↘ →
ACCELERATION DIRECTION:		
TYPE OF INJURY:	• Fractur • Epidural hematoma (EDH) • Contusion	• Concussion • Subdural hematoma (SDH) • Diffuse axonal injury (DAI)
CONCLUSION:	Conventional helmets are tested by dropping them vertically onto a flat surface and they are designed with that testing in mind.	By adding rotational protection to the helmet you add protection from those angled impacts.

Holbourn 1943

Löwenhielm 1974

Ommaya et al. 1967

Ommaya and Hirsch 1971

Gennarelli et al. 1982

McIntosh et al. 2011

Kleiven 2007

The team at KTH & Karlolinska

PETER HALLDIN

Founder of Mips

Assistant professor
KTH, Royal Institute of Technology

HANS VON HOLST

Founder of Mips

Professor and Neurosurgeon Karolinska University Hospital

SVEIN KLEIVEN

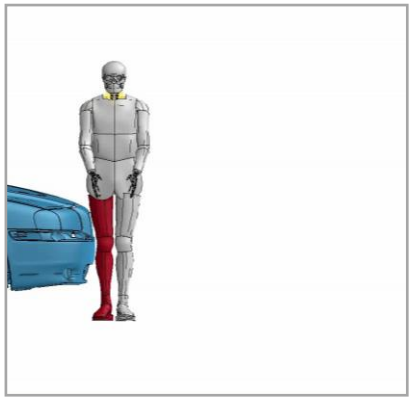
Founder of Mips

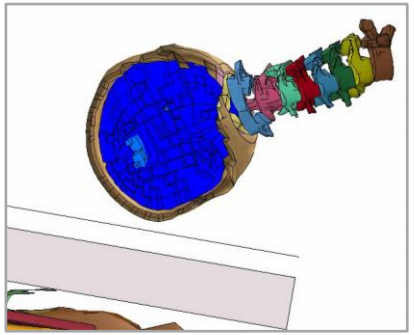
Professor at KTH, Royal Institute of Technology

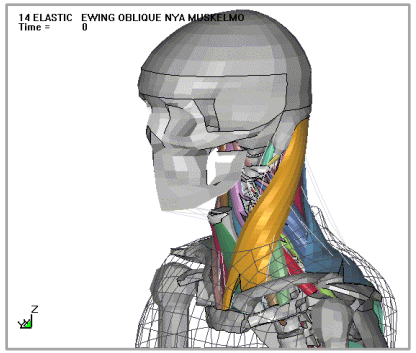
3-D model of the human brain

KARIN BROLIN

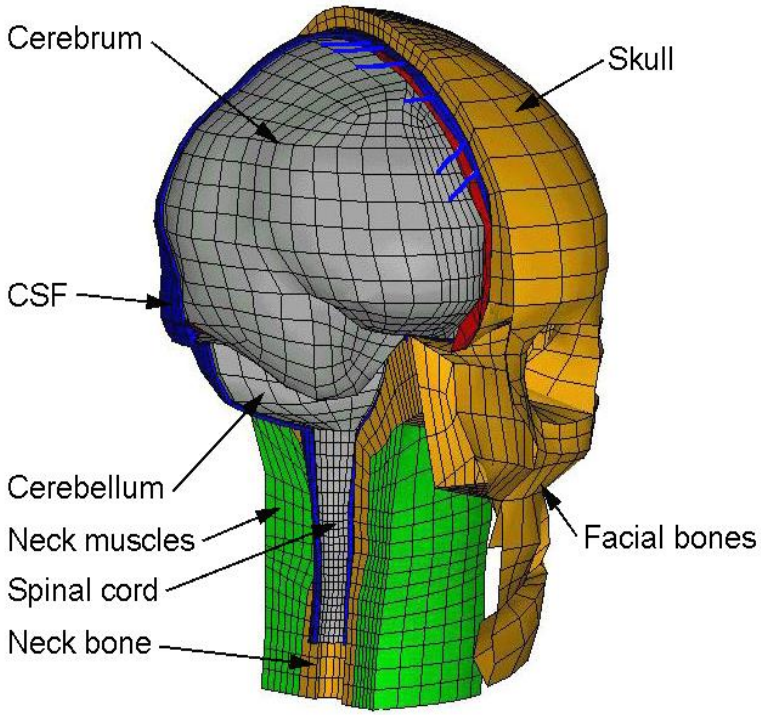
MAGNUS AARE



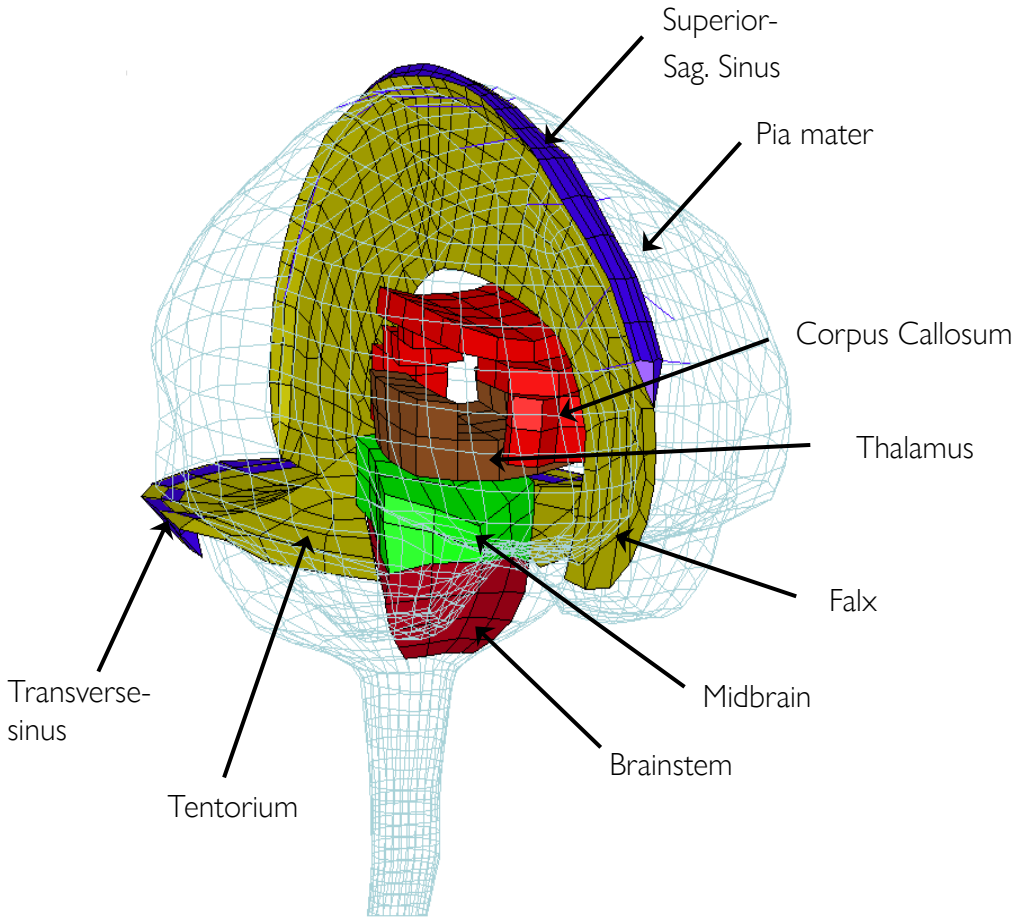




The KTH FE model of the human head and brain

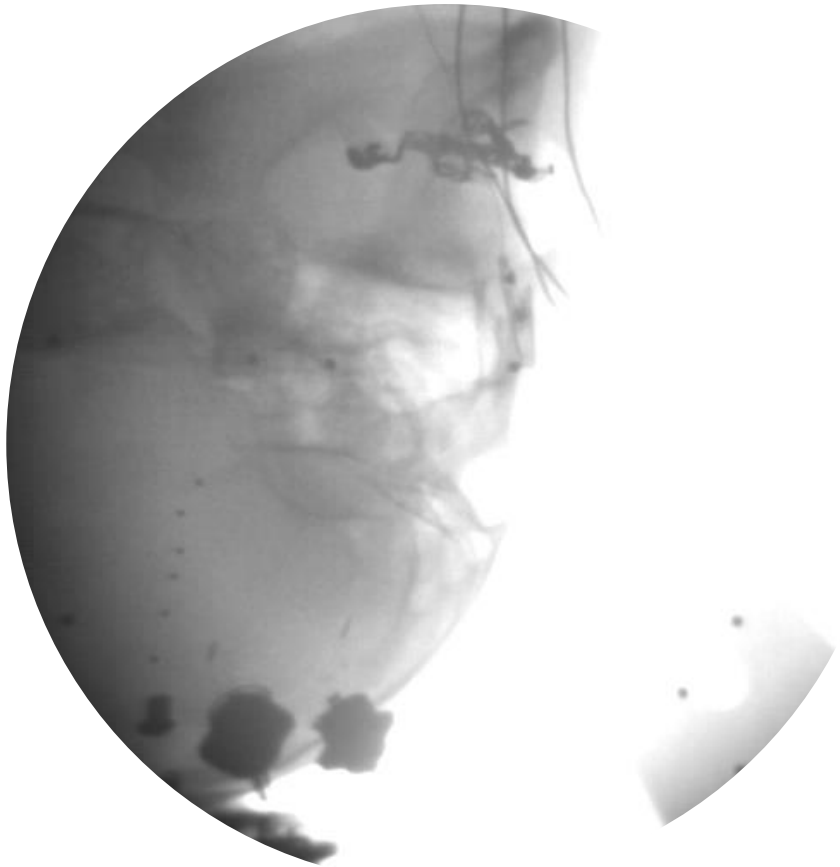


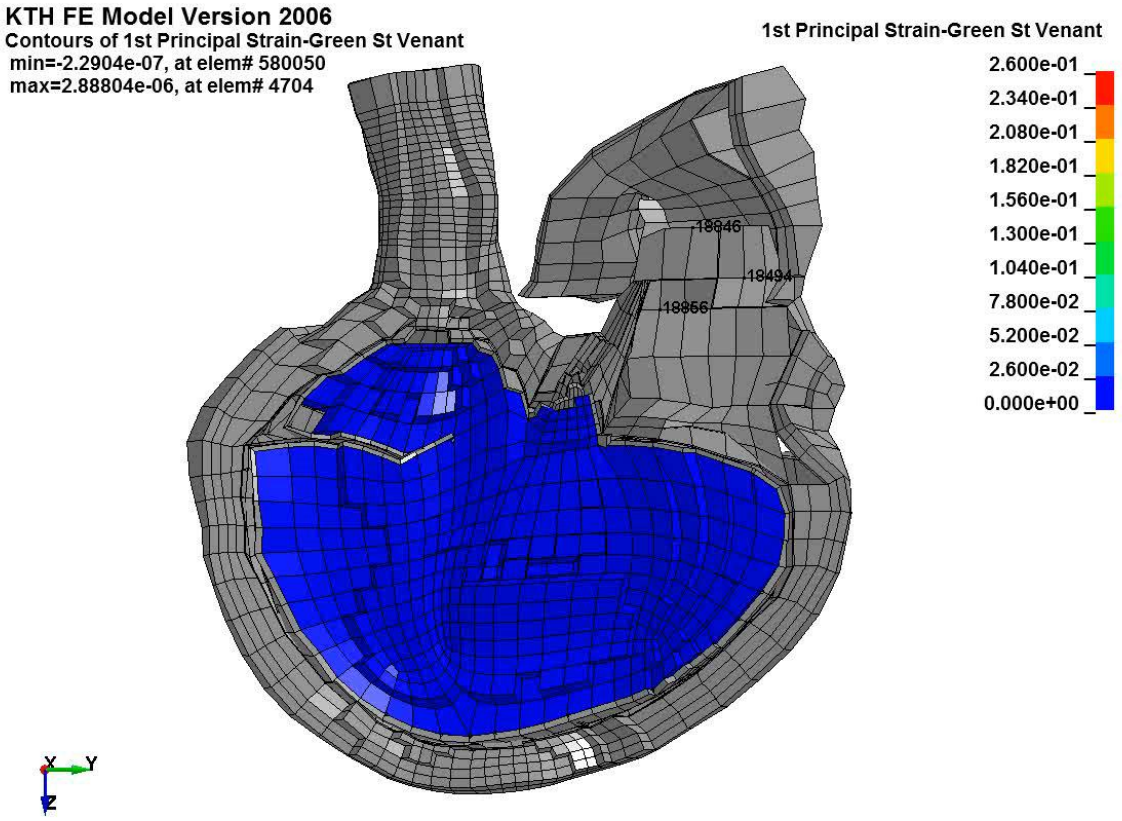
LS-DYNA



Kleiven et al. 2006

Validation of the KTH head model

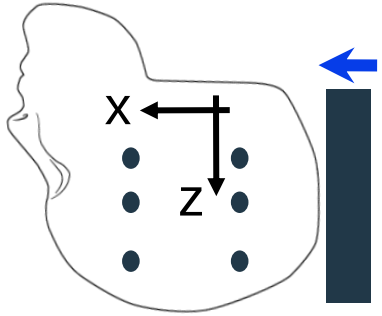


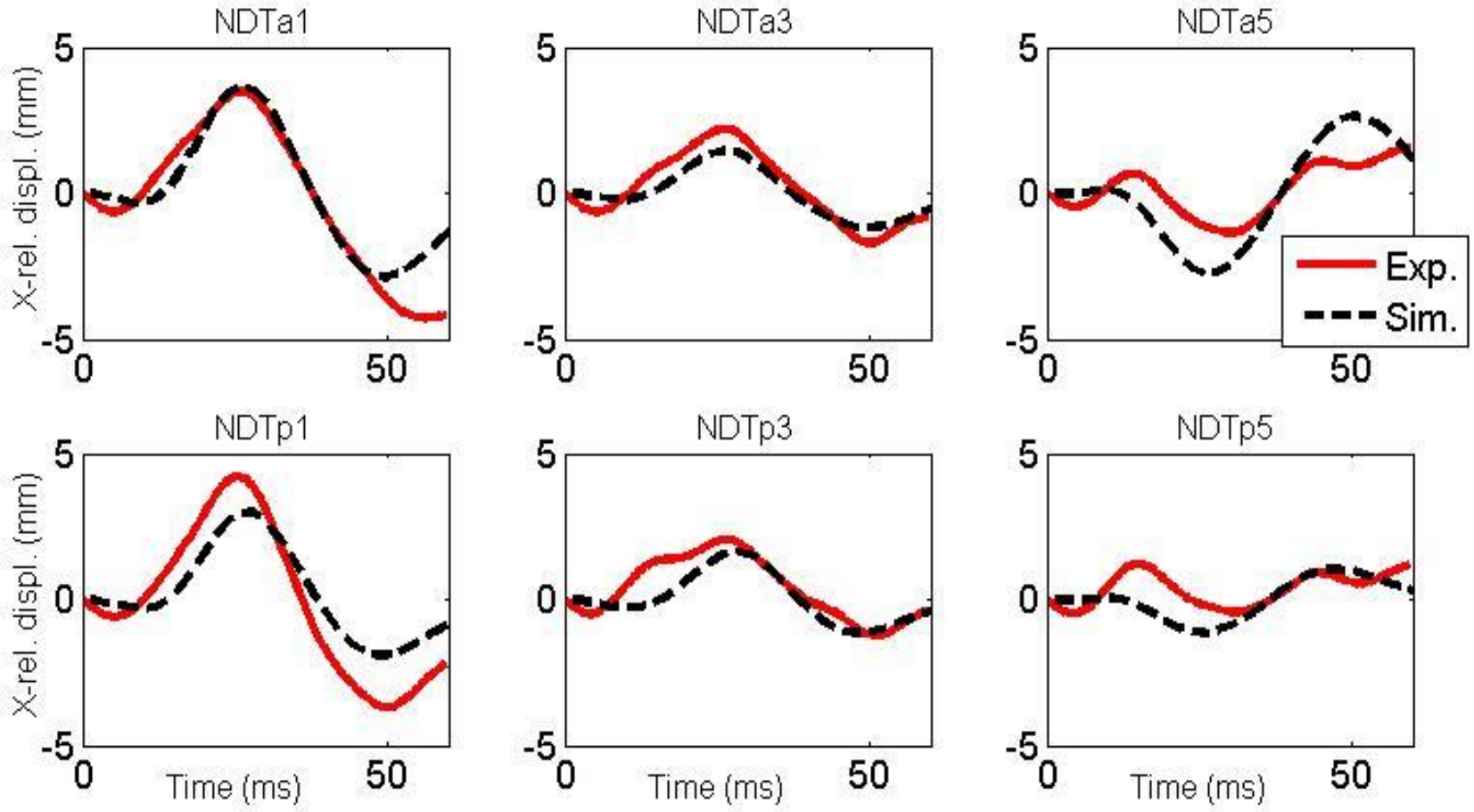


KLEIVEN AND HARDY
STAPP CAR CRASH JOURNAL 2002

Validation to experiment

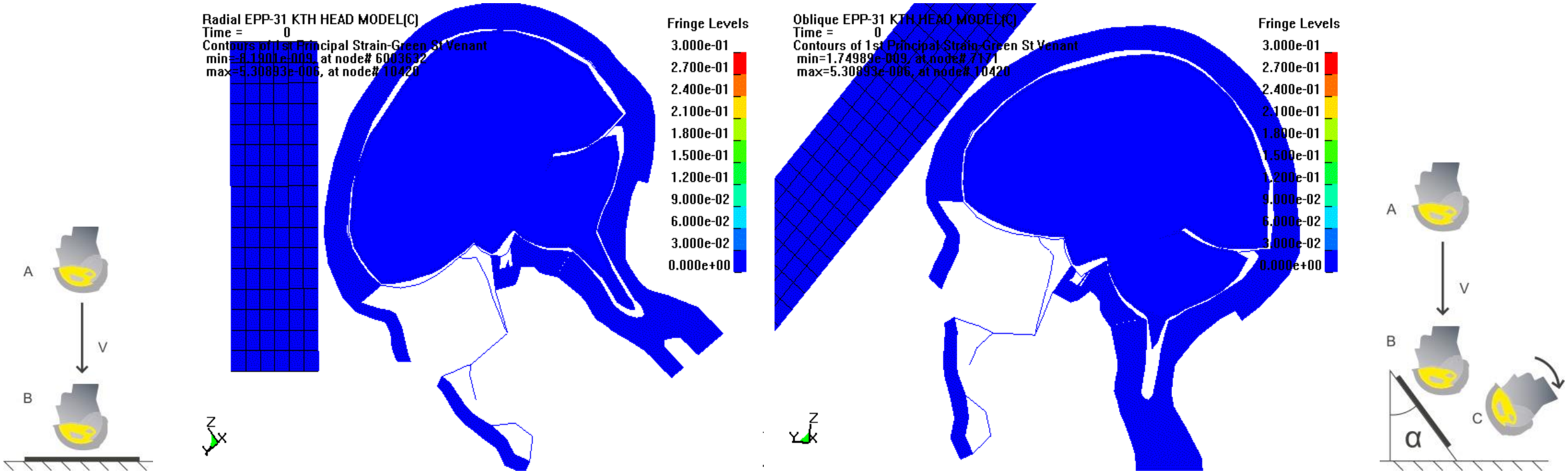
- Relative motion in the head





Kleiven and Hardy, Stapp Car Crash Journal 2002

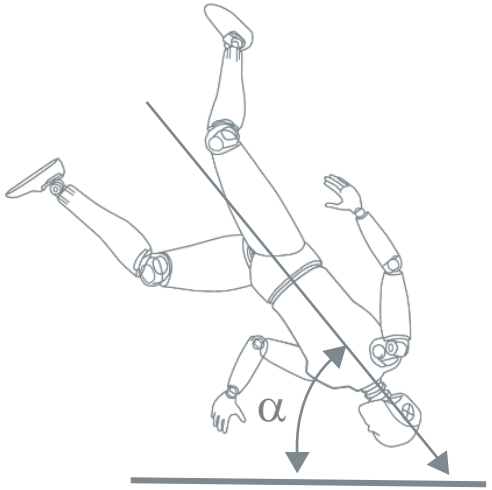
Comparing Radial vs. Oblique impact

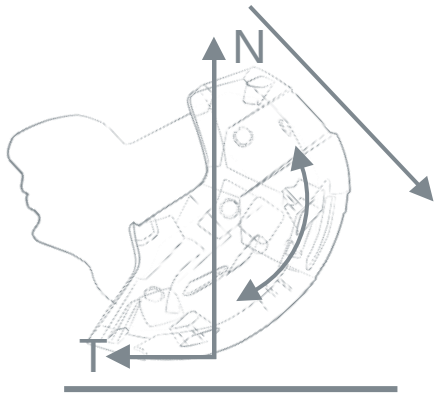


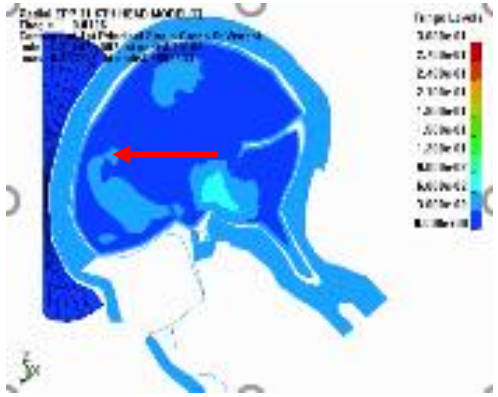
Kleiven et al. 2006

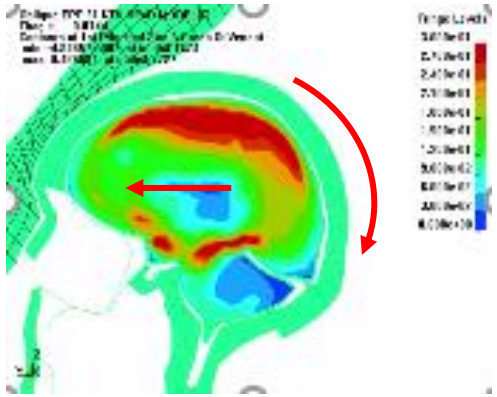
Summary: The need for safety steps like Mips

- Oblique impacts are common in most sports (Otte et al. 1999, Verschueren 2009, Mellor and Chinn 2006)
- Oblique impacts could lead to a tangential force, depending on the normal force and the coefficient of friction.
- Tangential force -> rotation
- The brain is more sensitive to rotation than pure translational motion. (Holbourn 1943, Genarelli 1983, Marguiles and Tibault 1992, Fijalkowski et al. 2007, Kleiven 2007)

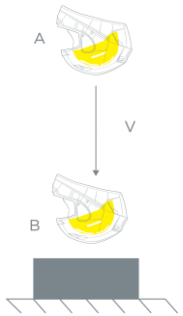








Mips approval test protocoll



Current helmet test standards EN1078, CPSC

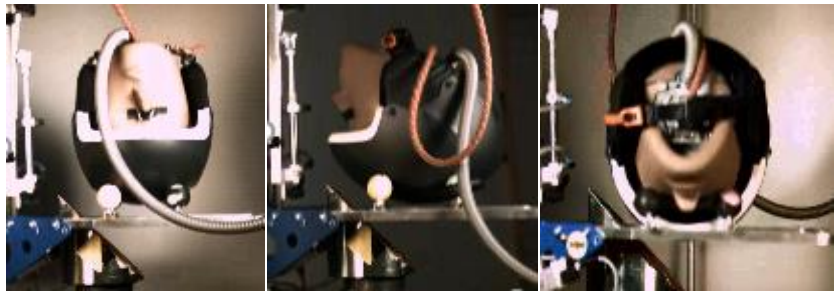
Linear acceleration → < 250G

CE

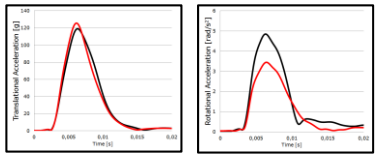
MIPS

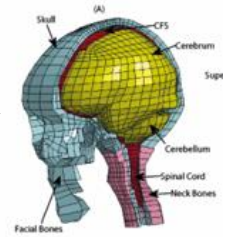
No MIPS

Xrot Yrot Zrot



Linear acceleration +
Angular acceleration





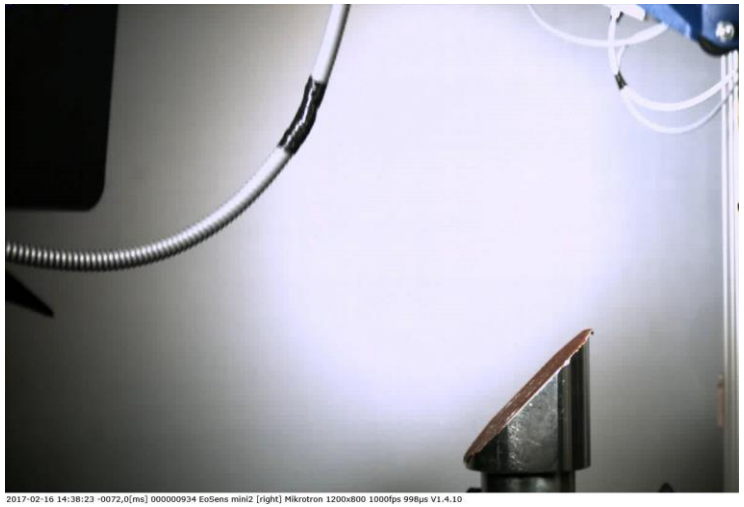
Strain reduction > 10%

→ Mips

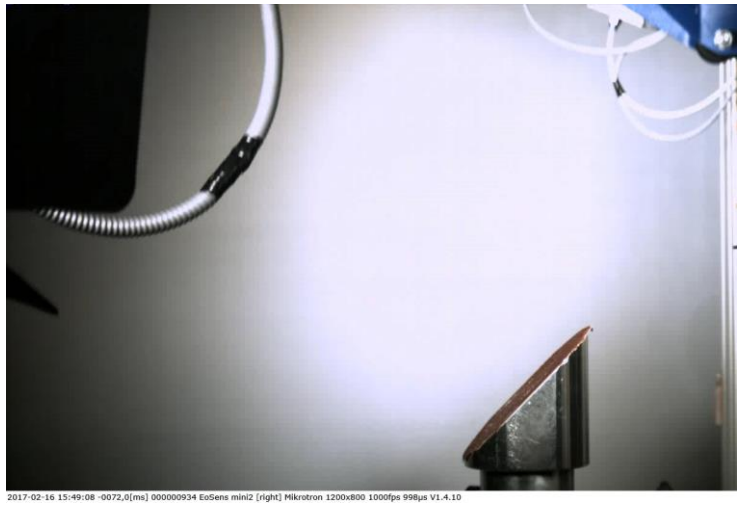
25

TEST METHOD BIKE AND SNOW – 6.5m/s

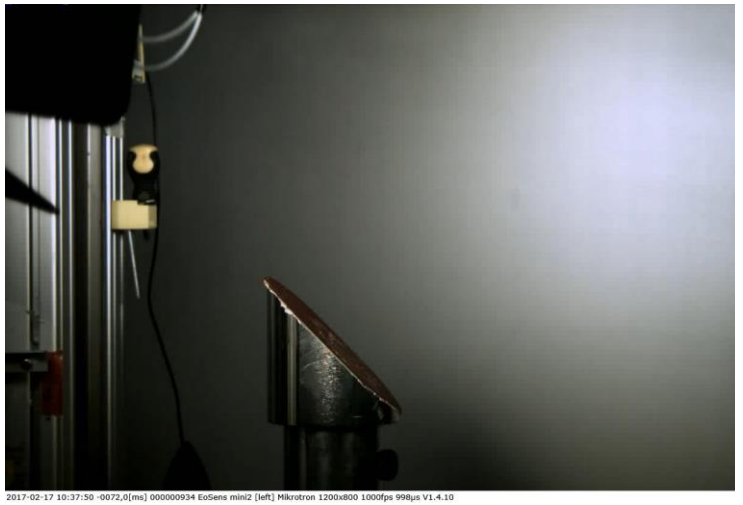
X-Rotation



Y-Rotation

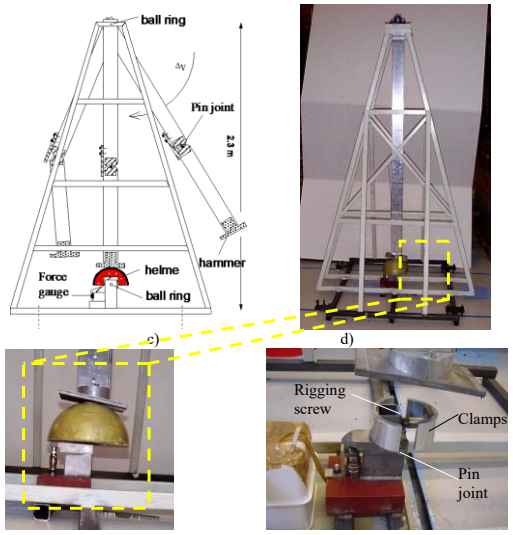


Z-Rotation



MIPS test method history

KTH 1996



UK 2000

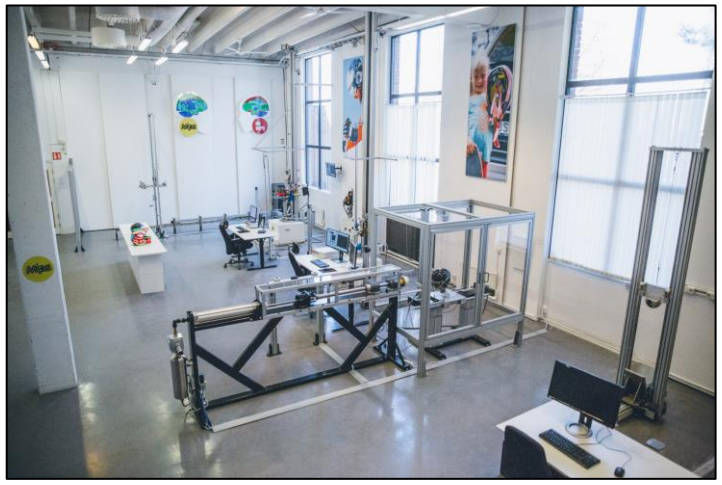
KTH 2001

-

KTH 2013

Danderyd 2014-2015

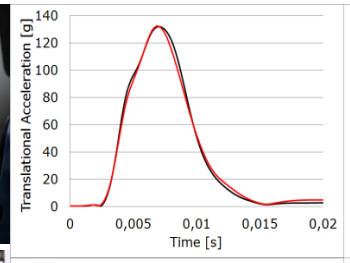
Täby 2016-

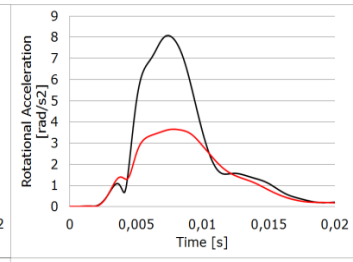


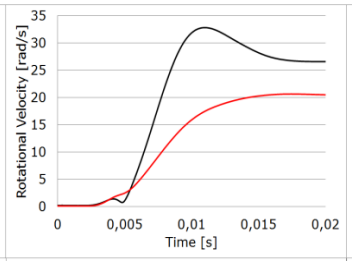
MIPS Test Laboratory

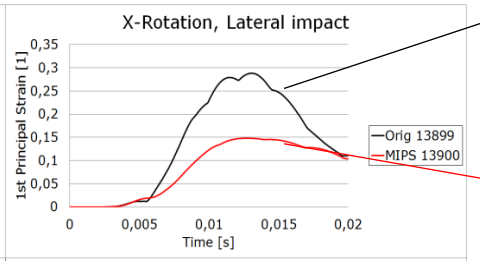
Example of mips function in x, y and z-rotation

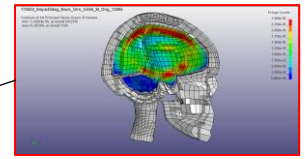
X rot

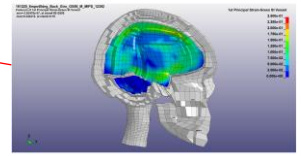




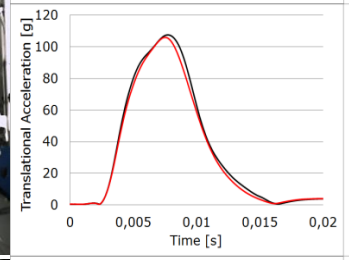


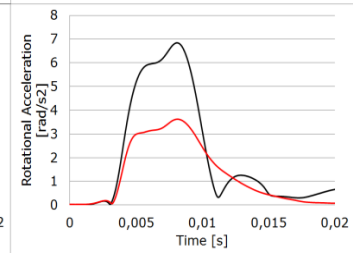


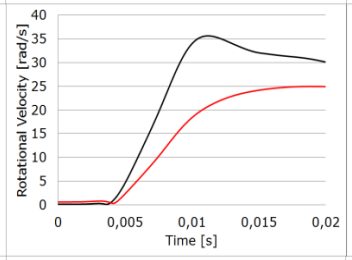


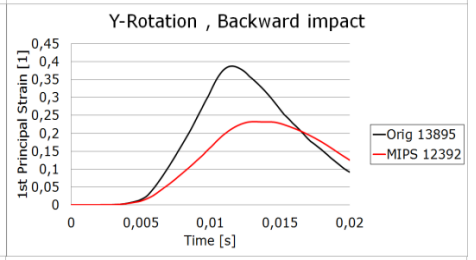


Y rot

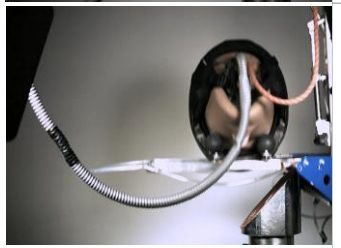


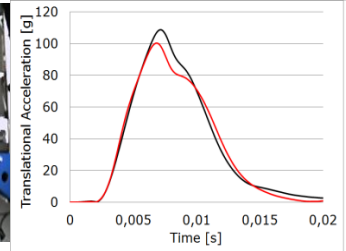


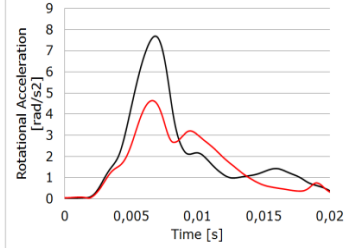


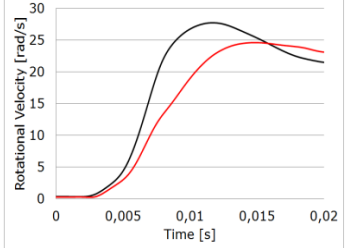


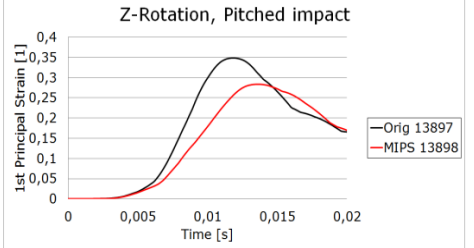
Zrot



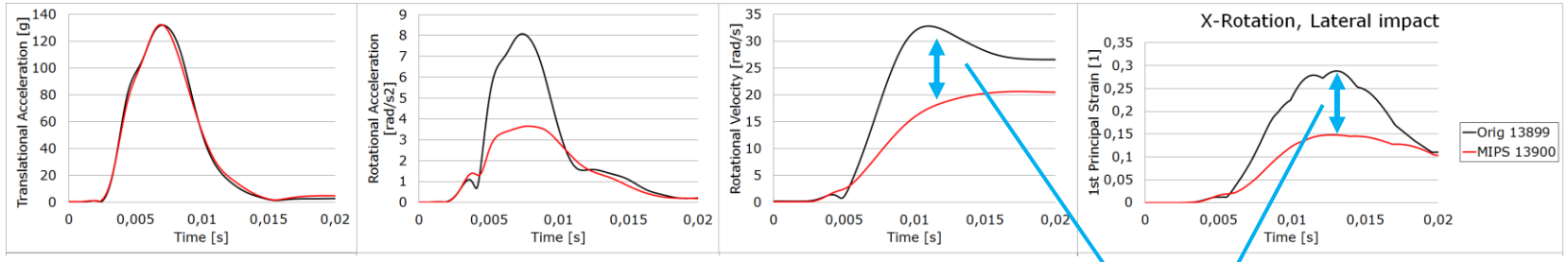




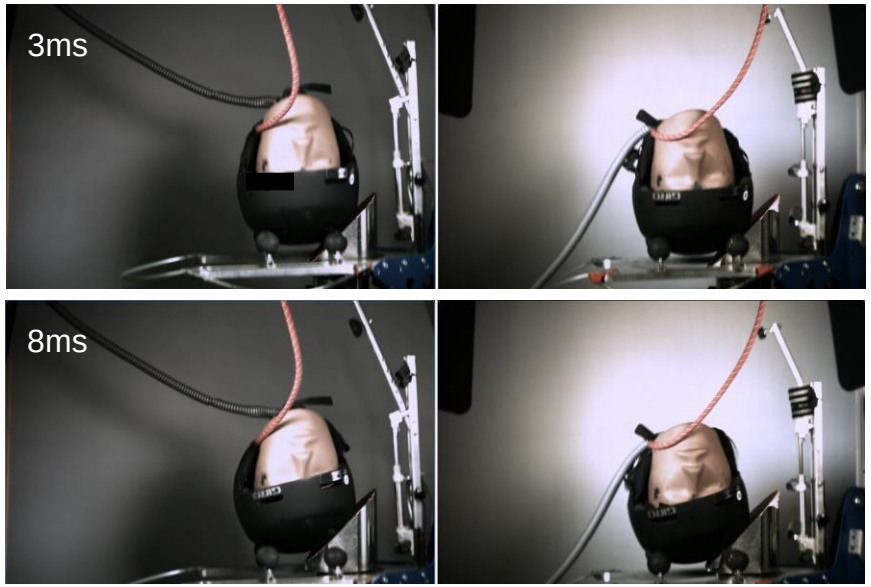




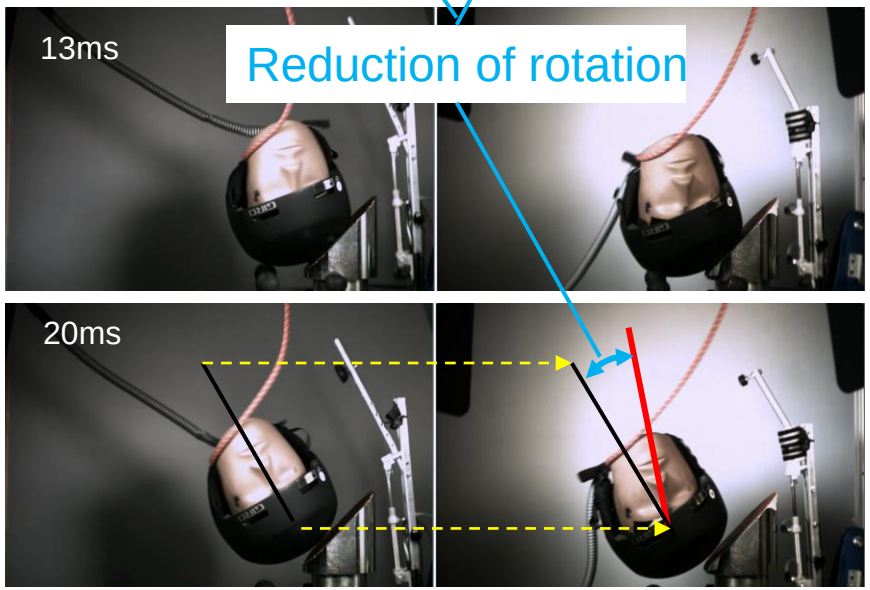
Example of mips function in x-rotation



No MIPS MIPS



No MIPS MIPS



Outline

- Mips introduction (What, How, Why)
- 25 years of Mips & FE
  - **Energy absorption in helmets with Mips**
  - The effect of the human cervical spine in helmet testing
  - Virtual Test Lab
  - Other projects
    - CEN TC158- New rotational test standard
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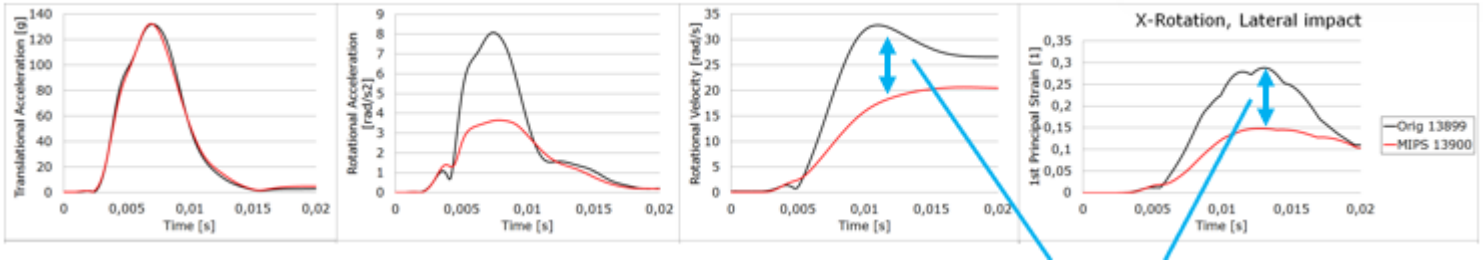
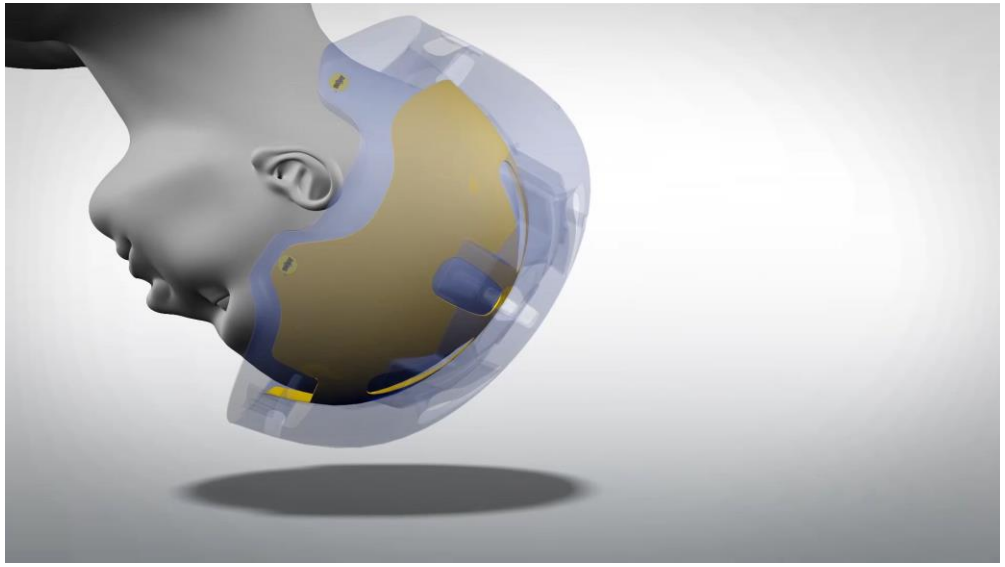
    - FE Head model evaluation

How does MIPS reduce rotational energy?



?

- Friction heat?
- Energy absorption in the fixation mechanisms?
- Spreading the load to larger volume of the EPS liner?



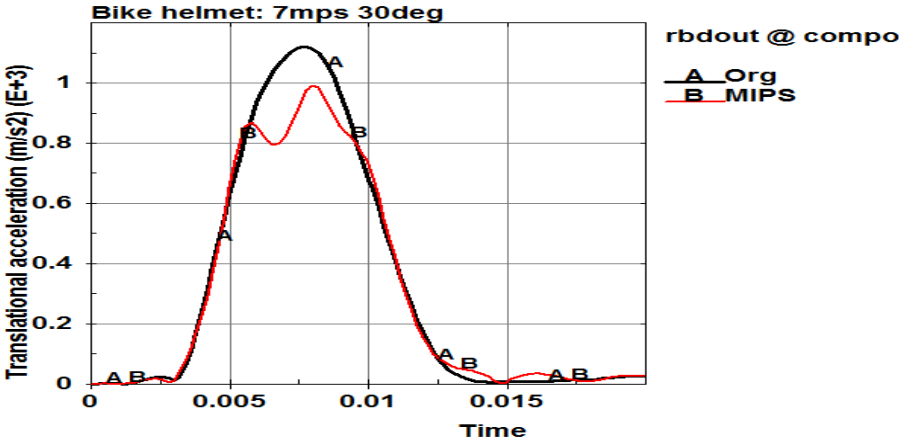
Kinematic analysis

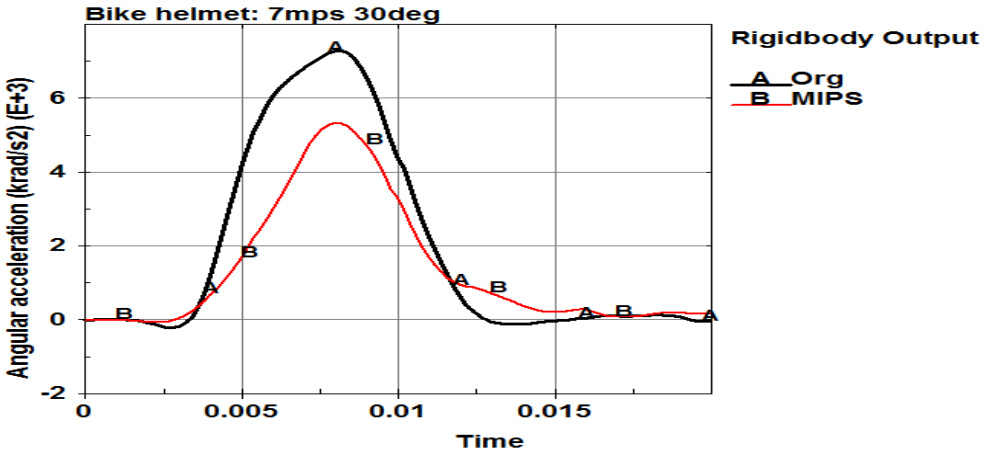
Mips

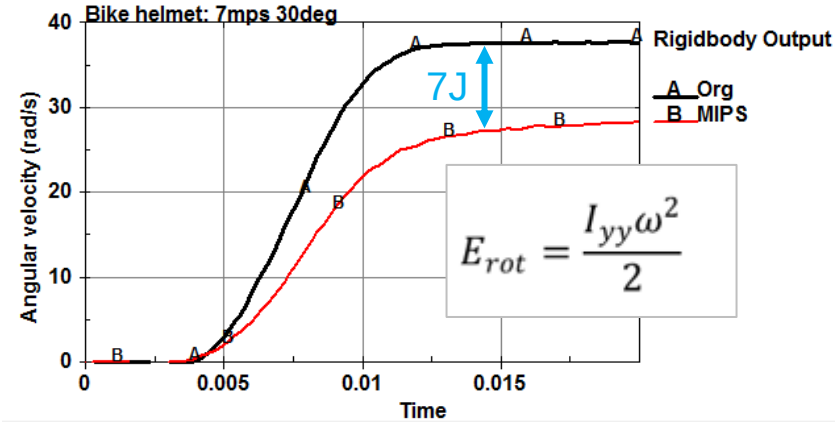
Original

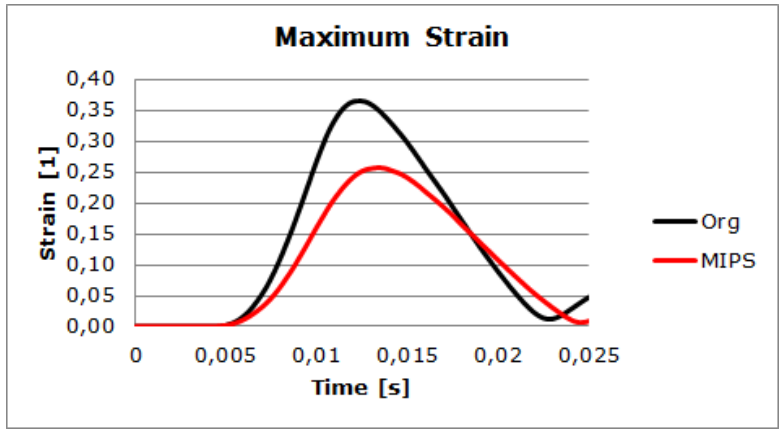
MIPS

Computed results from the FE HIII and human head



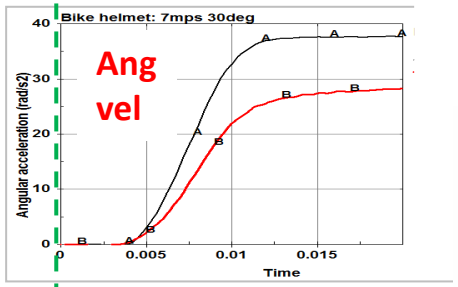


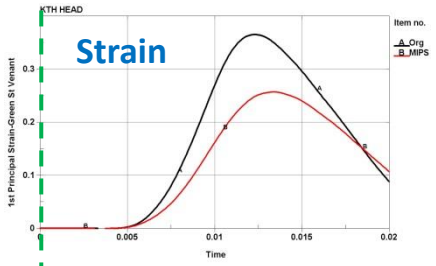




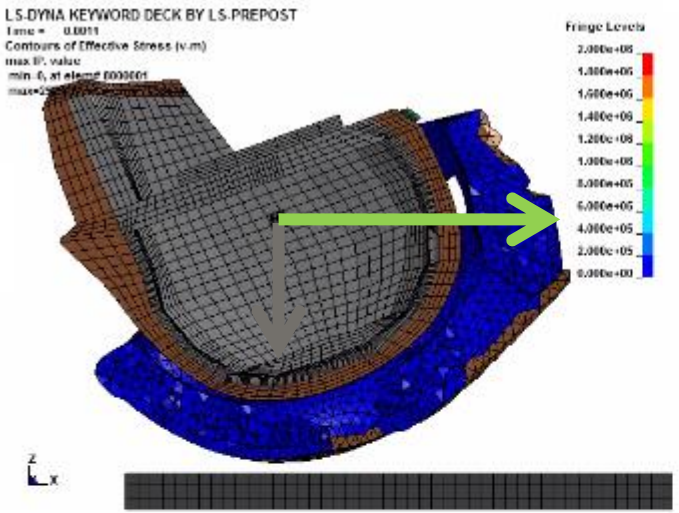
Kinematic analysis

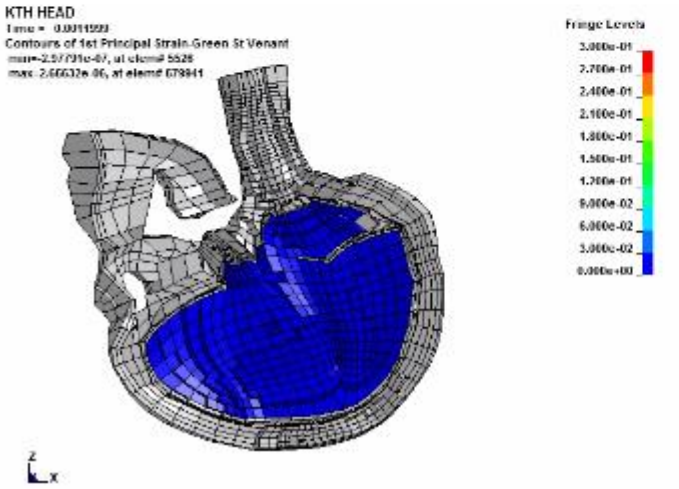
t=0.000s



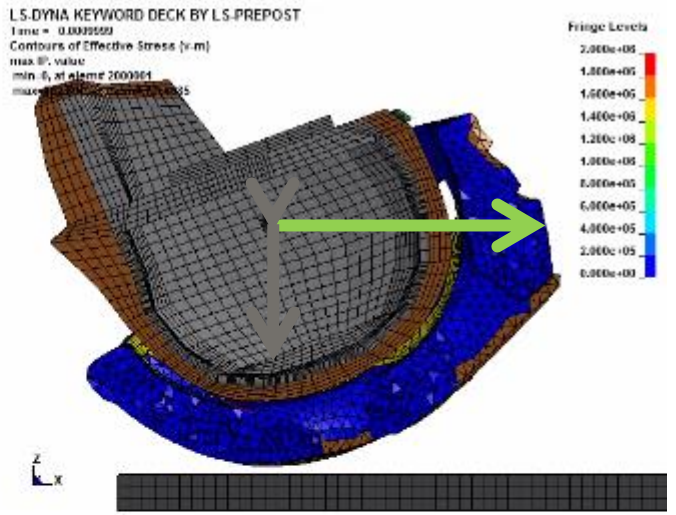


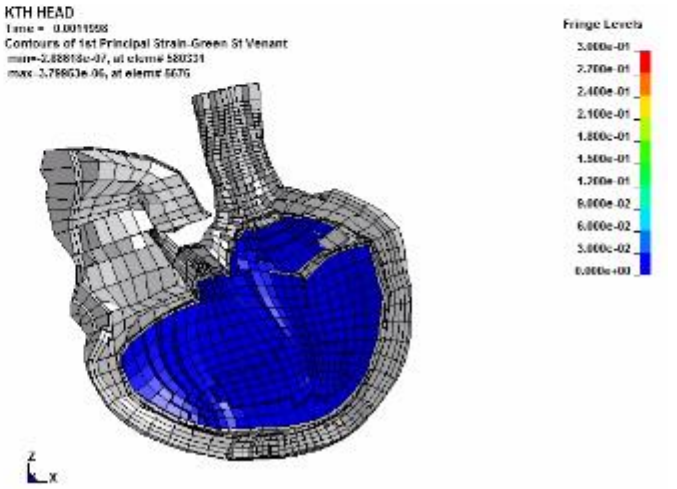
Original





MIPS





Kinematic analysis

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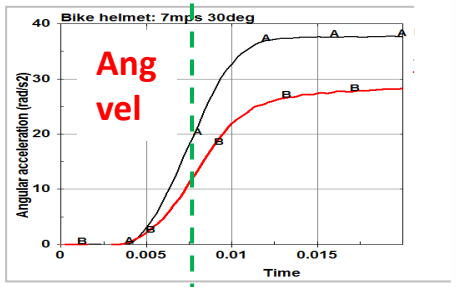
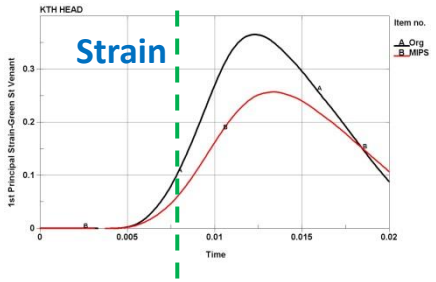
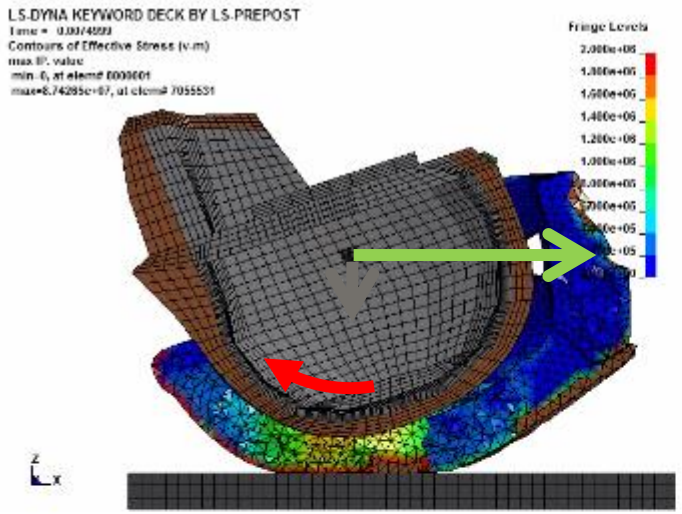
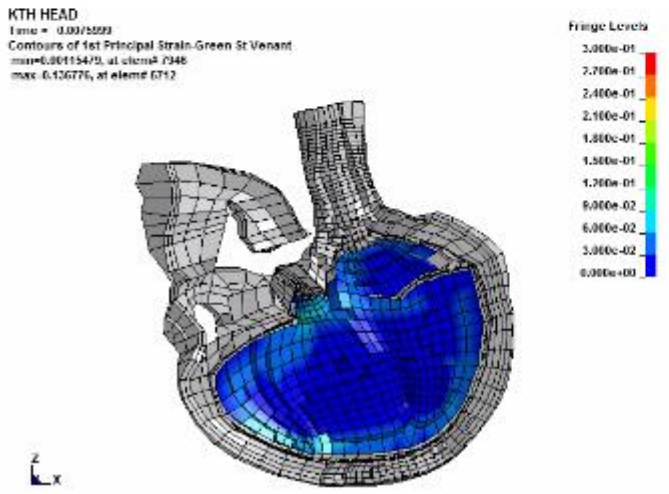


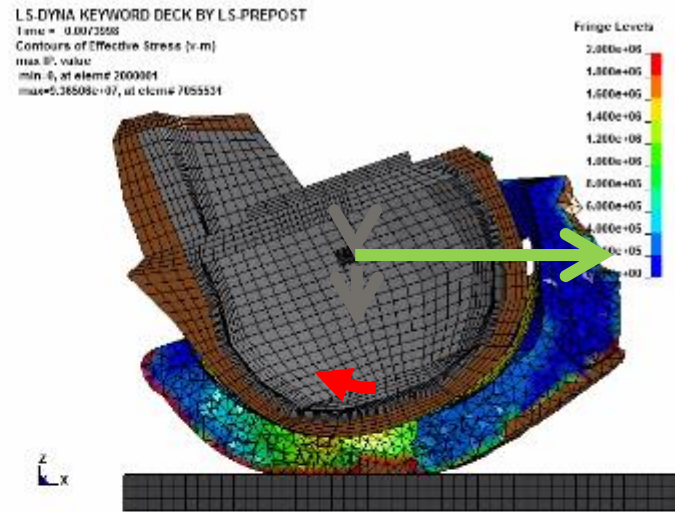


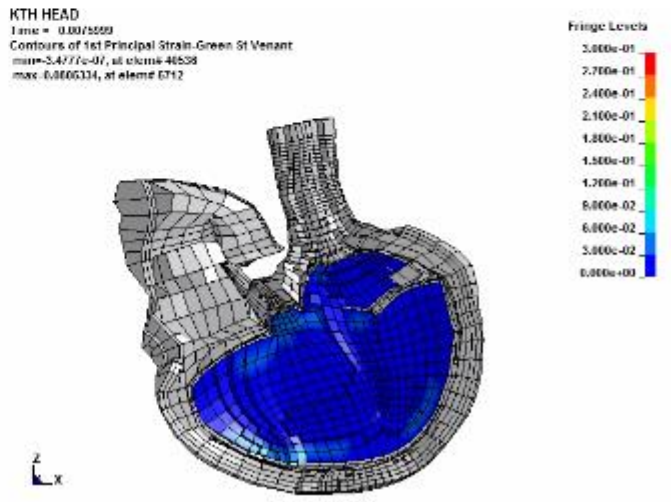
Original





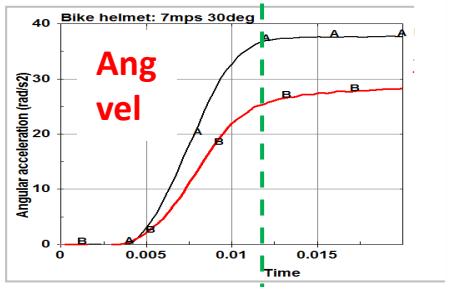
MIPS

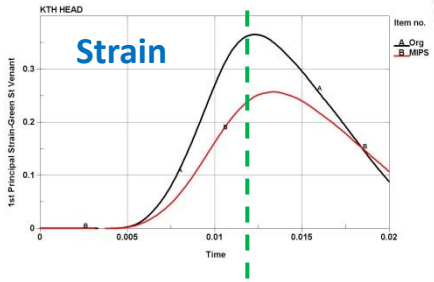




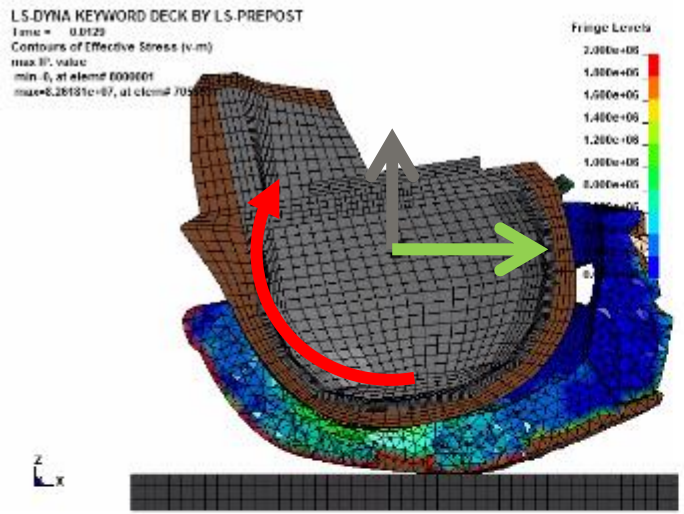
Kinematic analysis

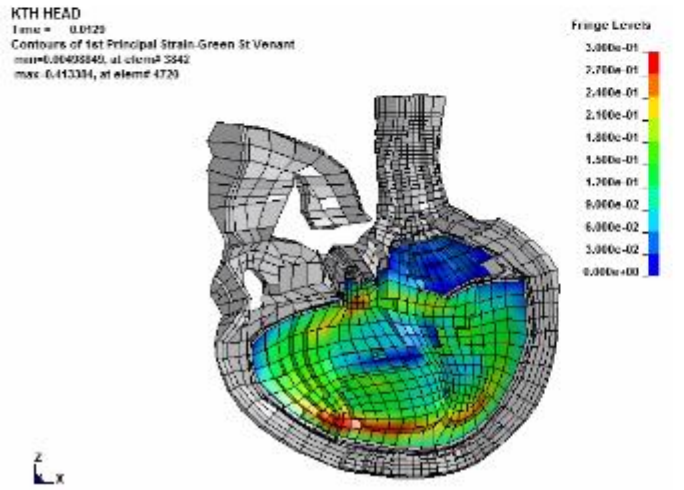
t=0.012s



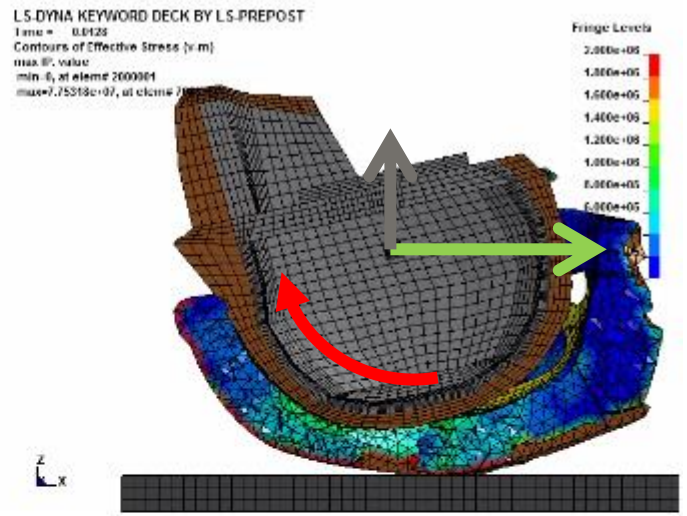


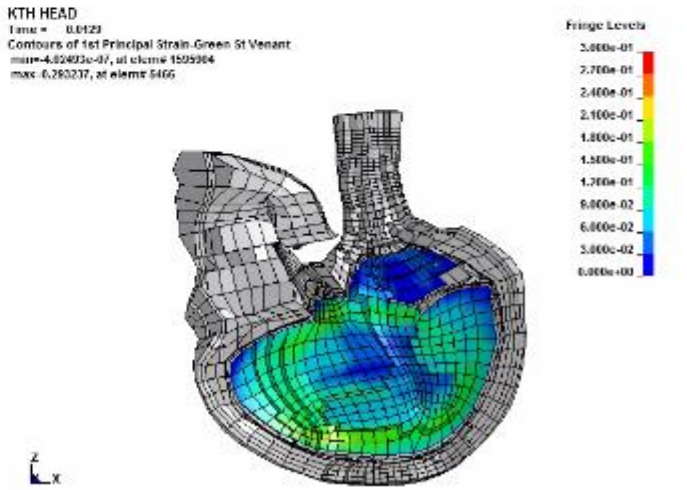
Original





MIPS





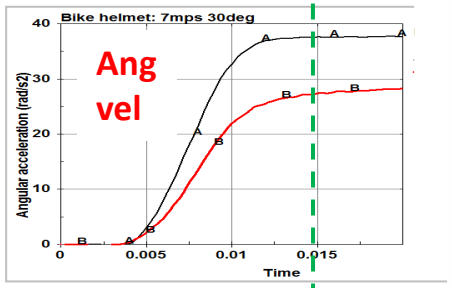
Kinematic analysis

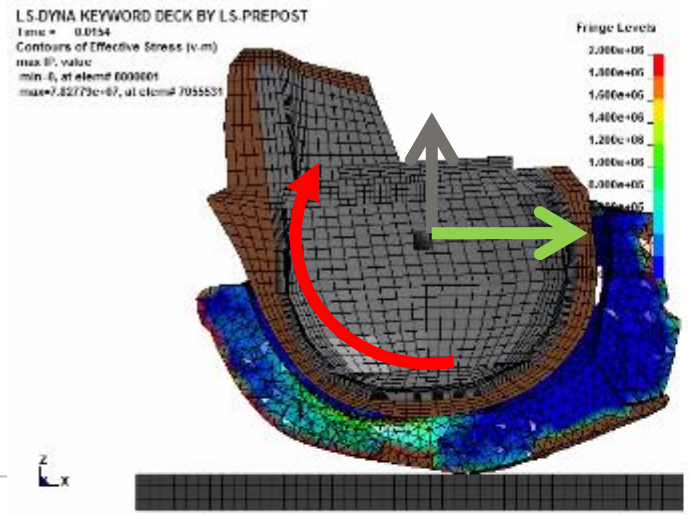
Mips

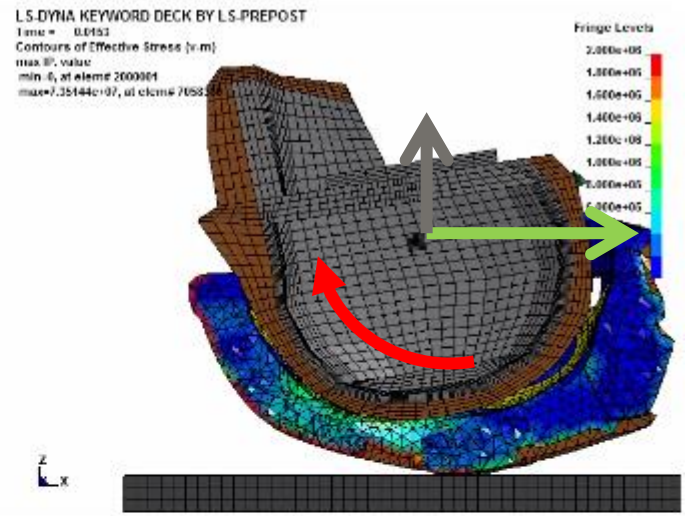
Original

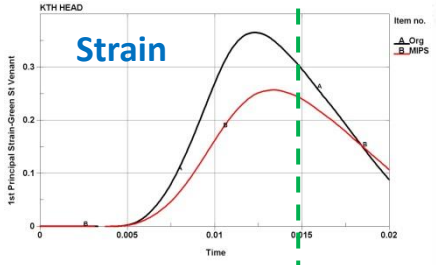
MIPS

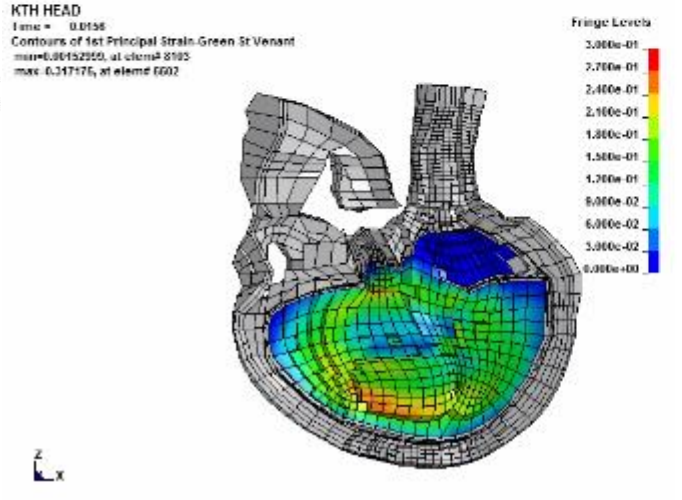
t=0.015s

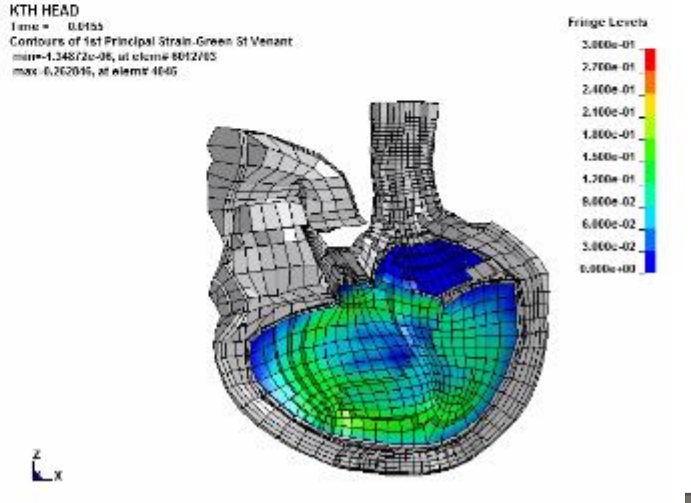






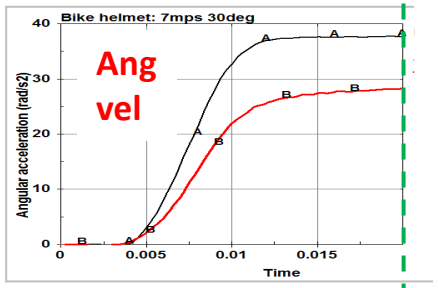


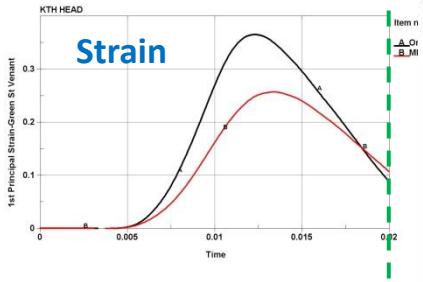




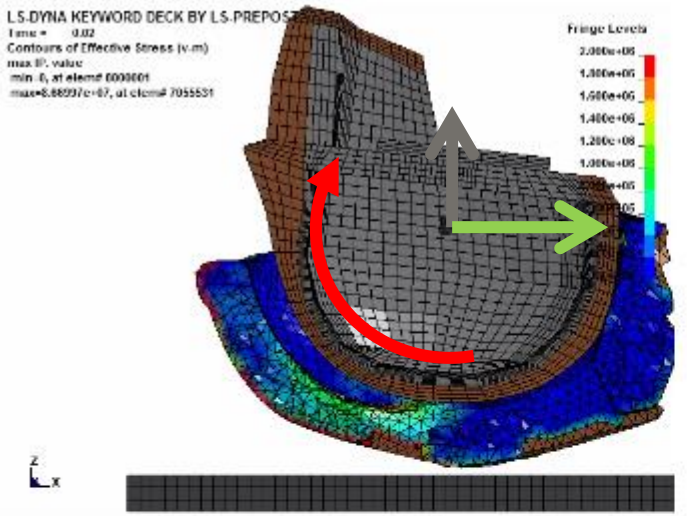
Kinematic analysis

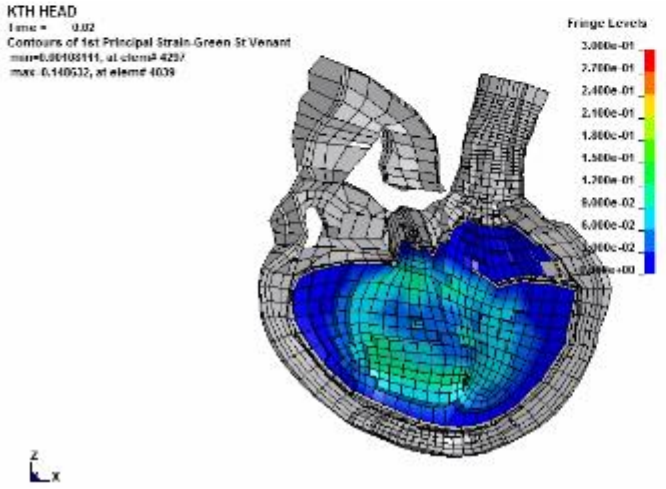
t=0.020s



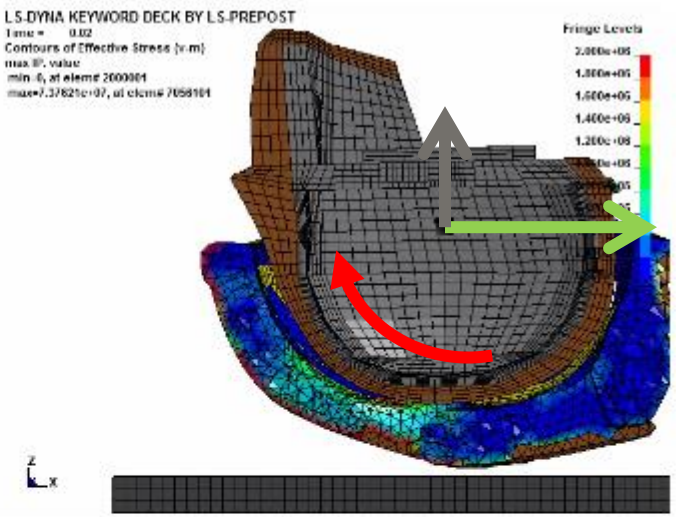


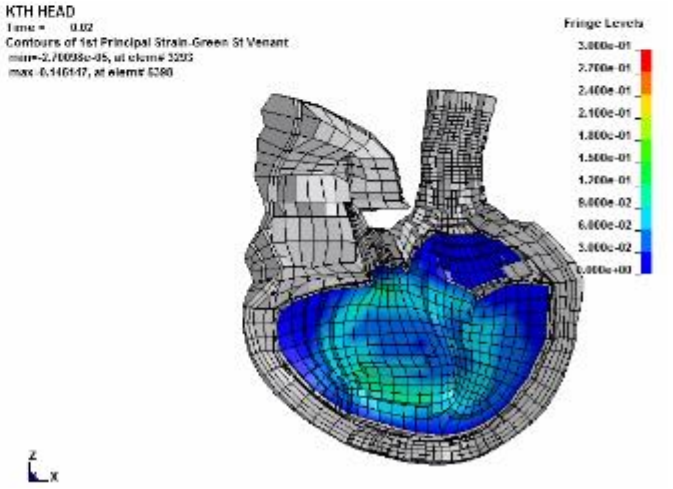
Original



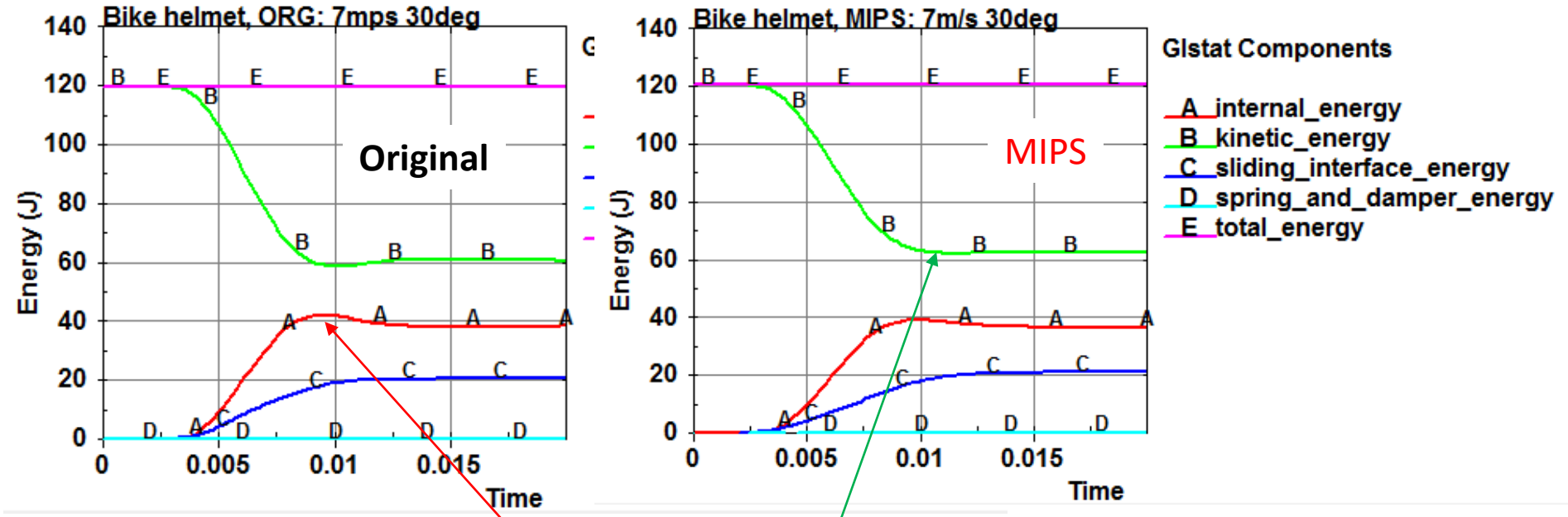


MIPS





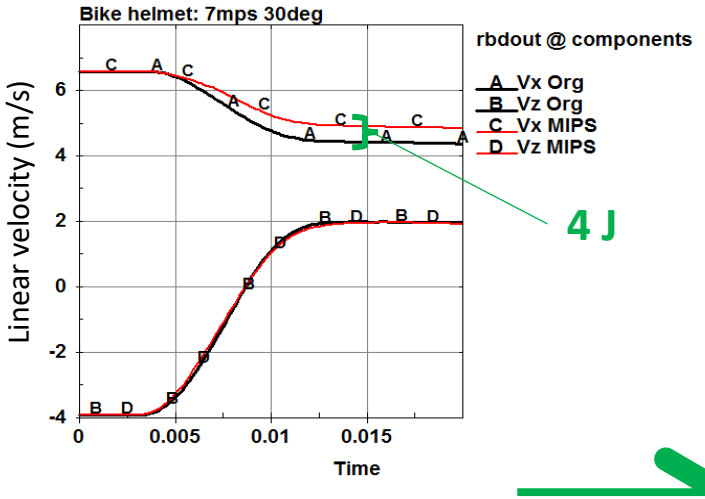
Energy from simulations

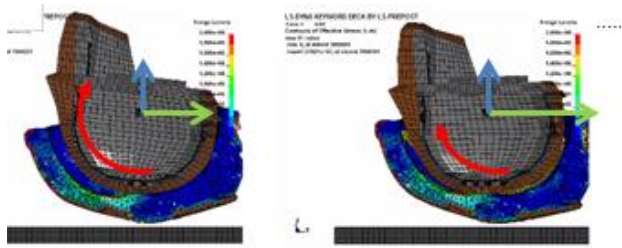


- The MIPS helmet shows higher kinetic energy after impact (X-velocity).
- The simulation with the original helmet design shows higher internal energy (EPS-liner).

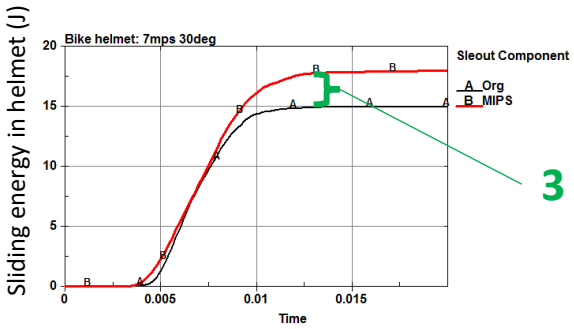
Energy balance and energy disipation in the MIPS helmet

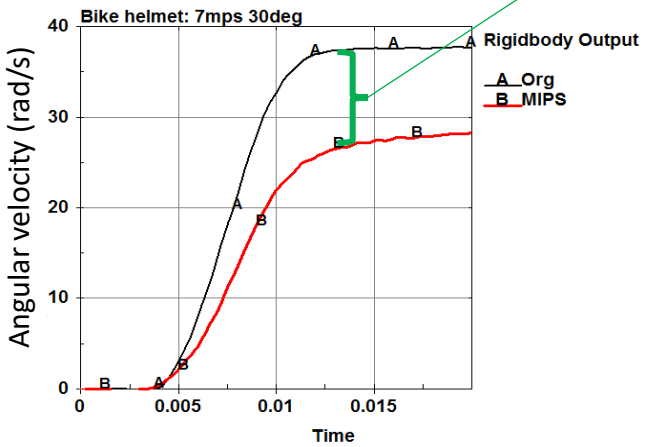
Some of the reduced rotational energy is due to higher linear velocity in X-direction after impact.





Some of the reduced rotational energy is due to sliding energy in the helmet.





$$E_{lin} = \frac{mv^2}{2} \qquad E_{rot} = \frac{I_{yy}\omega^2}{2}$$

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  - Virtual Test Lab
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    - Safety helmets and initial rotation
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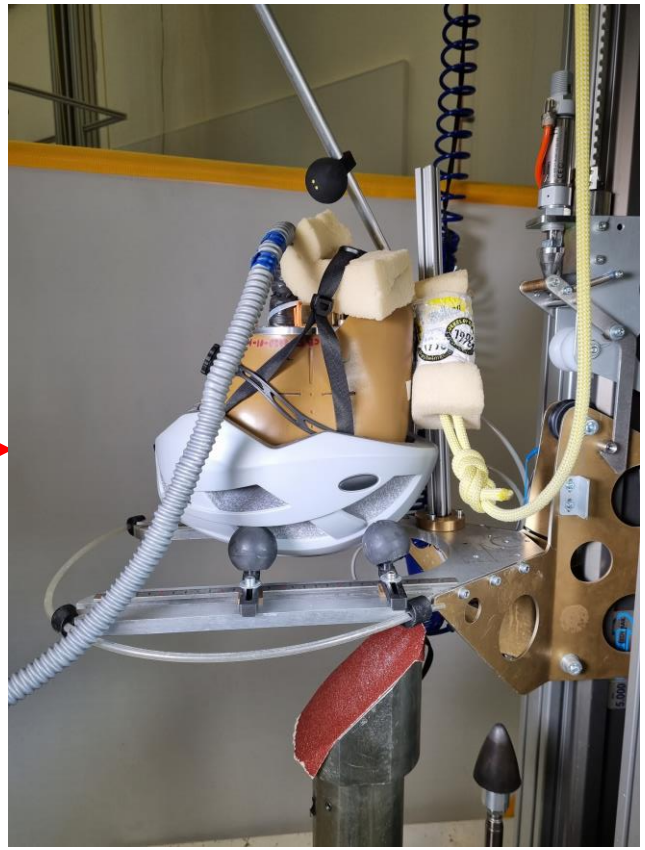
    - FE Head model evaluation

How to simplify the real accident?

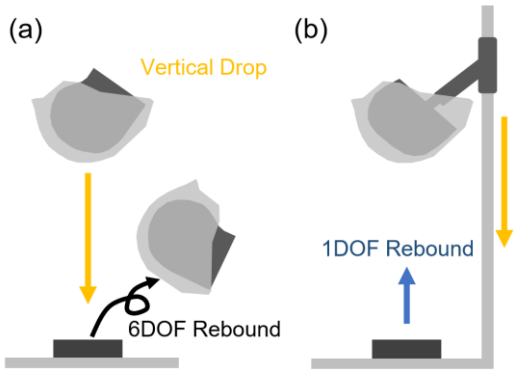
THE OBJECTIVES:

Take the real accident situation into the test laboratory and create both experimental and virtual test methods aiming towards safer helmets.



Overview of Test standards/methods for bike, snow, Moto

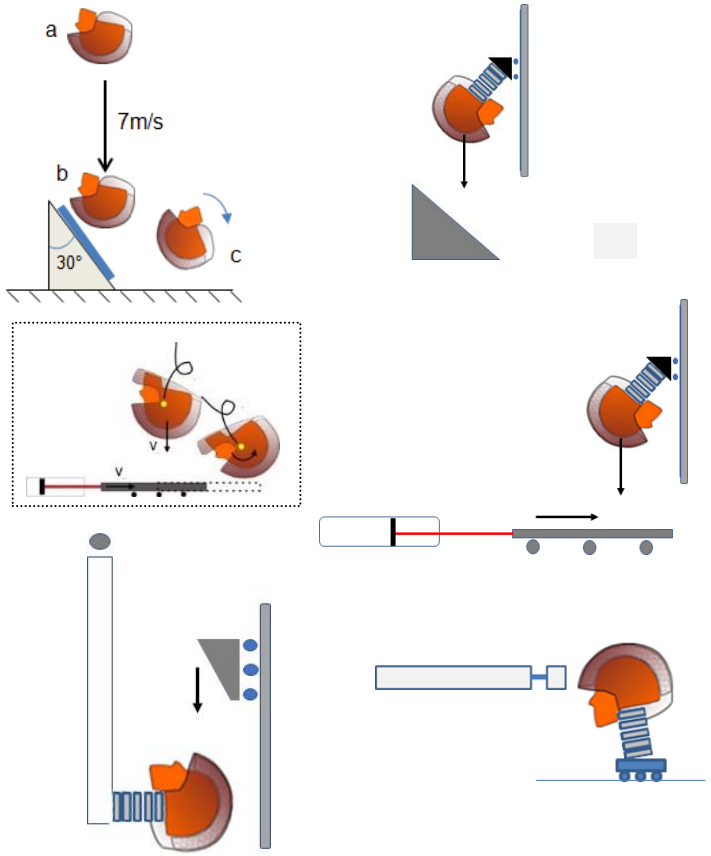
Current test standards

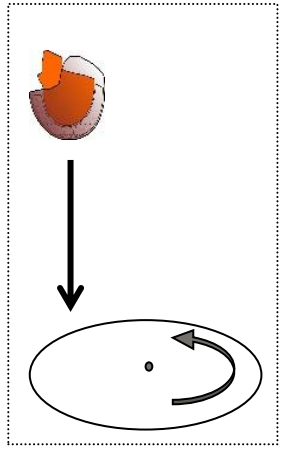


Europe
(CEN, BSI)

US
(ASTM, DOT, SNELL, CPSC)

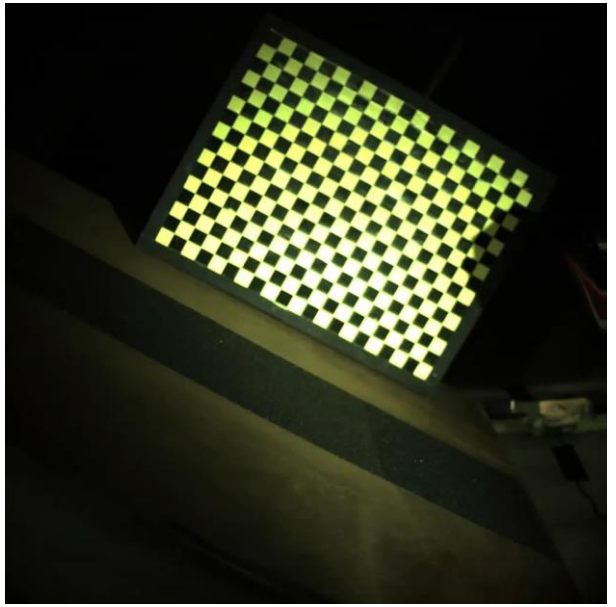
Potential oblique test methods





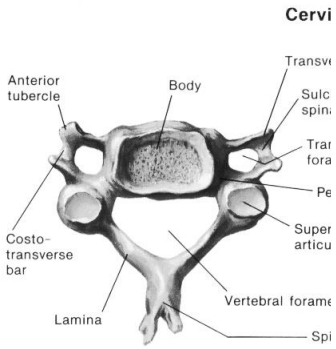
Aldman et al. 1976
Halldin et a. 2001
Pang et al. 2011
Deck et al. 2011
NOCSAE 2014
Siegkas and Ghajari 2017

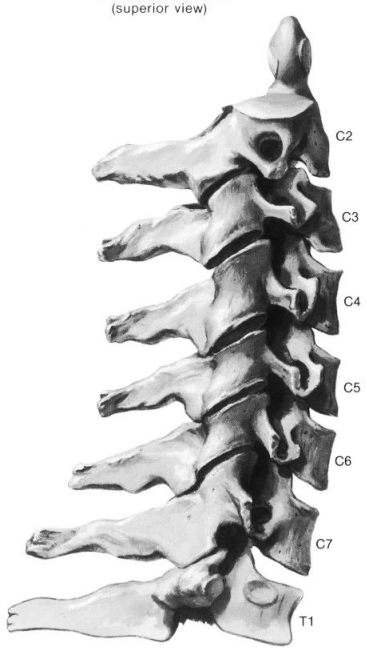
How to simplify?

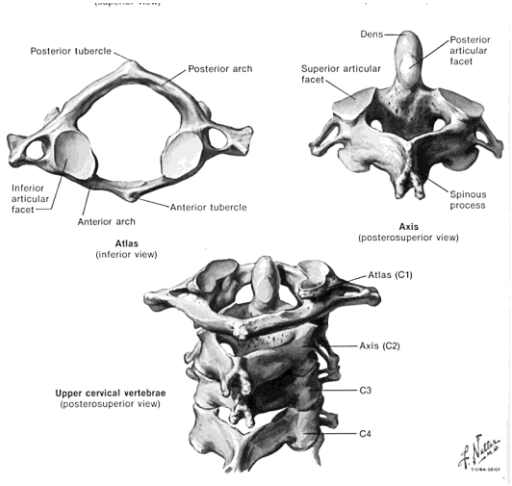


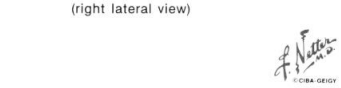
The Influence of the neck

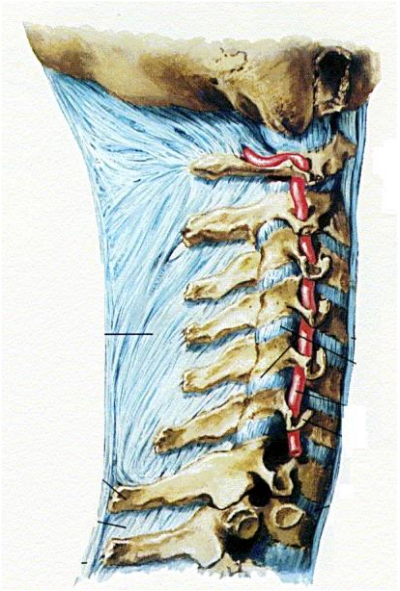
Anatomy of the cervical spine

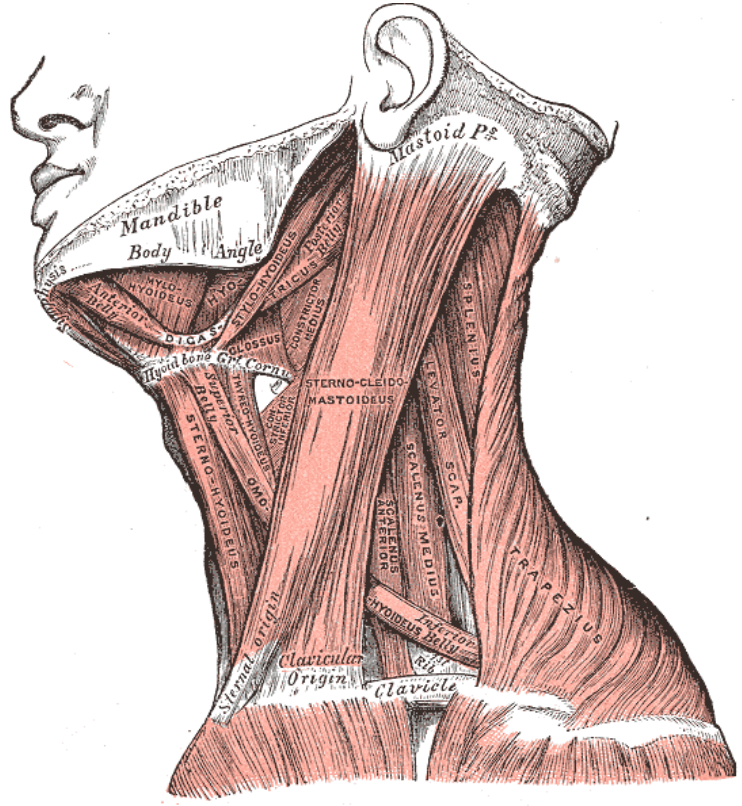




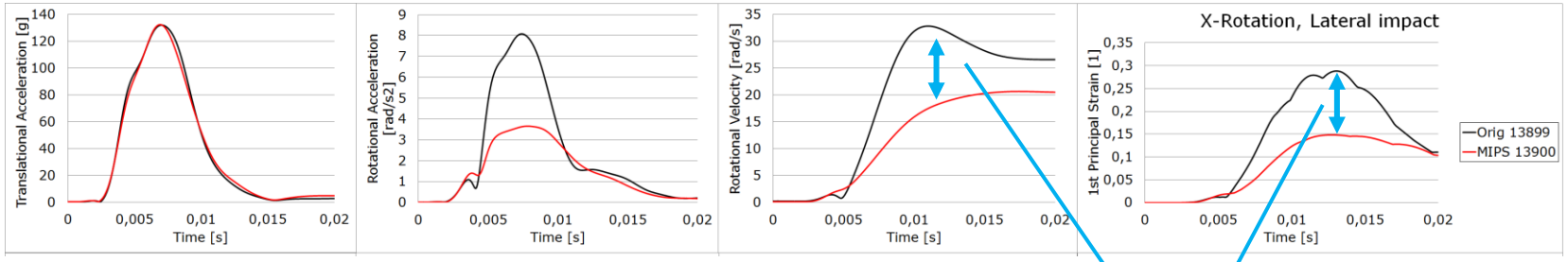




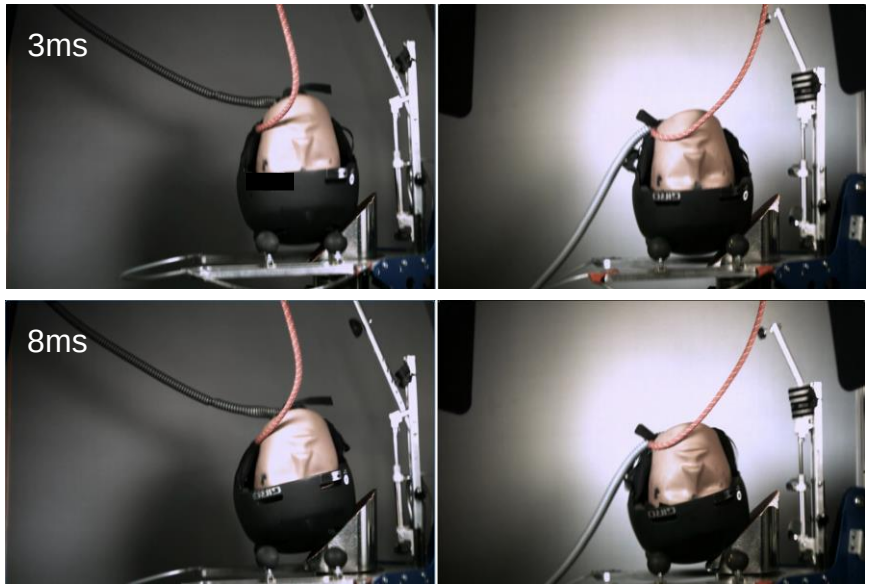




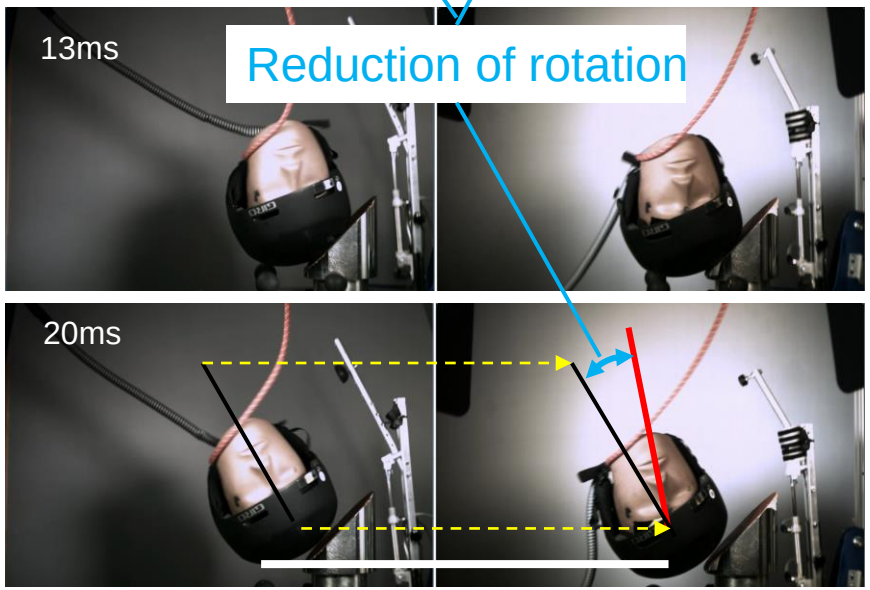
Example of mips function in x-rotation



No MIPS MIPS

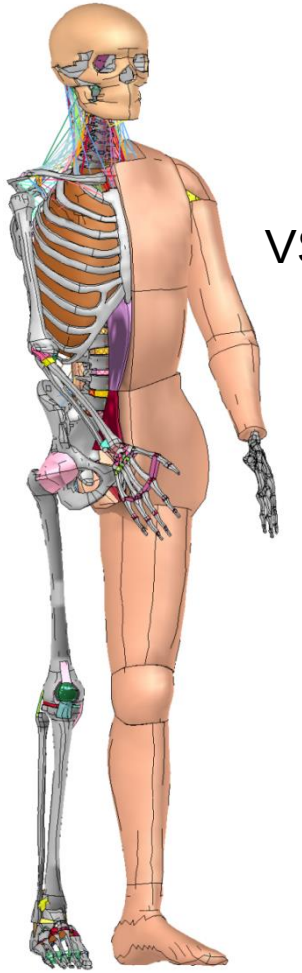


No MIPS MIPS

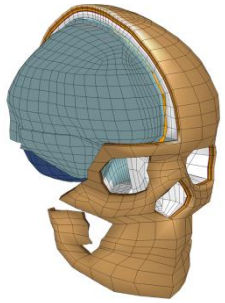


Head only v.s. complete body

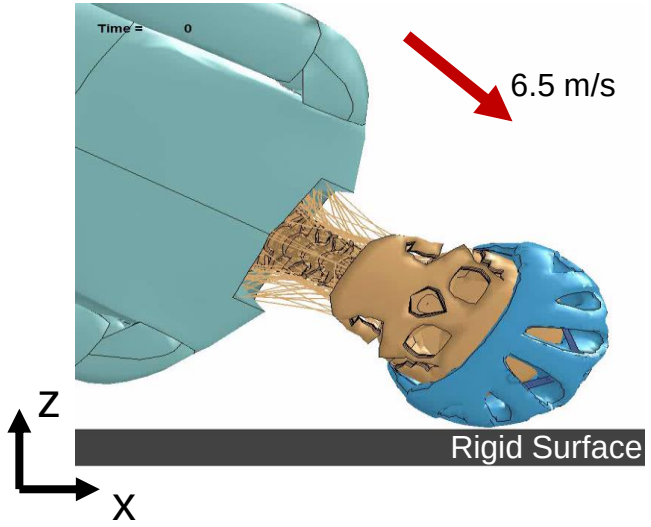
Cyclists Accident



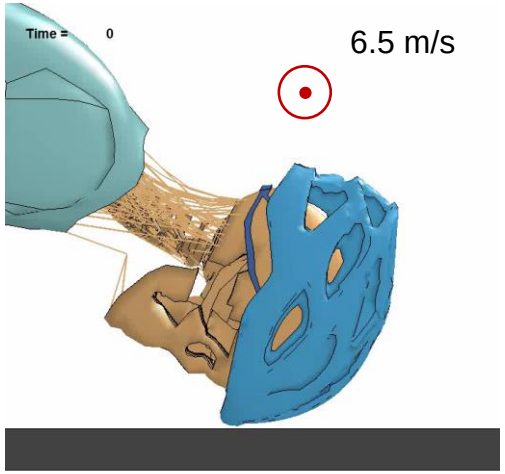
VS



Fall over Handlebars

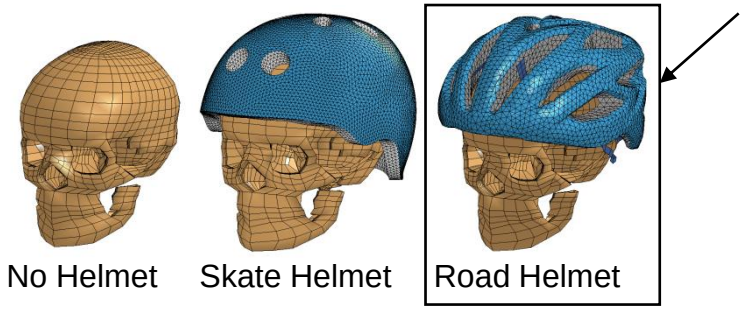


Side fall



Variations

Rotation around anatomical axes



Passive
Startled

∑120 Simulations

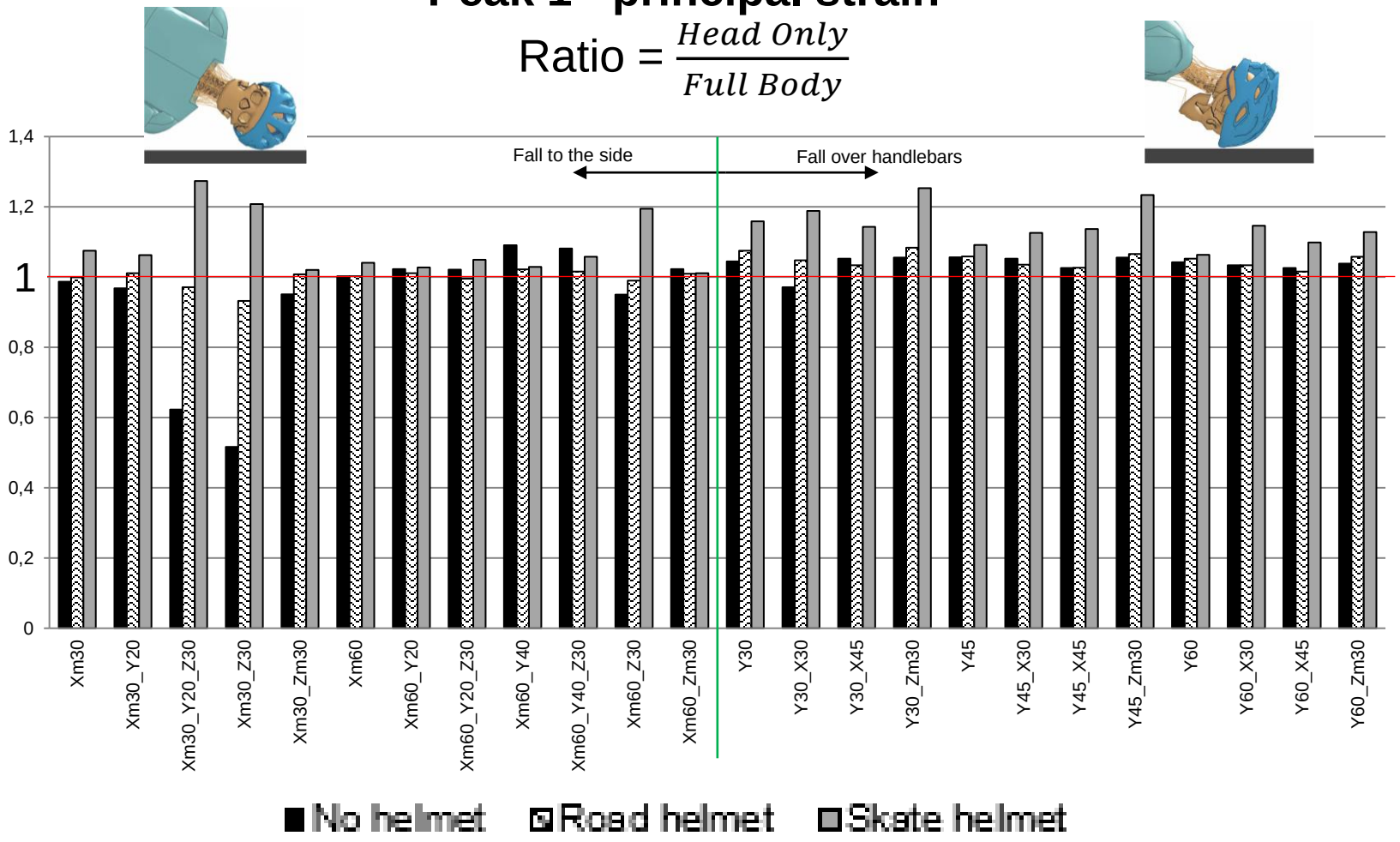
(Fahlsted et al 2015, IRCOBI)

Head only v.s. complete body

Results

Peak 1st principal strain

Ratio = $\frac{Head\ Only}{Full\ Body}$

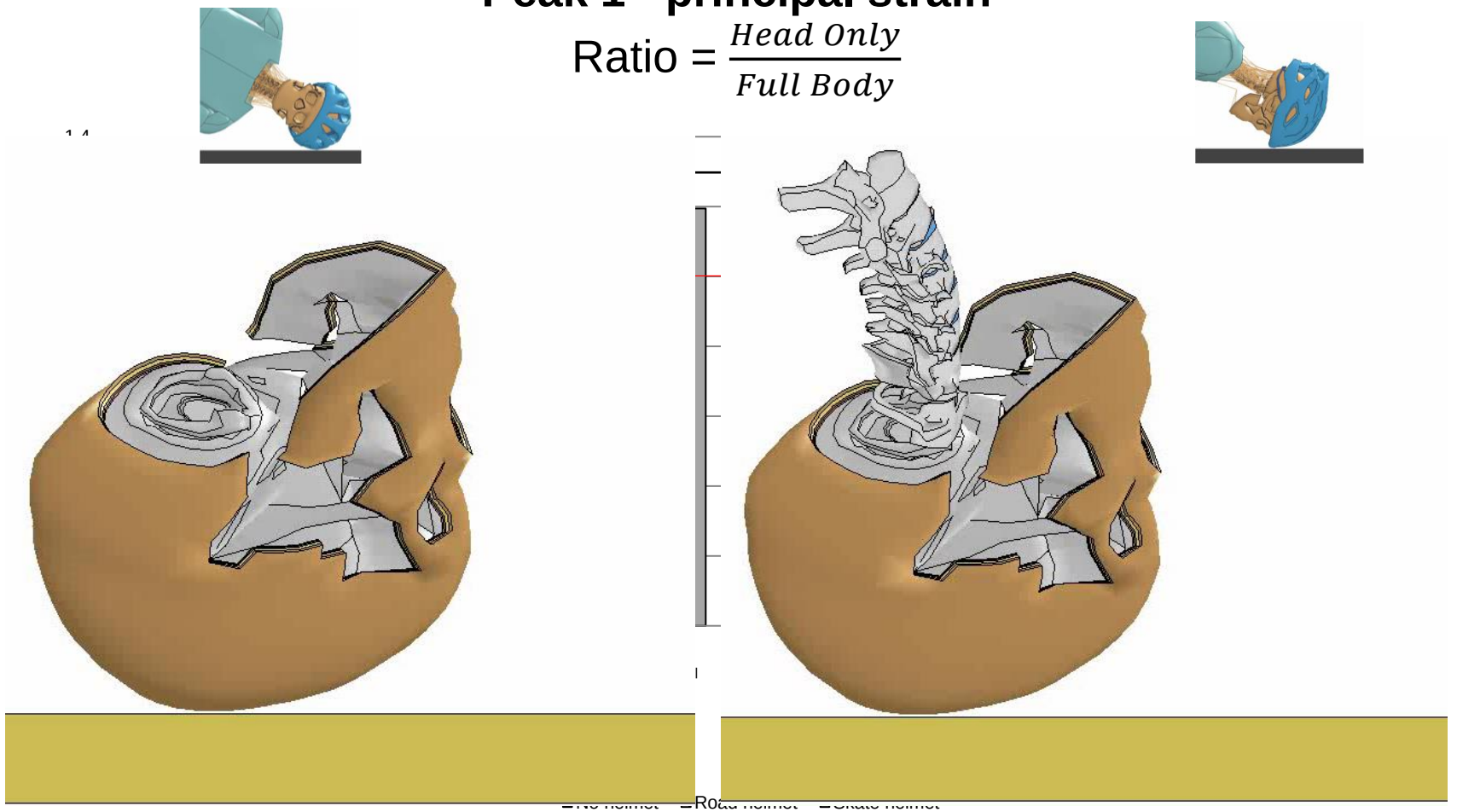


Head only v.s. complete body

Results

Peak 1st principal strain

Ratio = $\frac{Head\ Only}{Full\ Body}$

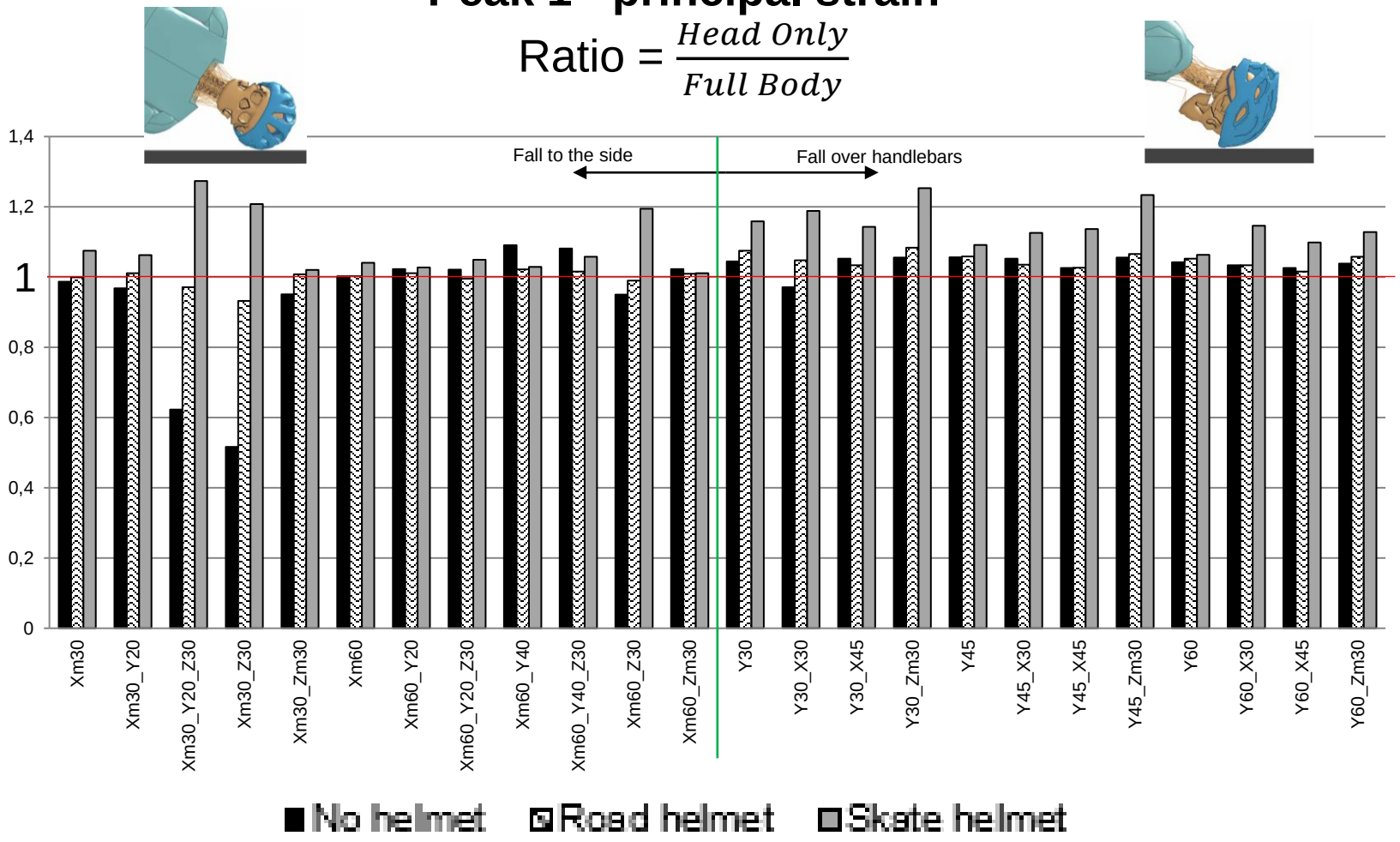


Head only v.s. complete body

Results

Peak 1st principal strain

Ratio = $\frac{Head\ Only}{Full\ Body}$

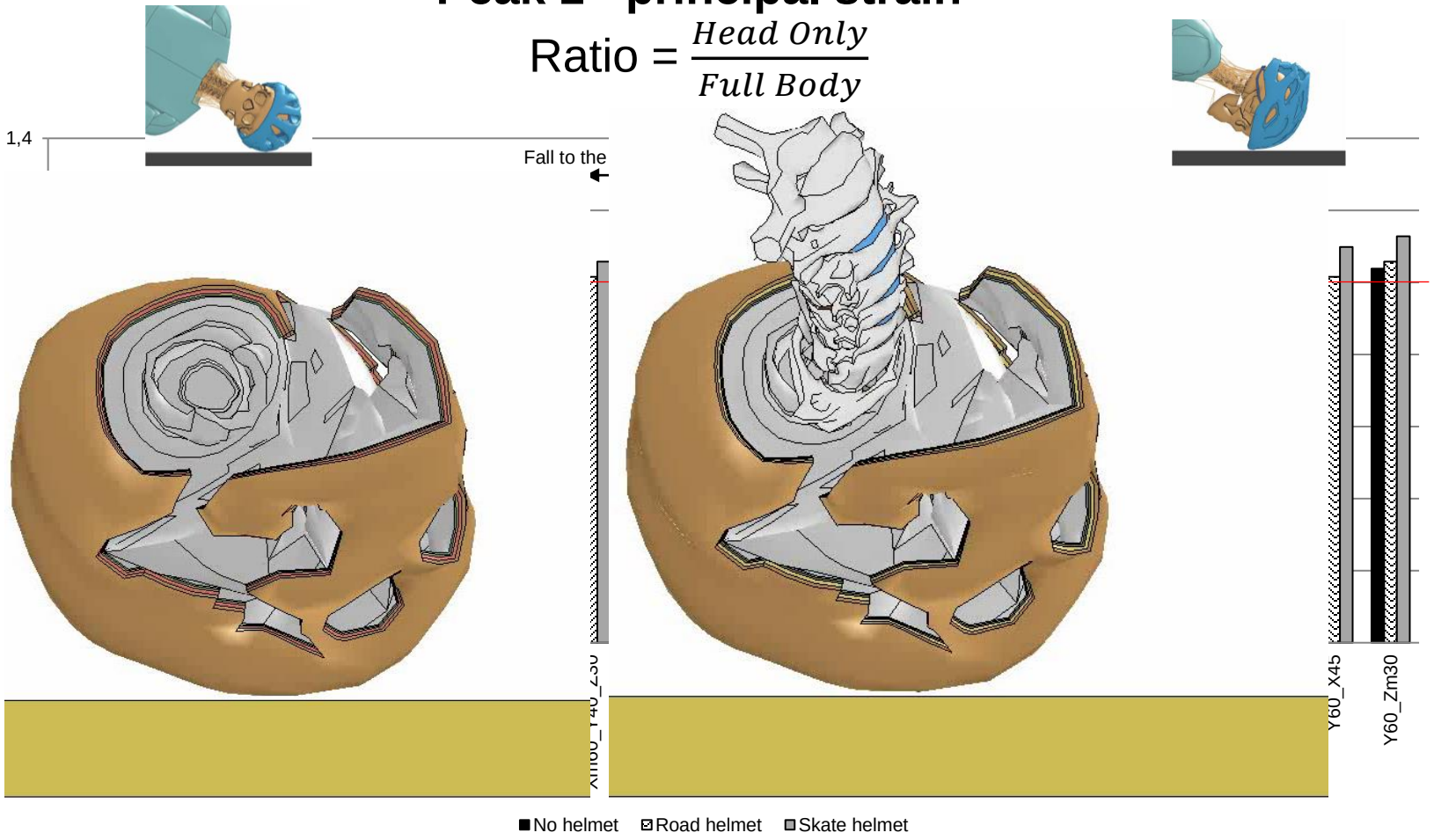


Head only v.s. complete body

Results

Peak 1st principal strain

$$\text{Ratio} = \frac{Head\ Only}{Full\ Body}$$

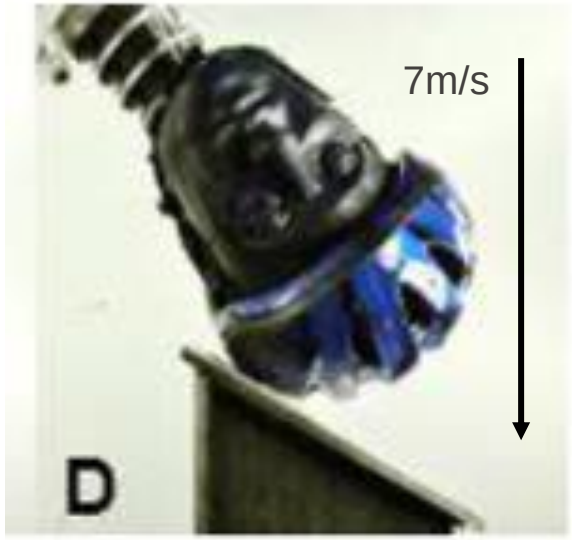


The Hybrid III neck

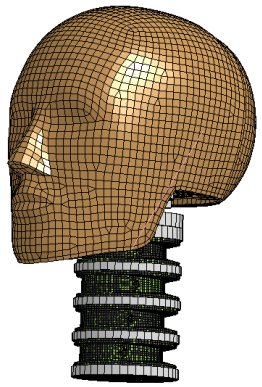
Siegkas and Ghajari 2017

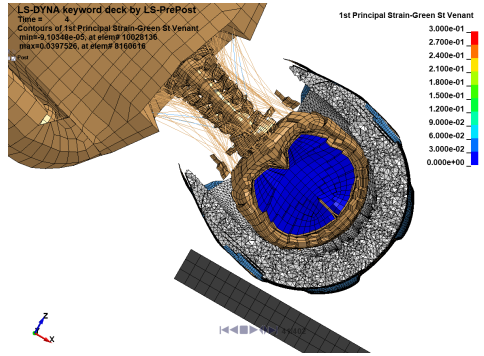
NOCSAE

Using the HIII neck in helmet testing ?

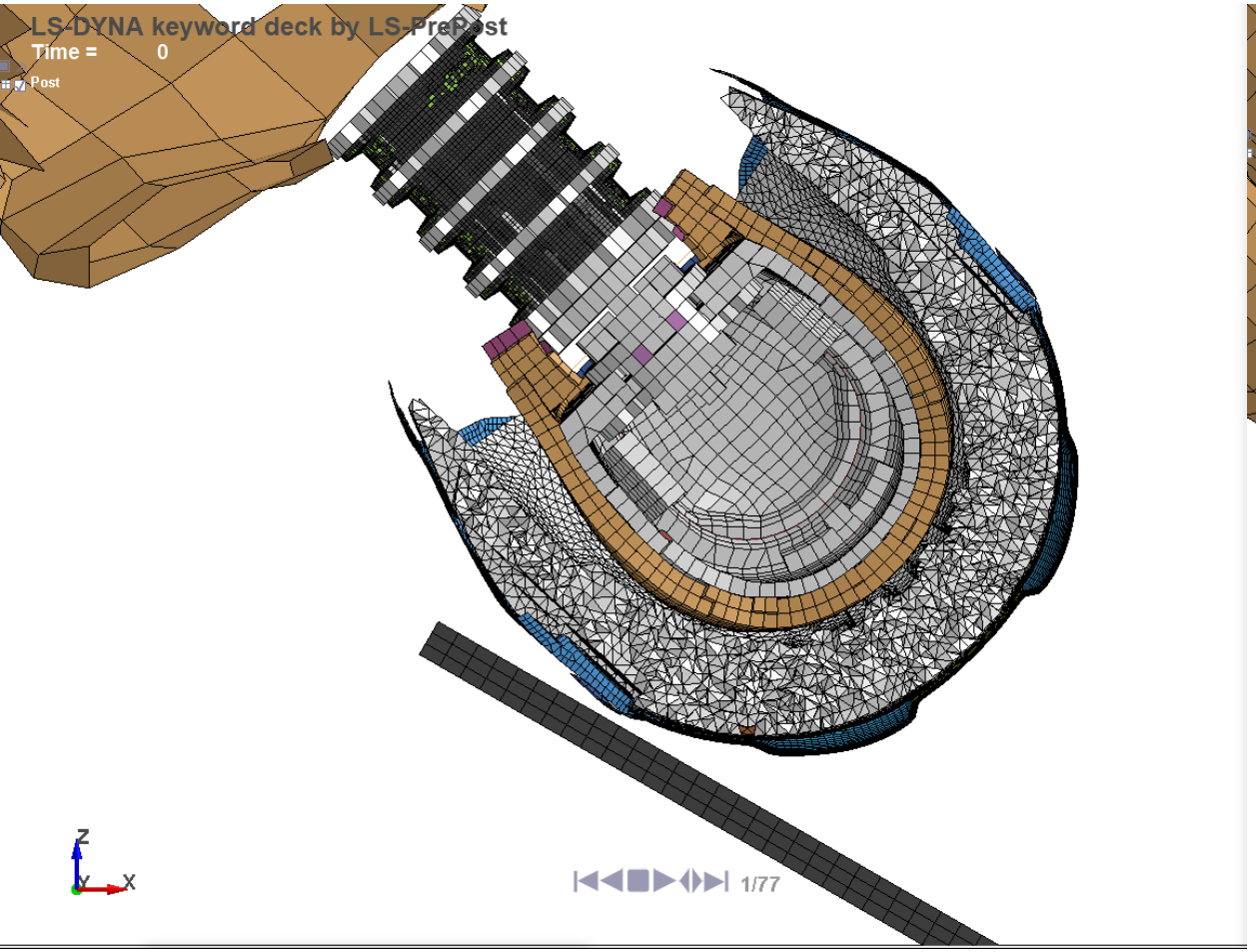


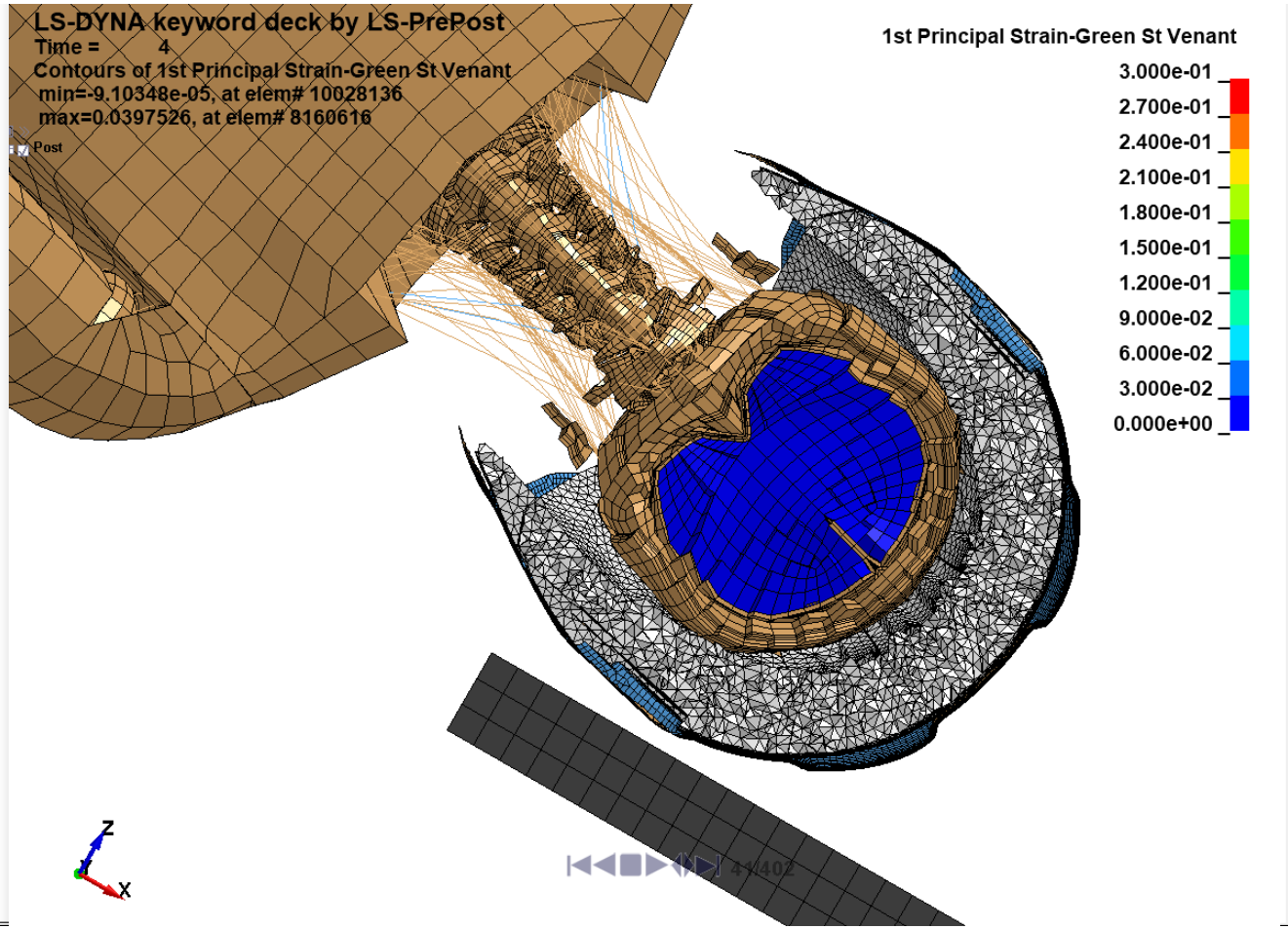
Bland et al. 2018



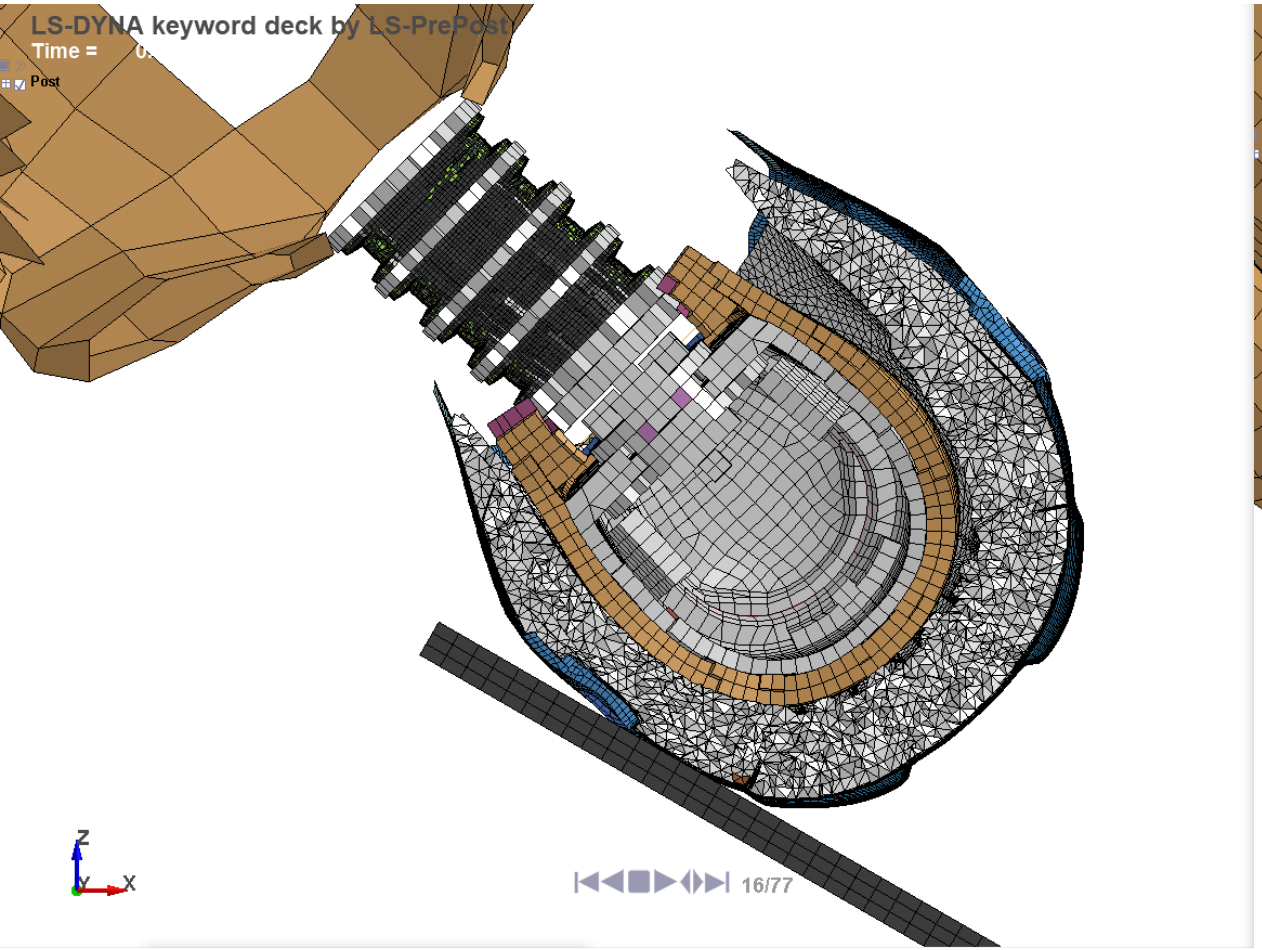


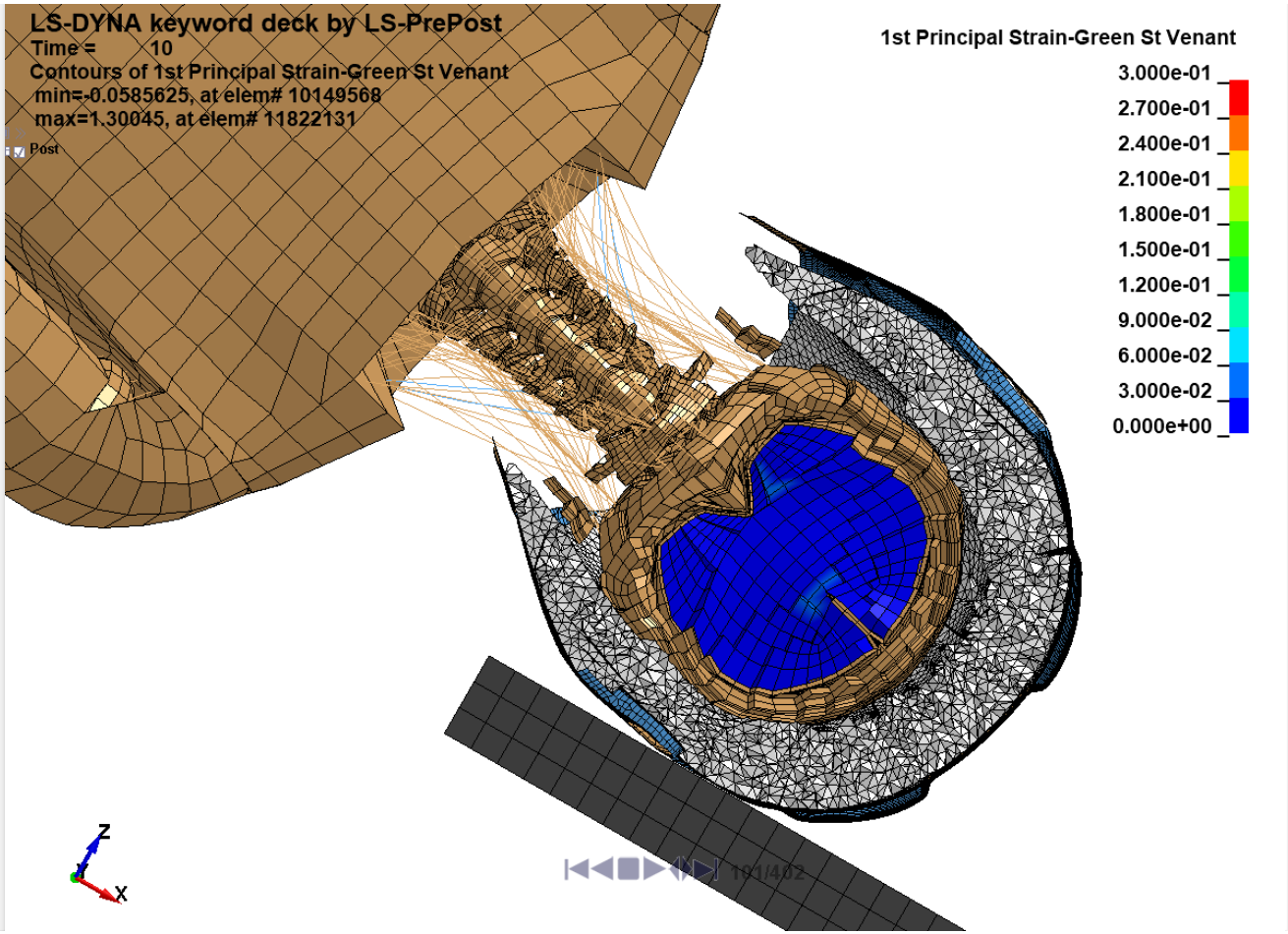
HIII v.s. KTH Neck My0.7





6ms


LS-DYNA keyword deck by LS-PrePost
Time =
Post
Z
Y
X
16/77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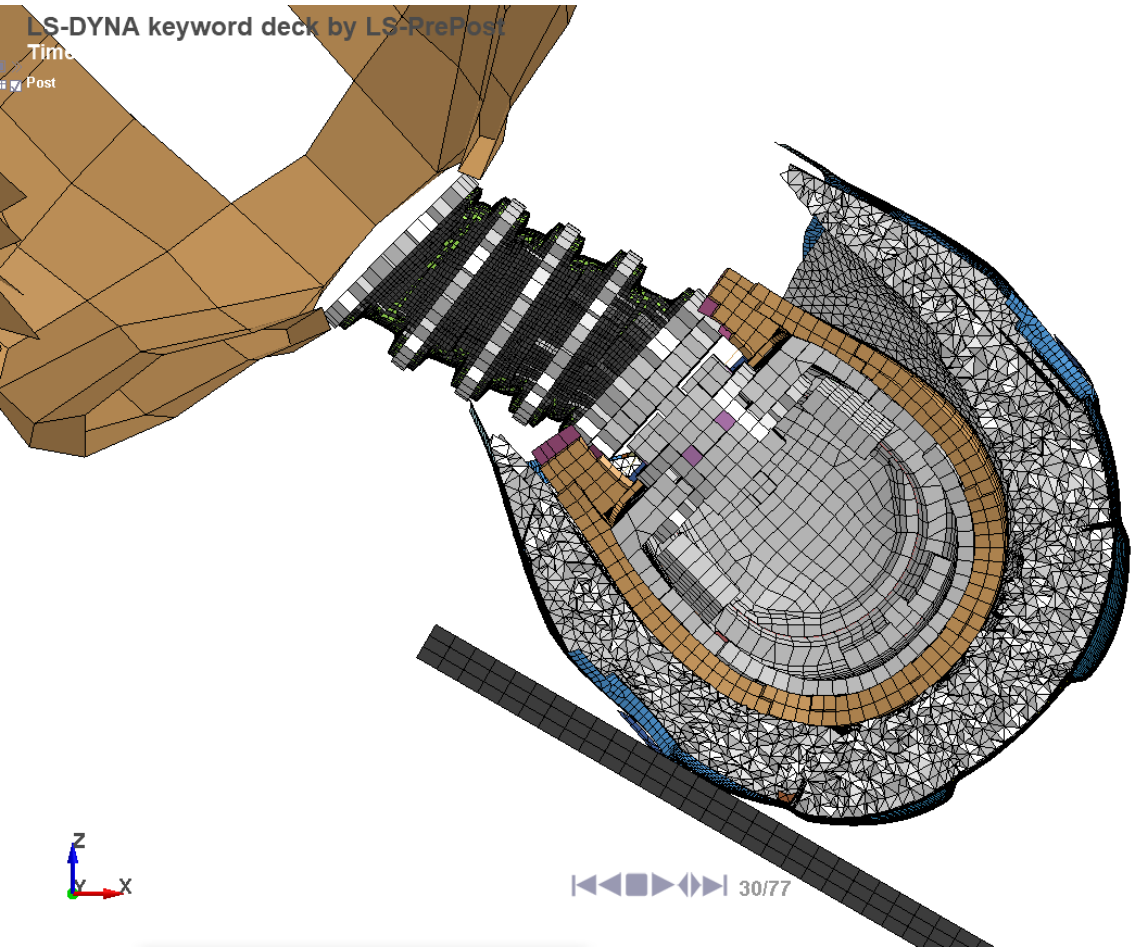
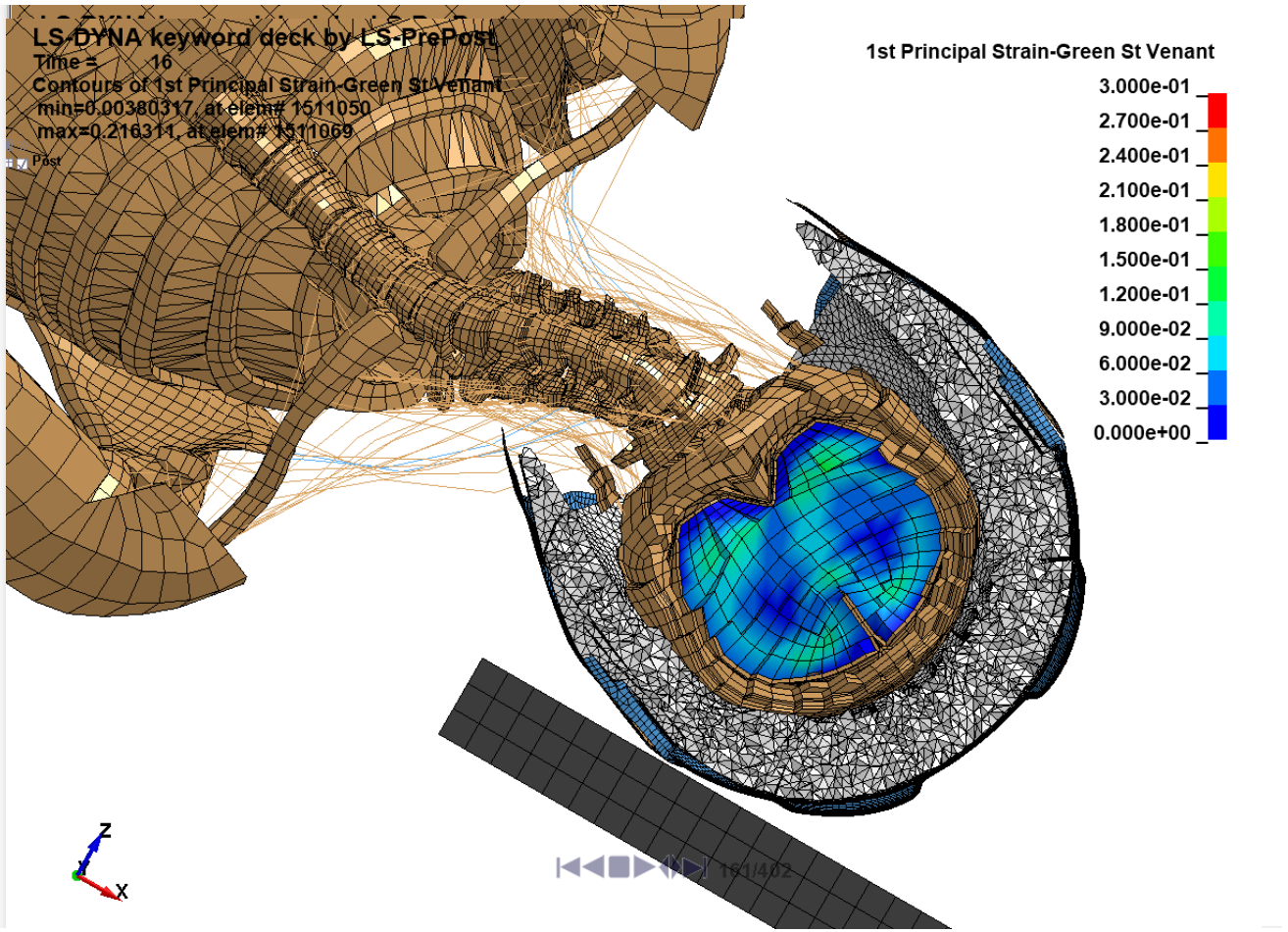
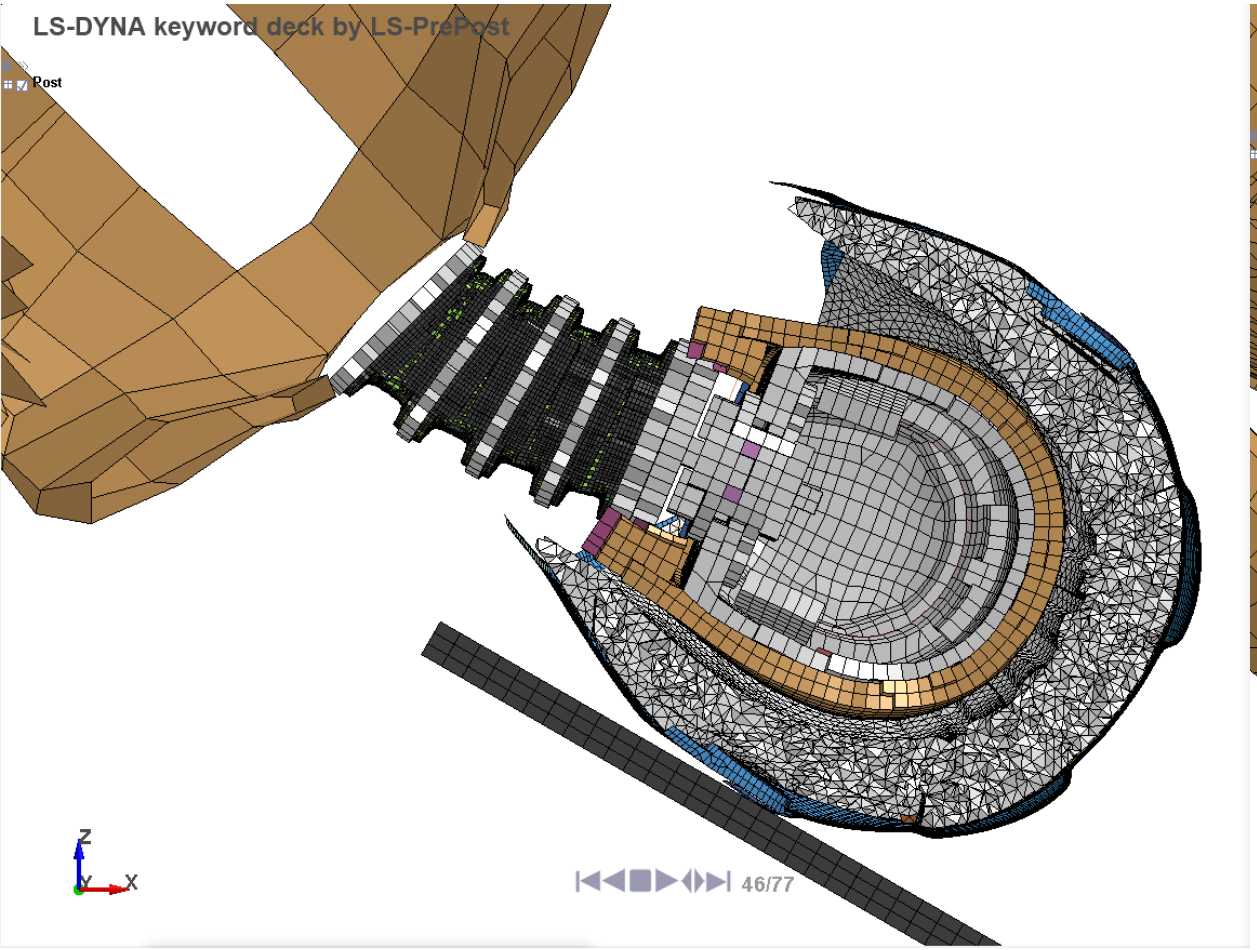
Time = 10
Contours of 1st Principal Strain-Green St Venant
min=-0.0585625, at elem# 10149568
max=1.30045, at elem# 11822131
Post
1st Principal Strain-Green St Venant
3.000e-01
2.700e-01
2.400e-01
2.100e-01
1.800e-01
1.500e-01
1.200e-01
9.000e-02
6.000e-02
3.000e-02
0.000e+00
Z
Y
X

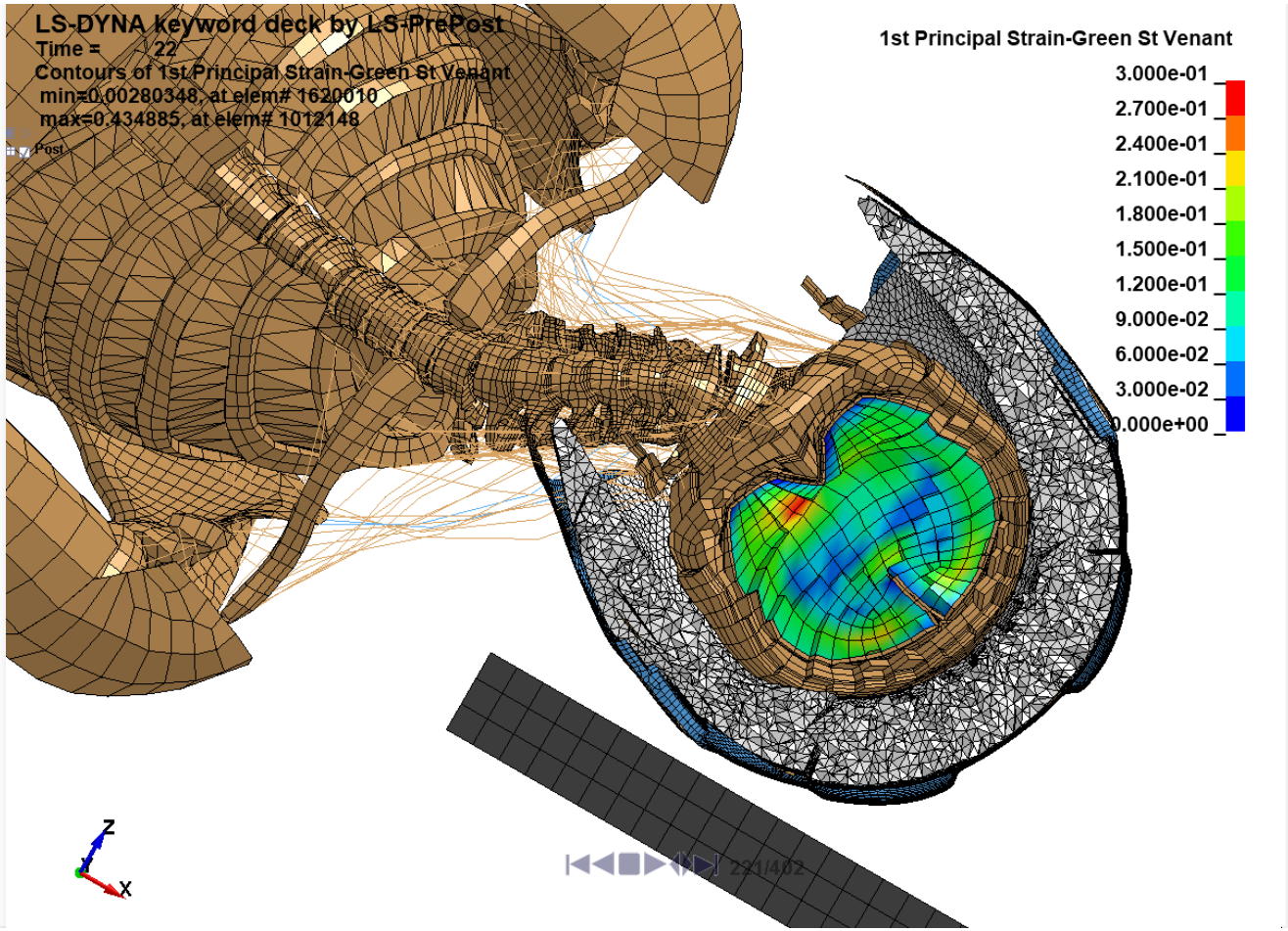
12ms


LS-DYNA keyword deck by LS-PrePost
Post
Z
Y
X
30/77


LS-DYNA keyword deck by LS-PrePost
Time = 16
Contours of 1st Principal Strain-Green St Venant
min=0.00380317, at elem# 1511050
max=0.216311, at elem# 1511069
Post
1st Principal Strain-Green St Venant
3.000e-01
2.700e-01
2.400e-01
2.100e-01
1.800e-01
1.500e-01
1.200e-01
9.000e-02
6.000e-02
3.000e-02
0.000e+00
Z
Y
X

18 ms


LS-DYNA keyword deck by LS-PrePost
Post
Z
Y
X
46/77


LS-DYNA keyword deck by LS-PrePost
Time = 22
Contours of 1st Principal Strain-Green St Venant
min=0.00280348, at elem# 1620010
max=0.434885, at elem# 1012148
Post
1st Principal Strain-Green St Venant
3.000e-01
2.700e-01
2.400e-01
2.100e-01
1.800e-01
1.500e-01
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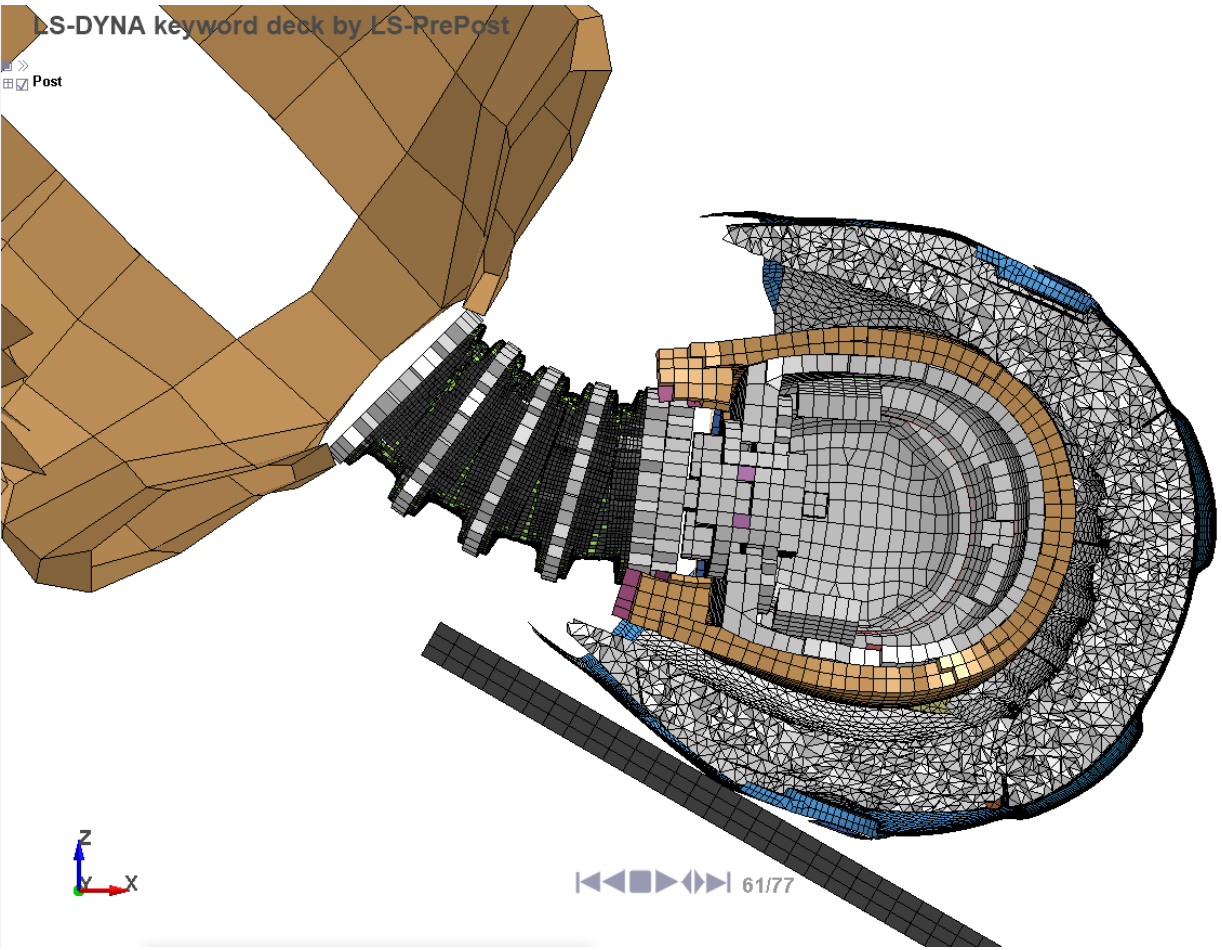
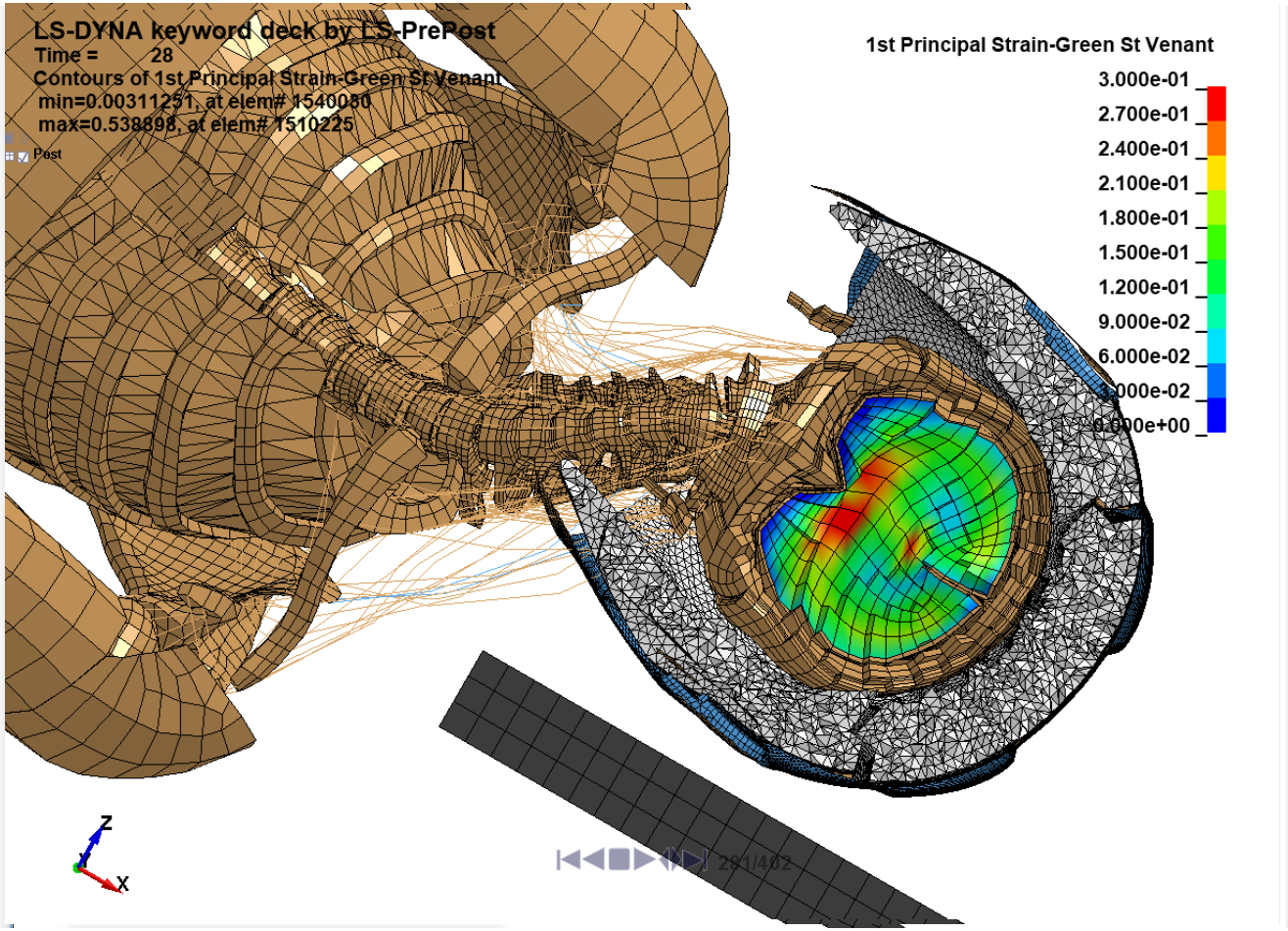
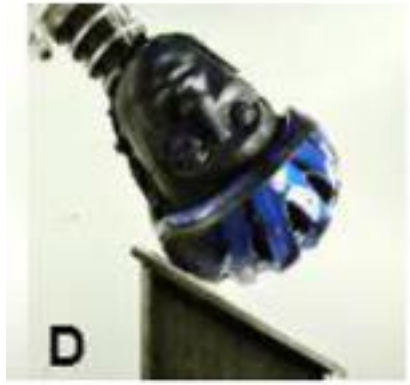
9.000e-02
6.000e-02
3.000e-02
0.000e+00
Z
Y
X
231/402

24ms

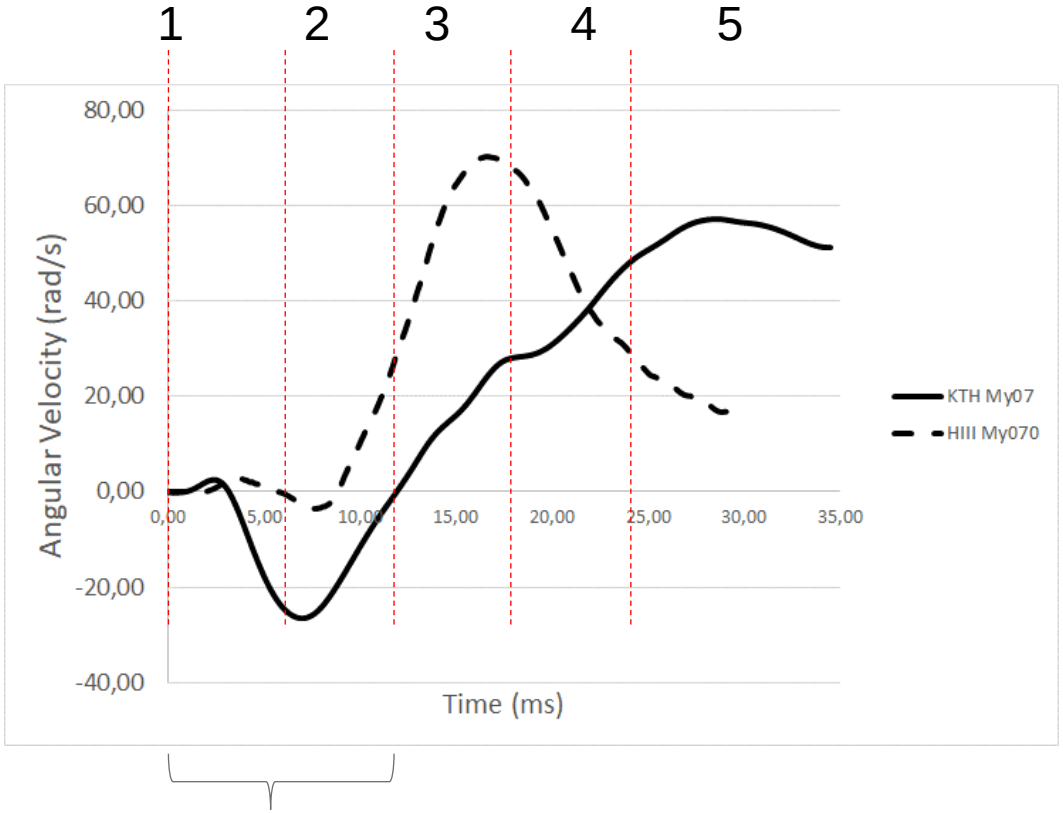

LS-DYNA keyword deck by LS-PrePost
Post
Z
Y
X
61/77


LS-DYNA keyword deck by LS-PrePost
Time = 28
Contours of 1st Principal Strain-Green St Venant
min=0.00311251, at elem# 1540080
max=0.538898, at elem# 1510225
Post
1st Principal Strain-Green St Venant
3.000e-01
2.700e-01
2.400e-01
2.100e-01
1.800e-01
1.500e-01
1.200e-01
9.000e-02
6.000e-02
3.000e-02
0.000e+00
Z
Y
X

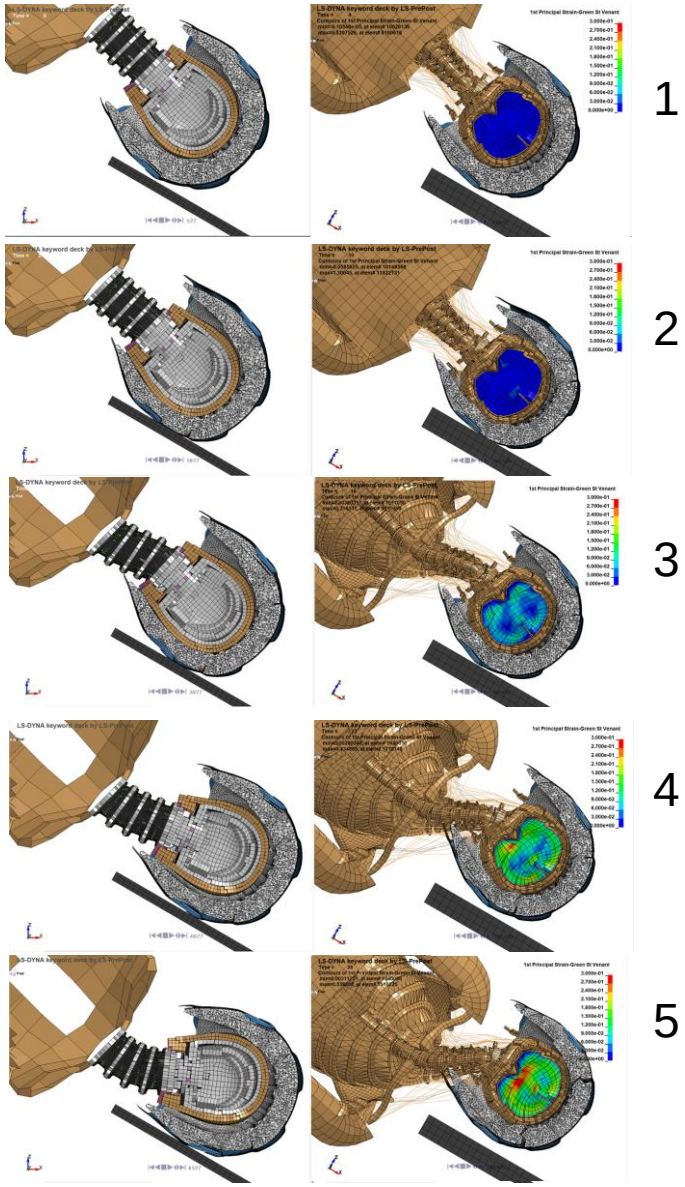
HUMAN NECK v.s. HIII NECK



Bland et al. 2018



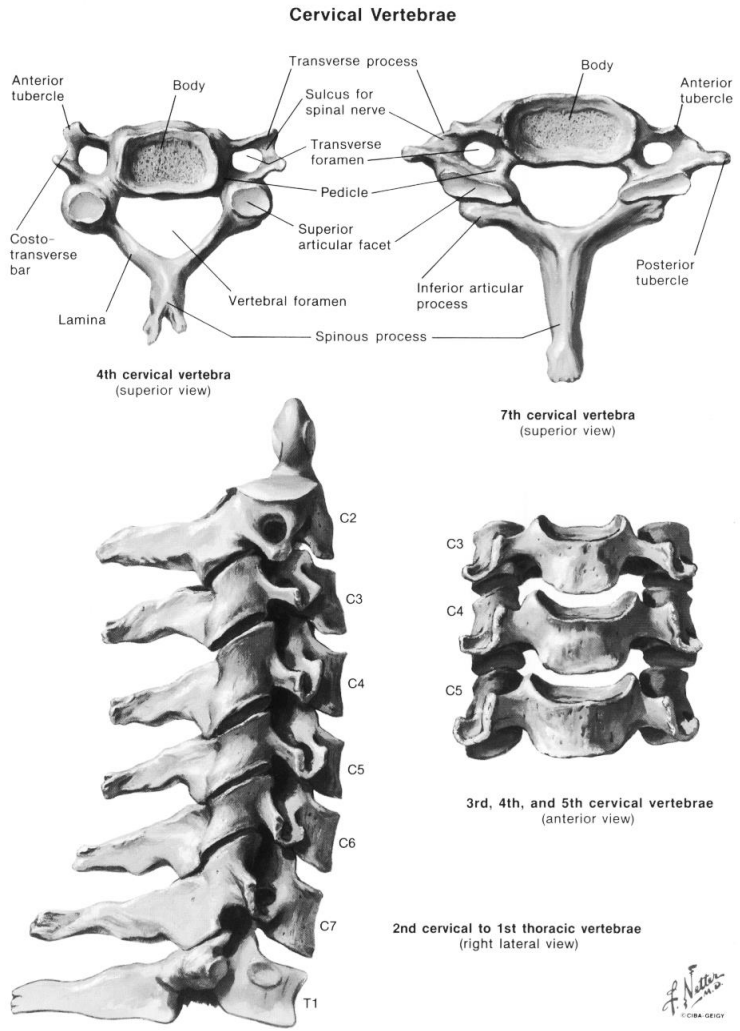
The HIII neck are stiffer than the KTH neck



Simplification – No neck

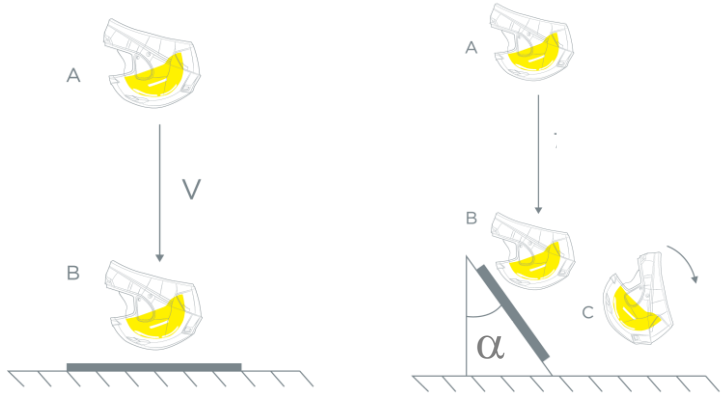
- The neck affect the boundary condition for the head in general
- However, the influence of the neck is small for short duration impacts
- The existing HIII neck is however not the perfect substitute

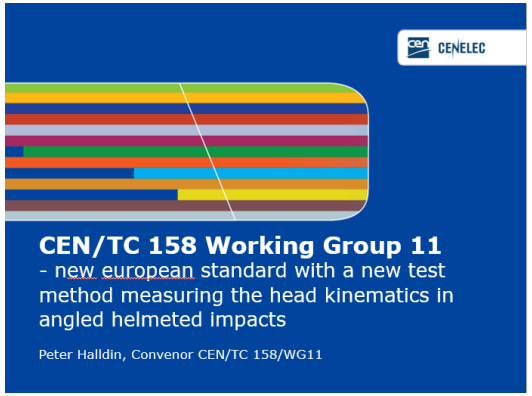
- It is therefore concluded not to use a neck (today)

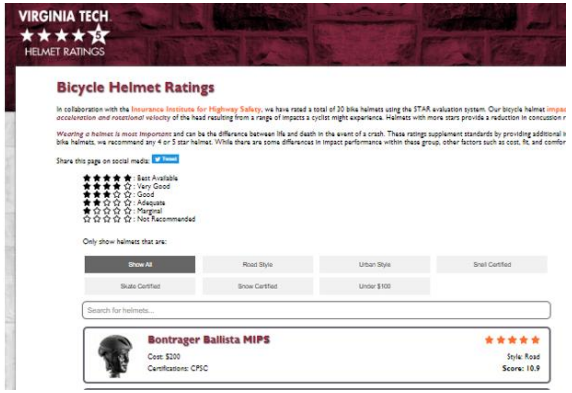


ONGOING WORK TOWARDS A NEW SPORT AND MOTOROCYCLE HELMET TEST METHOD

- Bike, Ski and EQ: **CEN TC158** (EU) New rotational test method.
- Motorcycle: **FIM** (Federation Internationale de Motorcyclisme)
- **ECE22.06** (Started the work to ad rotation into the European test standard)
- Bike: **Virginia Tech** (New rating methods including tangential impacts)





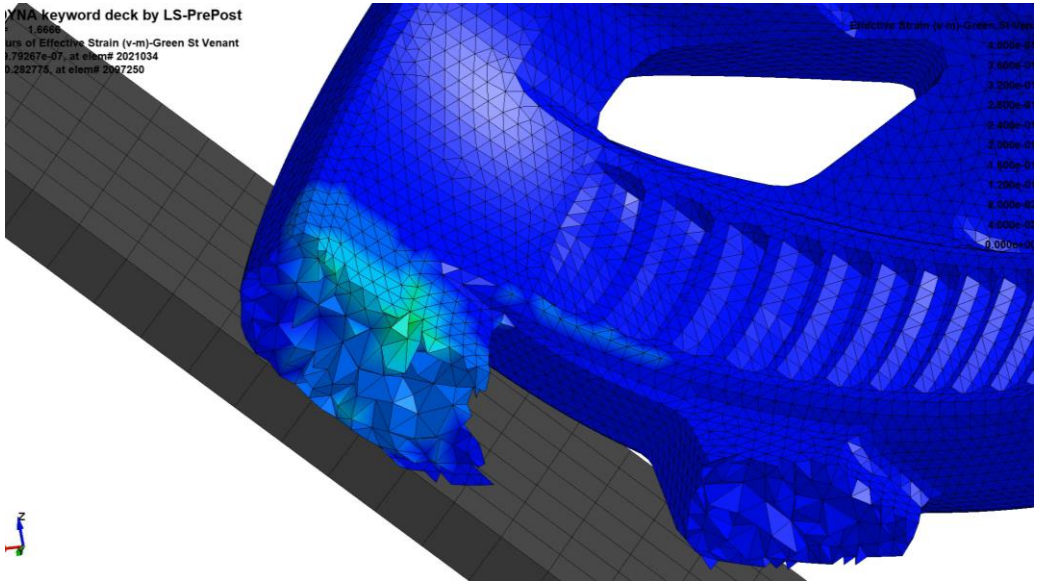


Outline

- Mips introduction (What, How, Why)
- 25 years of Mips & FE
  - Energy absorption in helmets with Mips
  - The effect of the human cervical spine in helmet testing
  - **Virtual Test Lab**
  - Other projects
    - CEN TC158- New rotational test standard
    - Safety helmets and initial rotation
    - Child helmets
    - Chin bar test
    - FE Head model evaluation

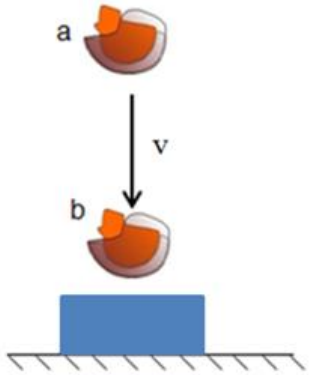
Mips VTL

Virtual Test Lab



How to design a helmet - Basic course I

Current test methods



< 250G = Pass

Table 13.3 Design requirement for cycle helmet

Function	Protective cycle helmet
Objective	Maximise energy absorption/unit volume
Constraints	Load on skull < damage-load

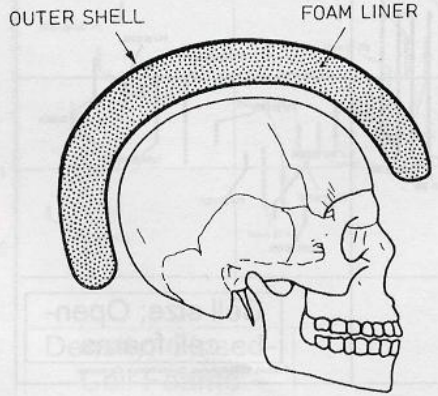
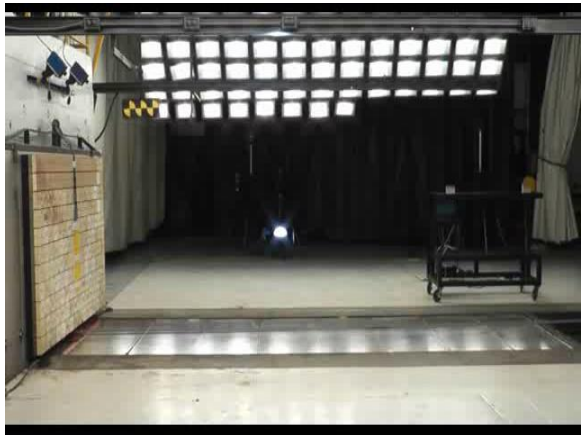


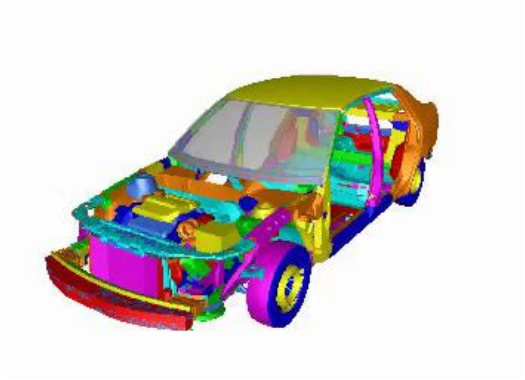
Figure 13.9 A cycle helmet. The liner must absorb as much energy per unit volume as possible without allowing the force on the skull to reach a damaging level.

Picture from Gibson and Ashby 1999

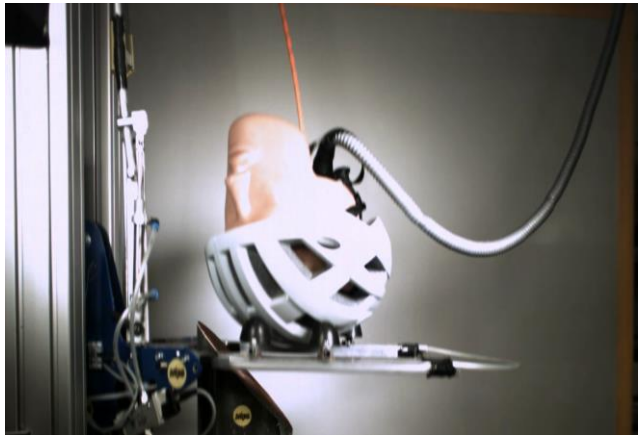
Virtual testing of safety

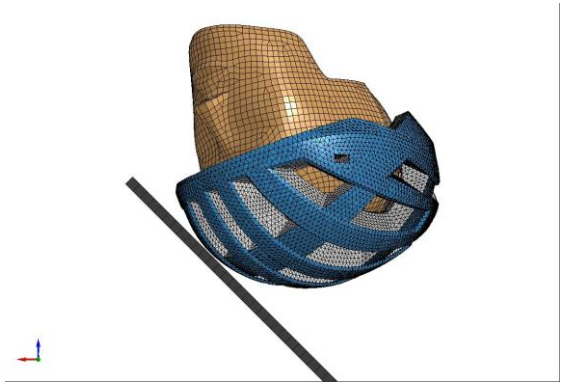
AUTOMOTIVE INDUSTRY
1995





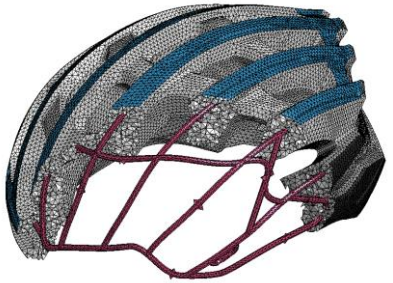
HELMET INDUSTRY 30
YEARS BEHIND

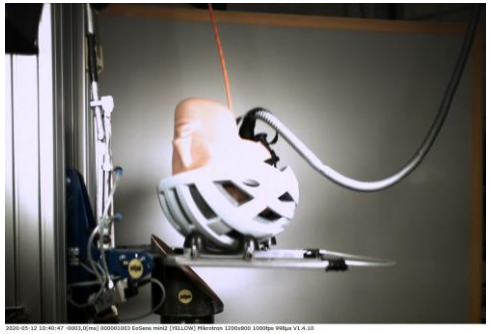




Why is there a need for VTL today and why have no one done it?

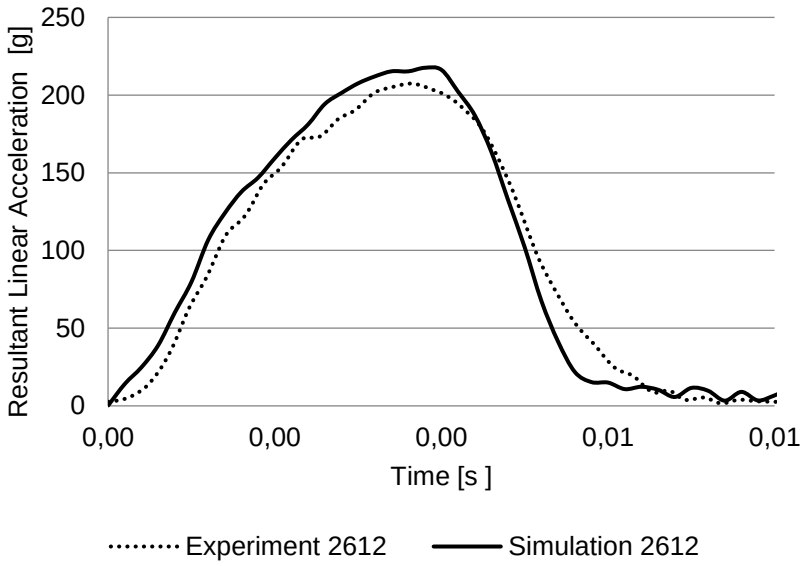
- More sophisticated helmet designs than just 20mm of EPS and an ABS shell
- More advanced test methods and standards to meet
- Helmet industry 30 years behind automotive industry



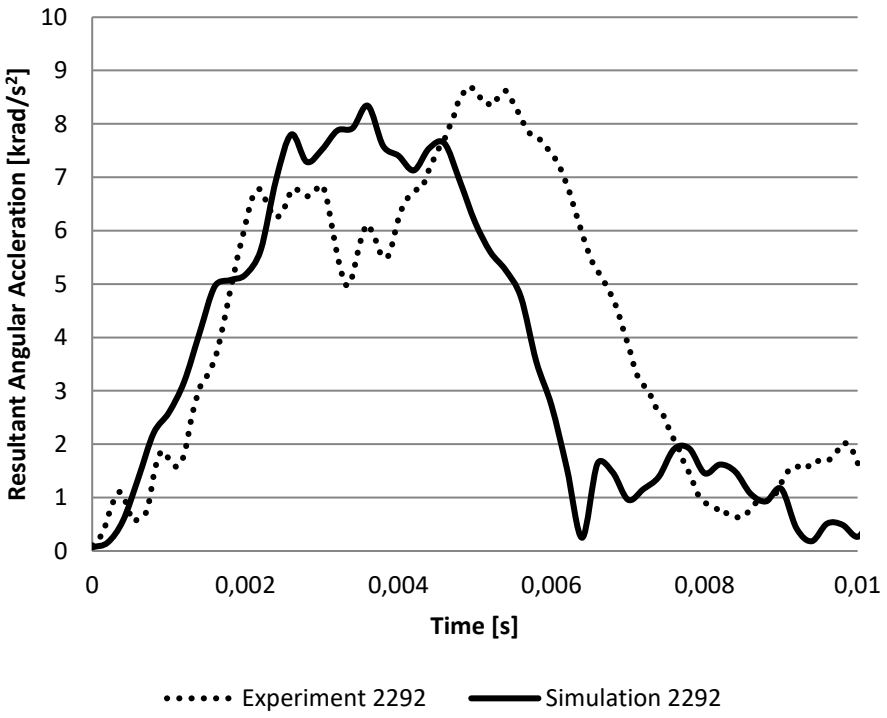


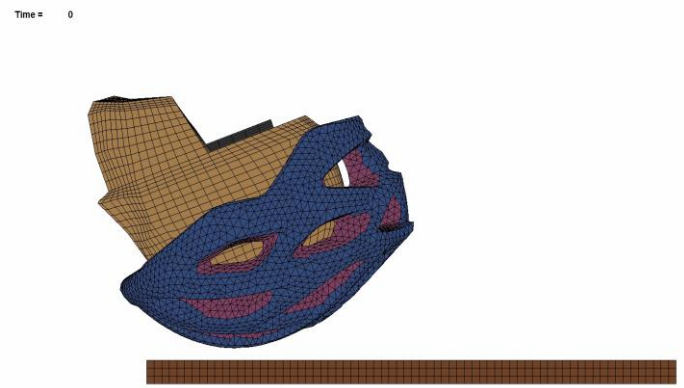
How difficult can it be ?

Helmet Validation 2010 – Radial Impact

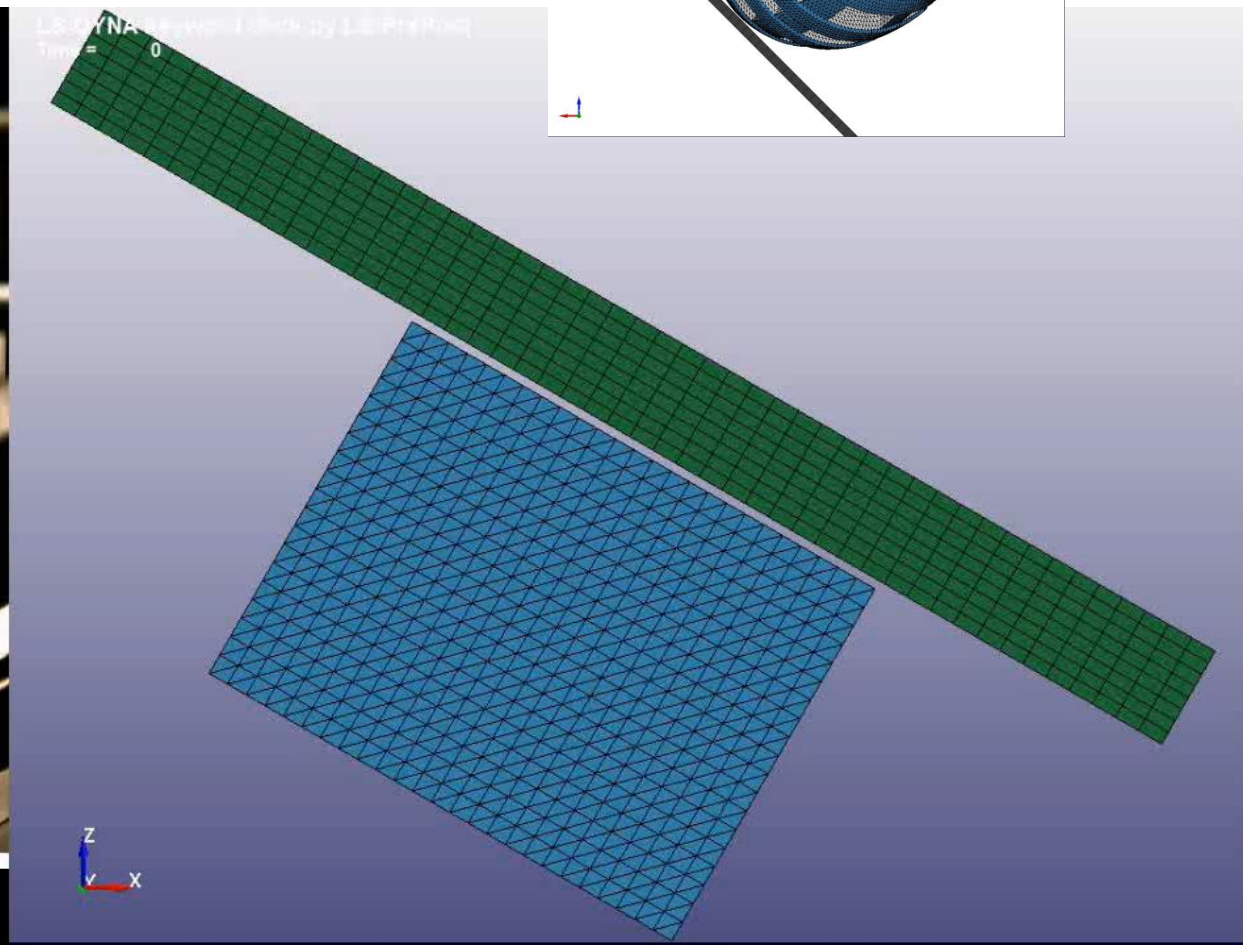


Helmet Validation 2010 – Oblique Impact





EPS experimental tests



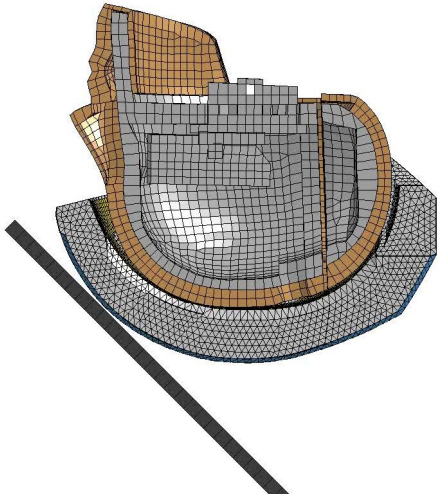
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

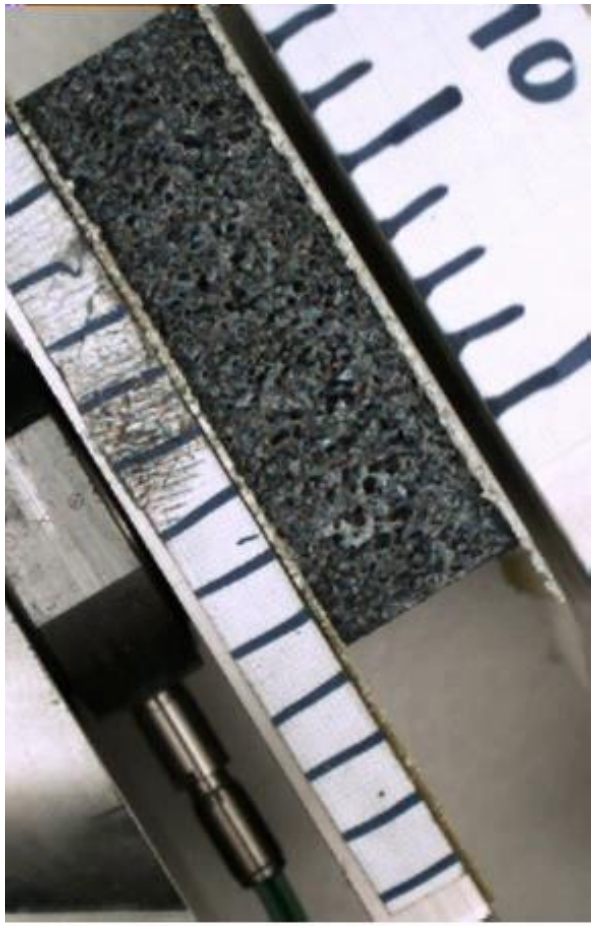
ϵ [-]

A constitutive model of an EPS foam

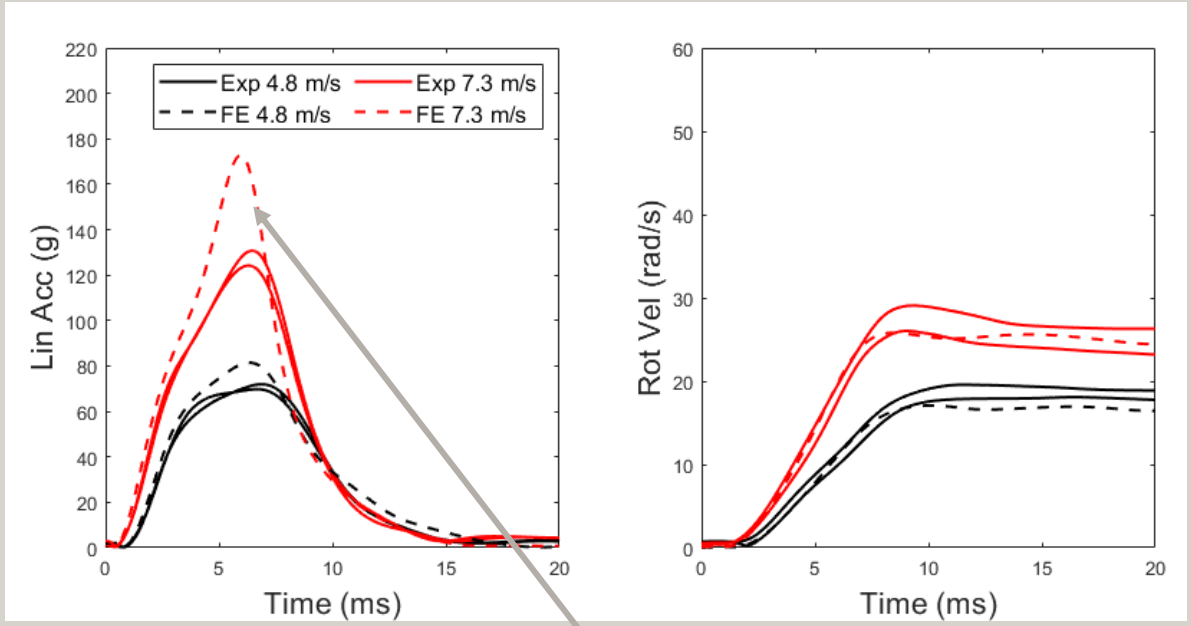
- Compression properties well documented
- Shear properties nearly nonexistent
- Combined compression and shear sparsely documented

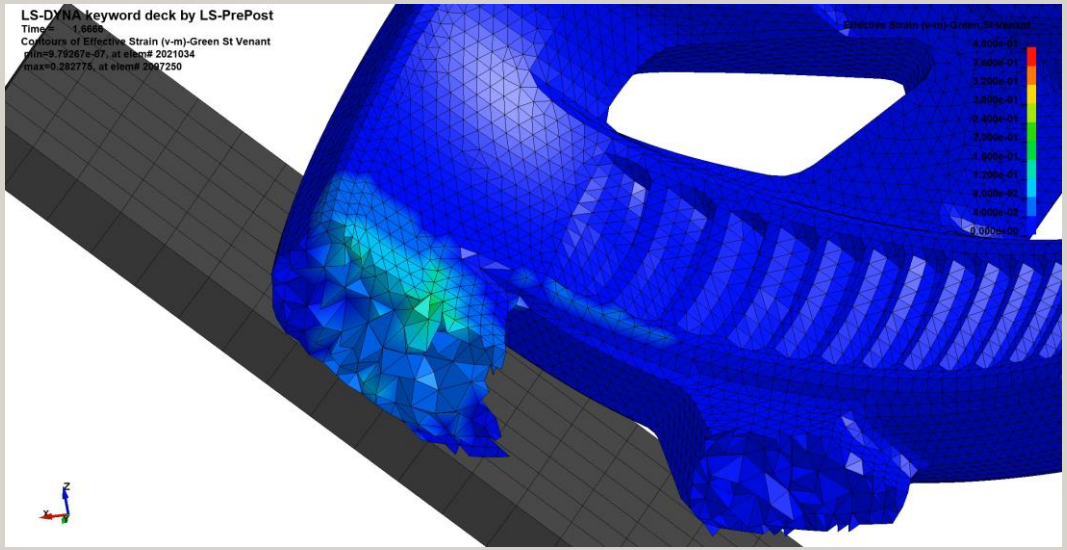
- And Fracture propagation





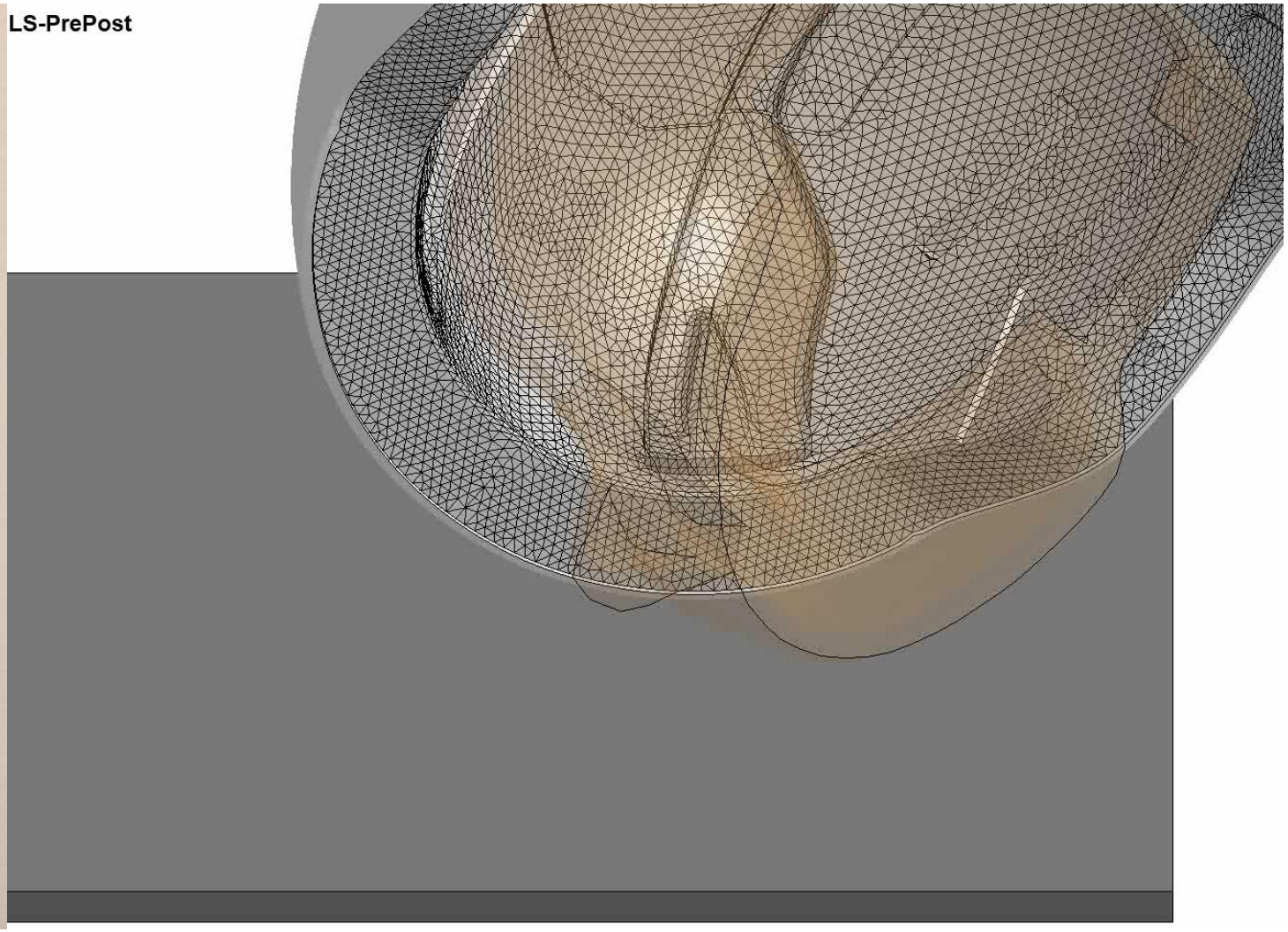
The need to model fracture





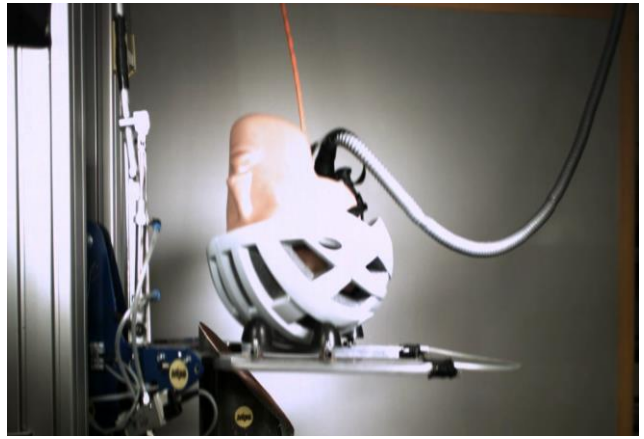
- Current material model does not capture behaviour of the fracture of EPS in impacts with higher speeds

Helmet with fracture model (Erode)



Mips VTL today and future

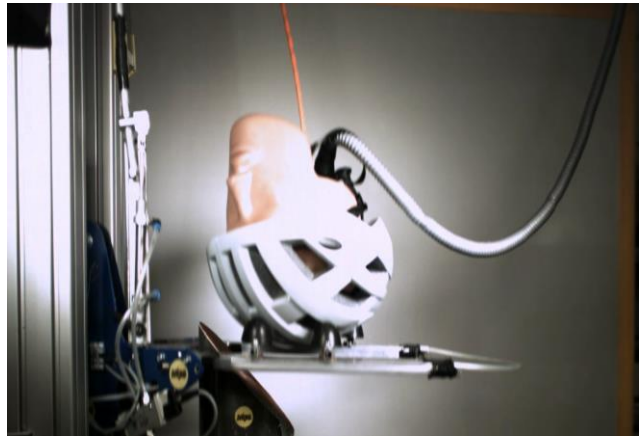
- Correlation to experiment (CORA)
- Validated Material models (U-mat?)
- Including Fracture



Mips VTL today and future

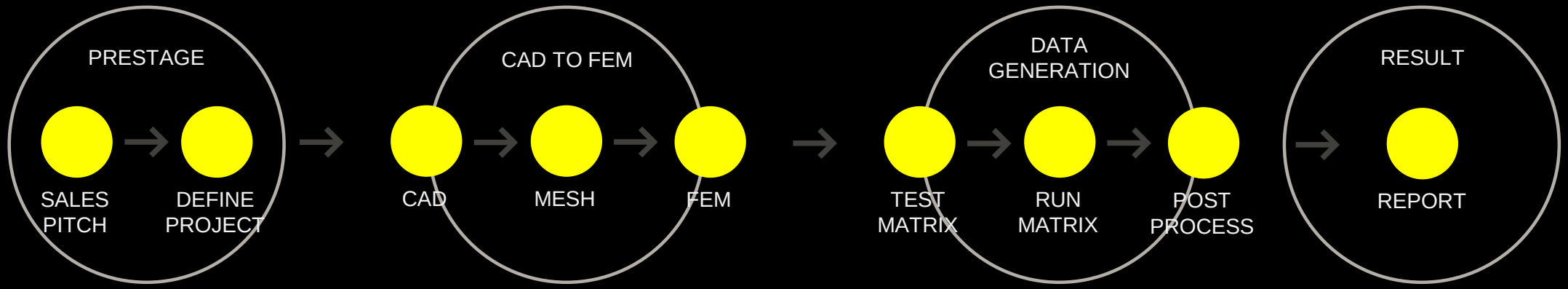
- Correlation to experiment (CORA)
- Validated Material models (U-mat?)
- Including Fracture

- Reduce time for each helmet project

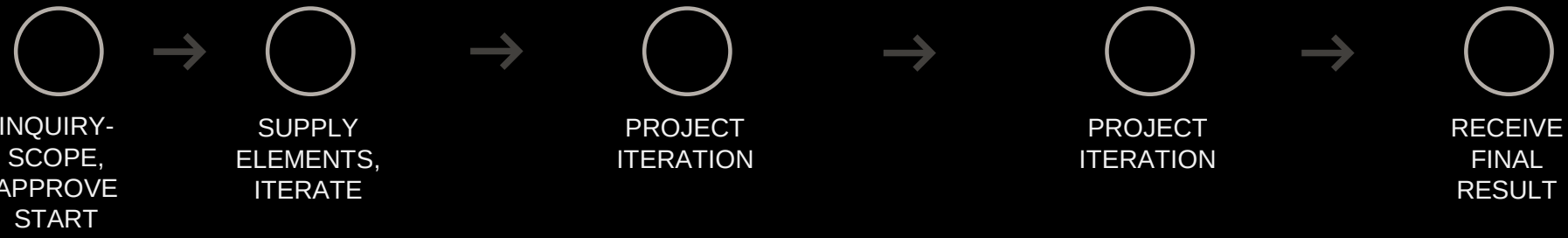



Mips
Black Box

General VTL delivery process



CLIENT TODOS



Make this faster!

General VTL delivery process

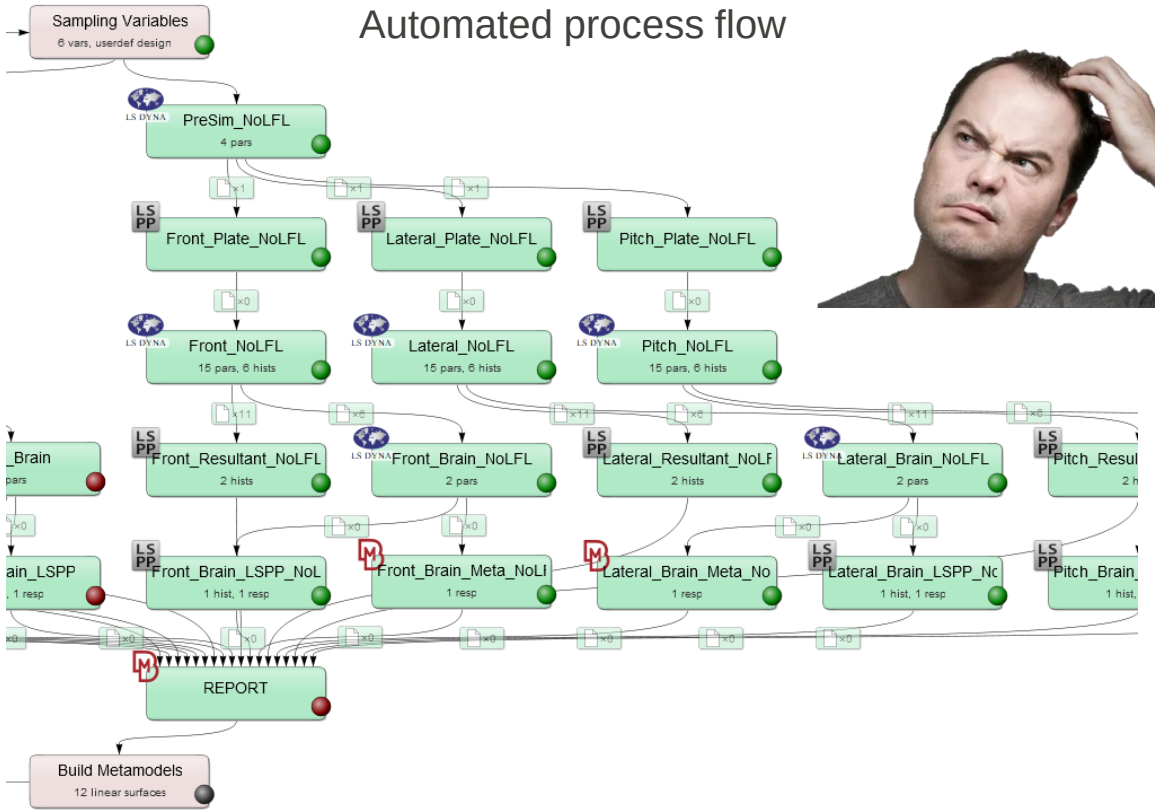
PRESTAGE

SALES PITCH → DEFINE PROJECT

CLIENT TODOS

INQUIRY-SCOPE, APPROVE START

Automated process flow



RESULT

REPORT

RECEIVE FINAL RESULT

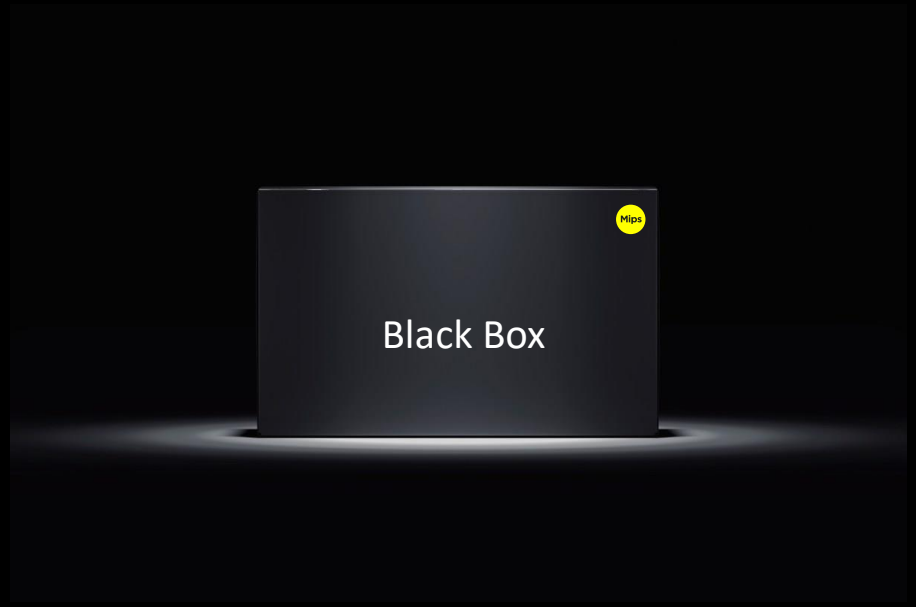
3-4 Weeks

Make this faster!

Black Box delivery process

PRESTAGE

CAD handover



RESULT

REPORT

CLIENT TODOS

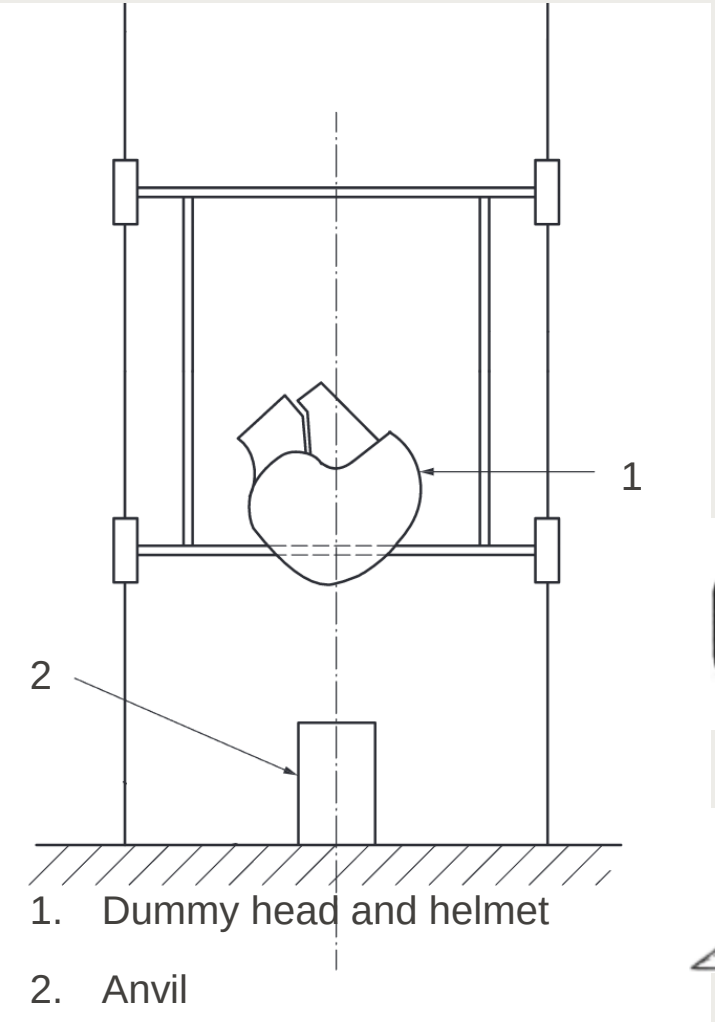
Handover CAD and say which box

RECEIVE FINAL RESULT

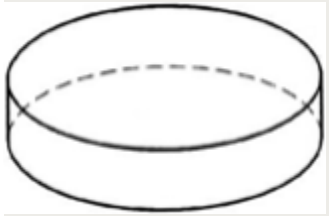
1 Day

Standard testing – Before helmets are manufactured

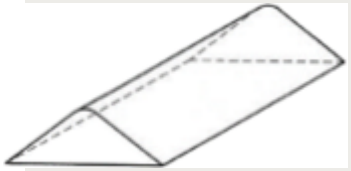
EUROPEAN BICYKLE HELMET TEST STANDARD – EN1078



1. Dummy head and helmet
2. Anvil

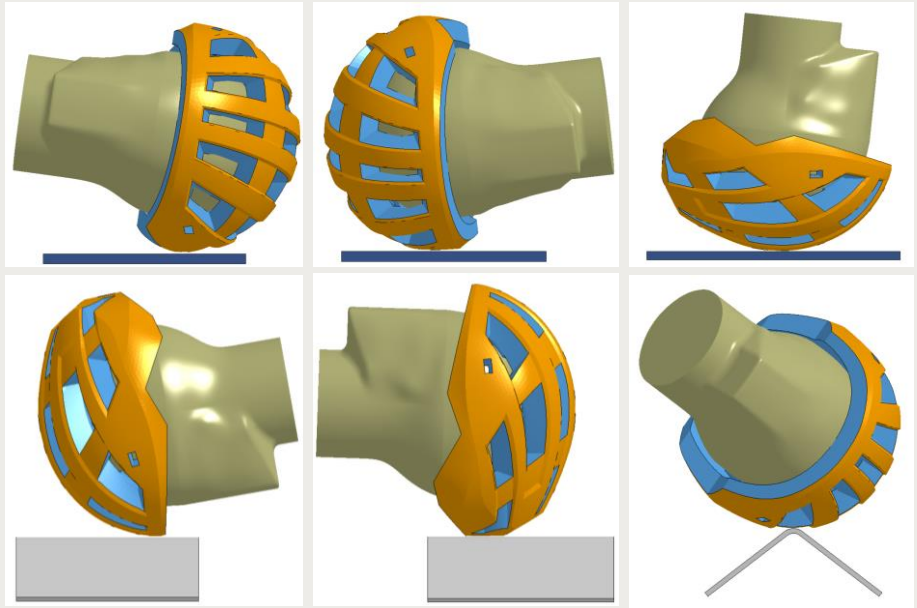


Flat anvil



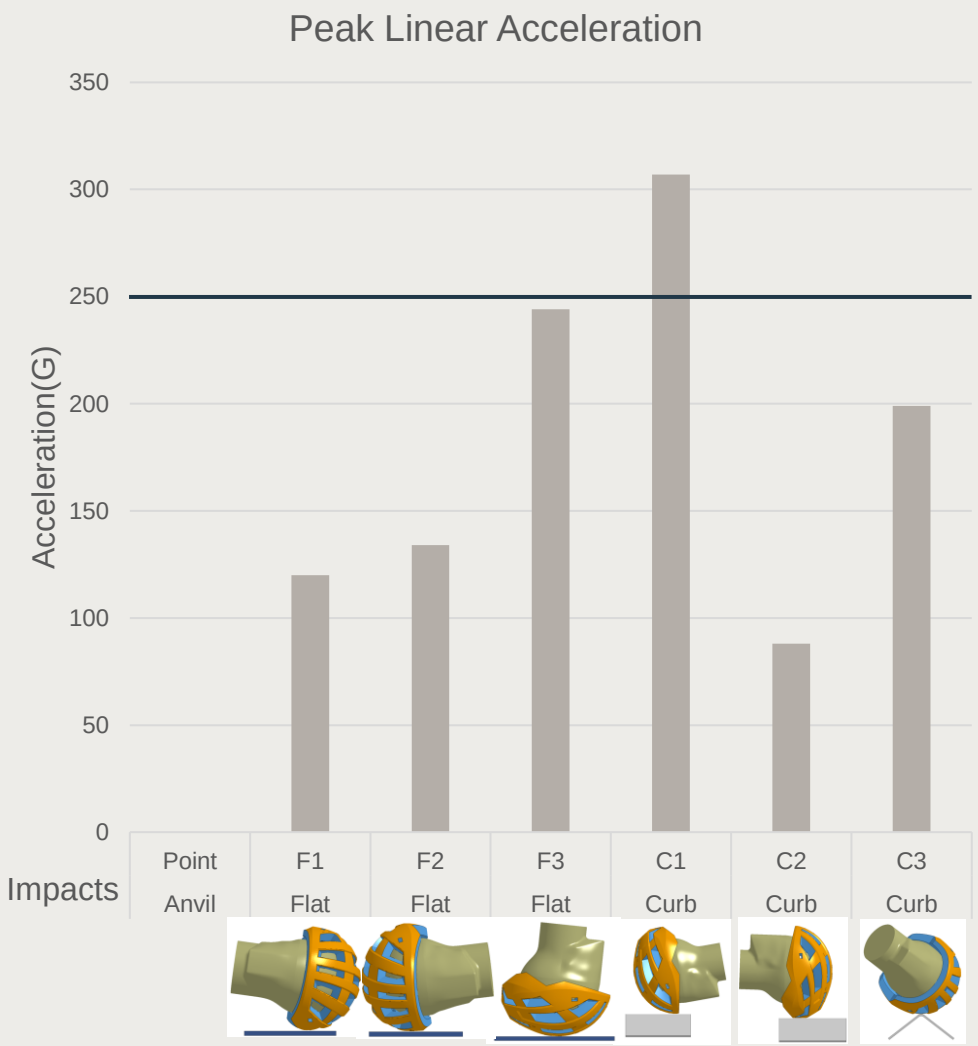
Curbstone anvil

- HELMET MANUFACTURER WANTS TO KNOW IF THEIR NEW HELMET HAS ANY WEAK SPOTS ACCORDING TO THE EN1078 TEST STANDARD BEFORE THEY MANUFACTURE THE HELMETS FOR EXPERIMENTAL TESTING AND CERTIFICATION.
- 3 IMPACT POINTS ON A CURBSTONE ANVIL AND 3 IMPACTS POINTS ON A FLAT ANVIL.



Predict results – Iteration 1

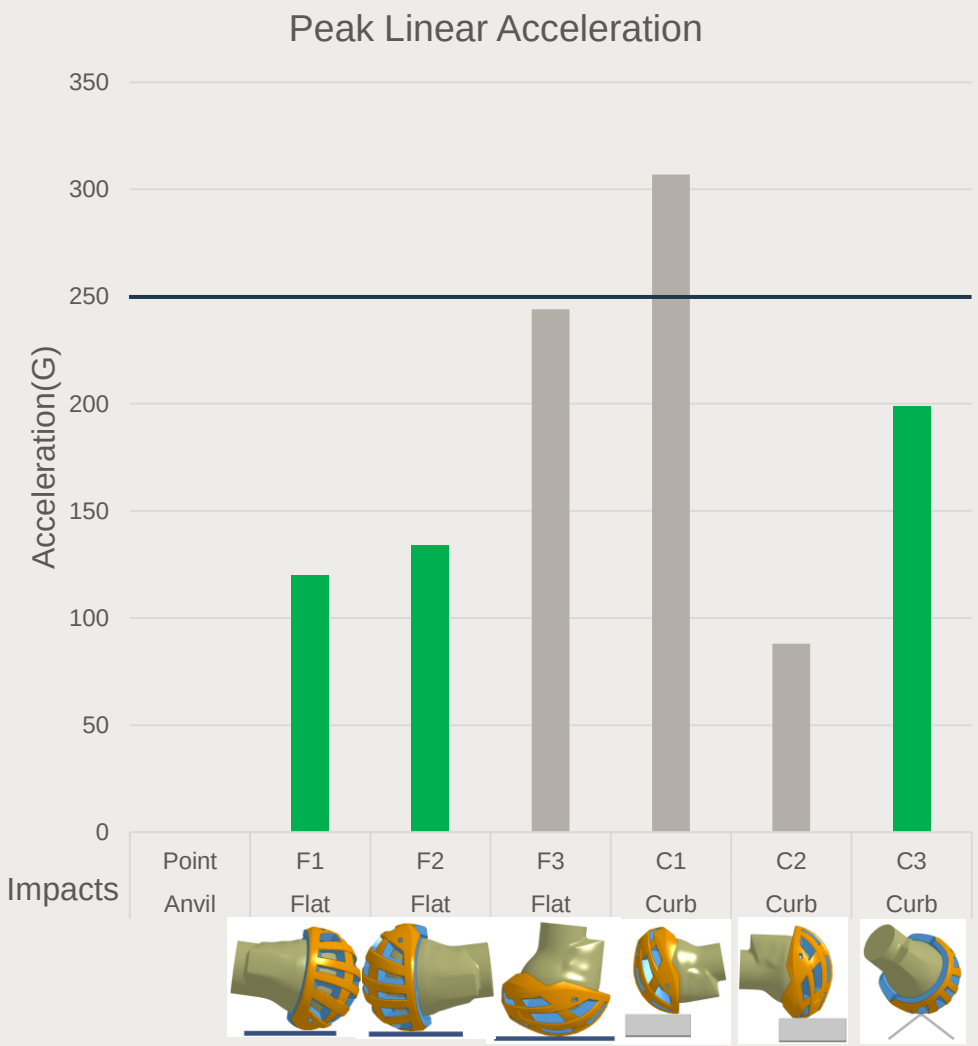
EN1078



- POSITION IN 3 CATEGORIES.
- INTERPRET RESULTS ACCORDING TO THE TEST STANDARD.
- INVESTIGATE SIMULATIONS AND IDENTIFY POTENTIAL CRITICAL IMPACTS.

Predict results – Iteration 1

EN1078



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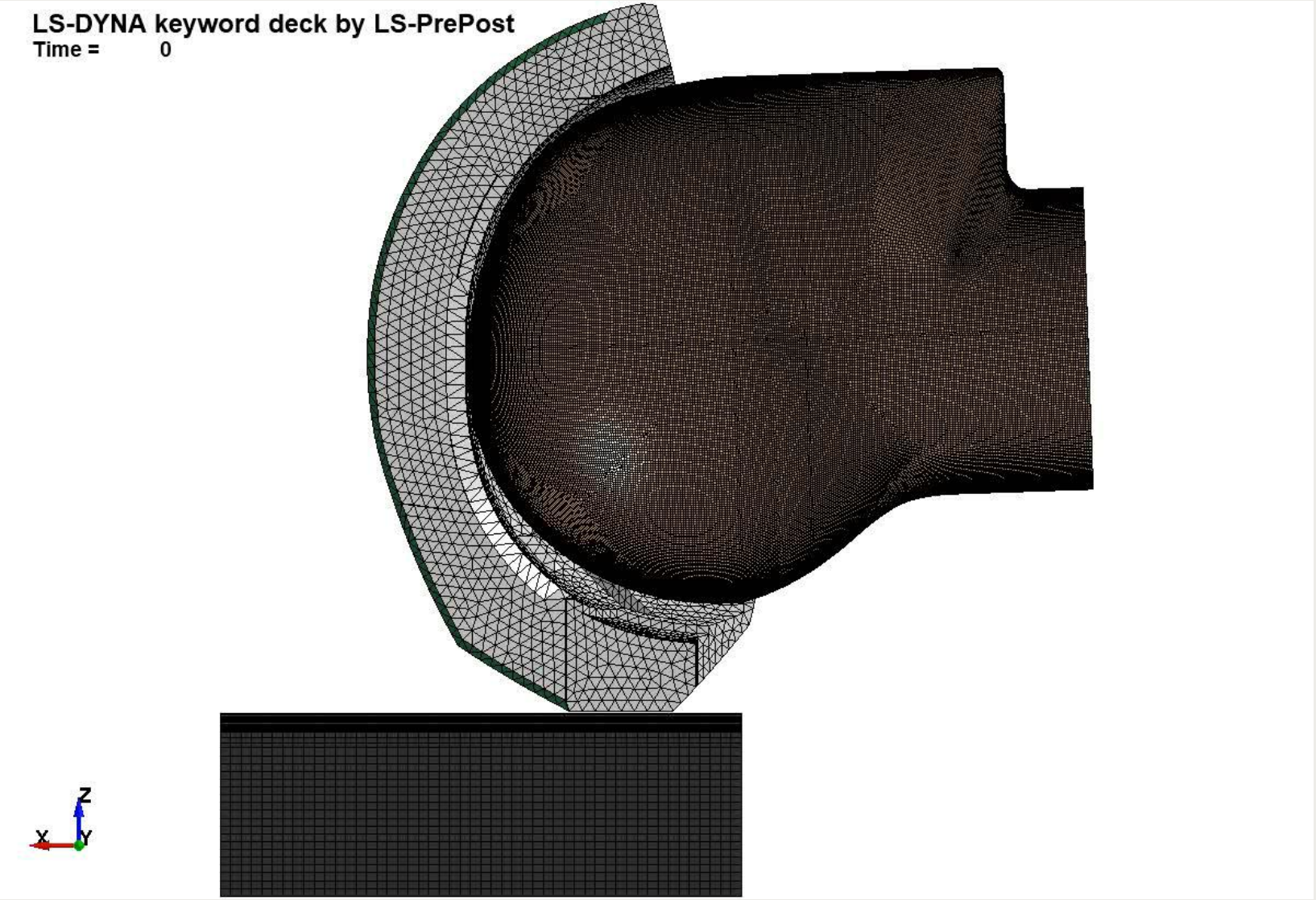
Predict results – Iteration 1

EN1078



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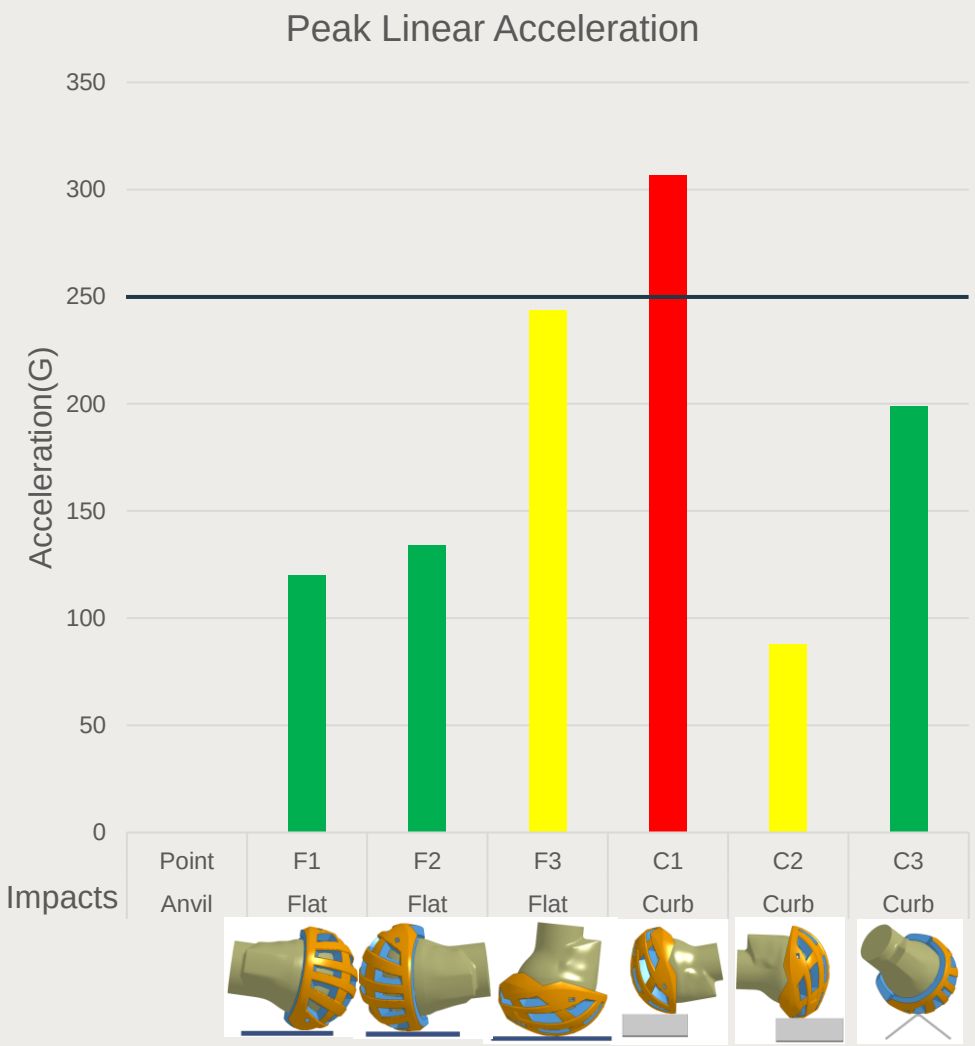
Predict results – Iteration 1

EN1078



- POSITION IN 3 CATEGORIES.
- INTERPRET RESULTS ACCORDING TO THE TEST STANDARD.
- INVESTIGATE SIMULATIONS AND IDENTIFY POTENTIAL CRITICAL IMPACTS.

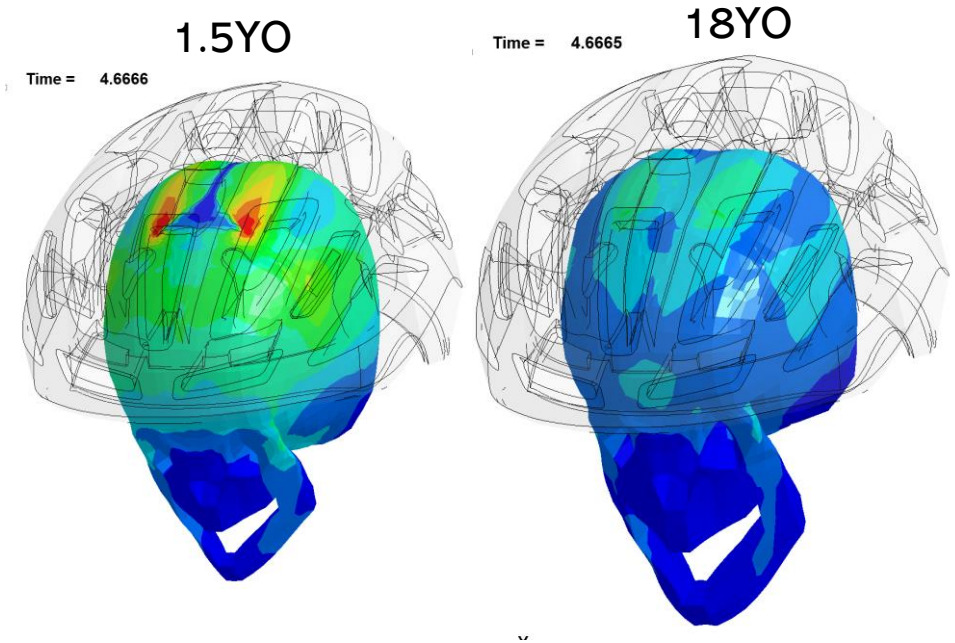
Outline

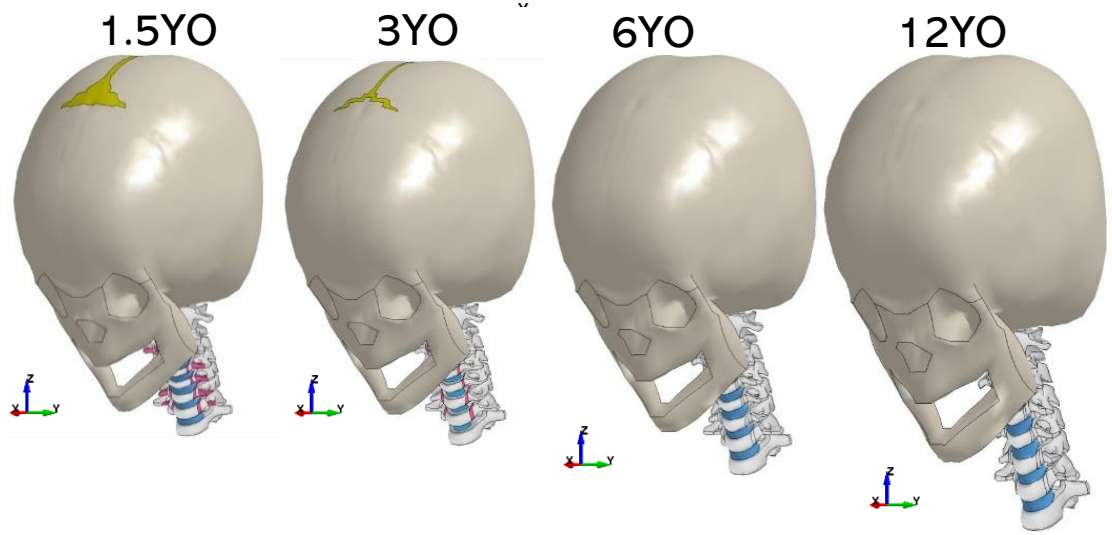
- Mips introduction (What, How, Why)
- 25 years of Mips & FE
  - Energy absorption in helmets with Mips
  - The effect of the human cervical spine in helmet testing
  - Virtual Test Lab
  - **Other projects**
    - CEN TC158- New rotational test standard
    - Safety helmets and initial rotation
    - Child helmets
    - Chin bar test
    - FE Head model evaluation

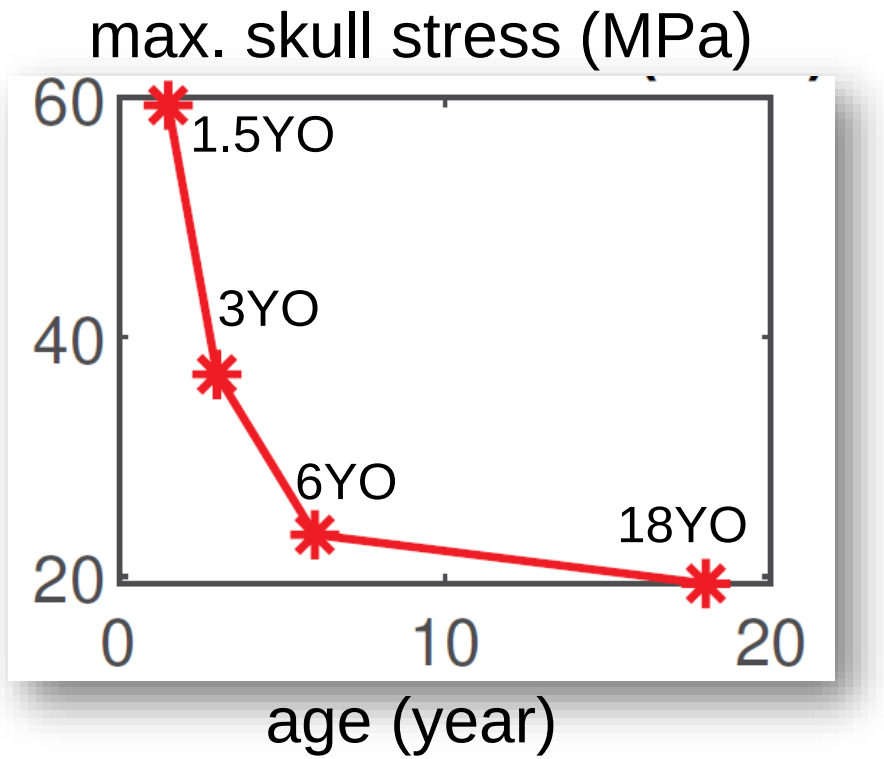
Simulating Fall accidents (Construction helmets)

Linear crown

Results: Skull stress

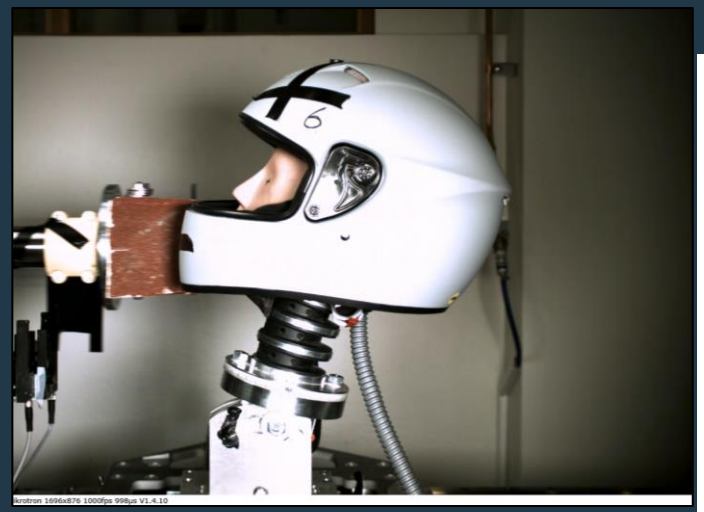


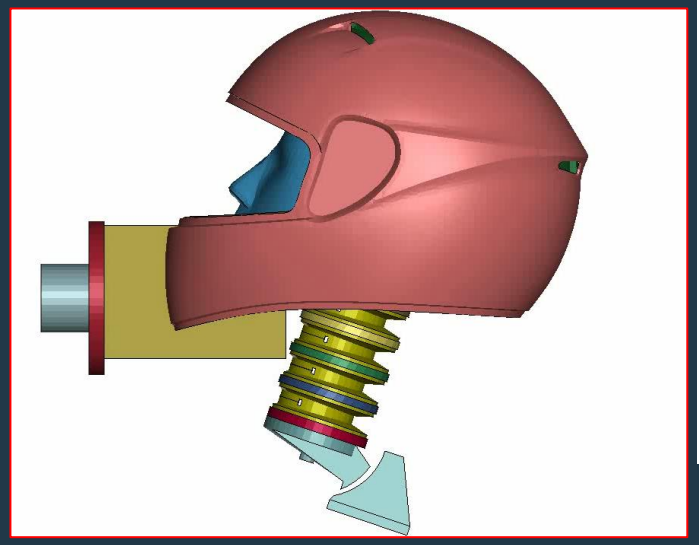


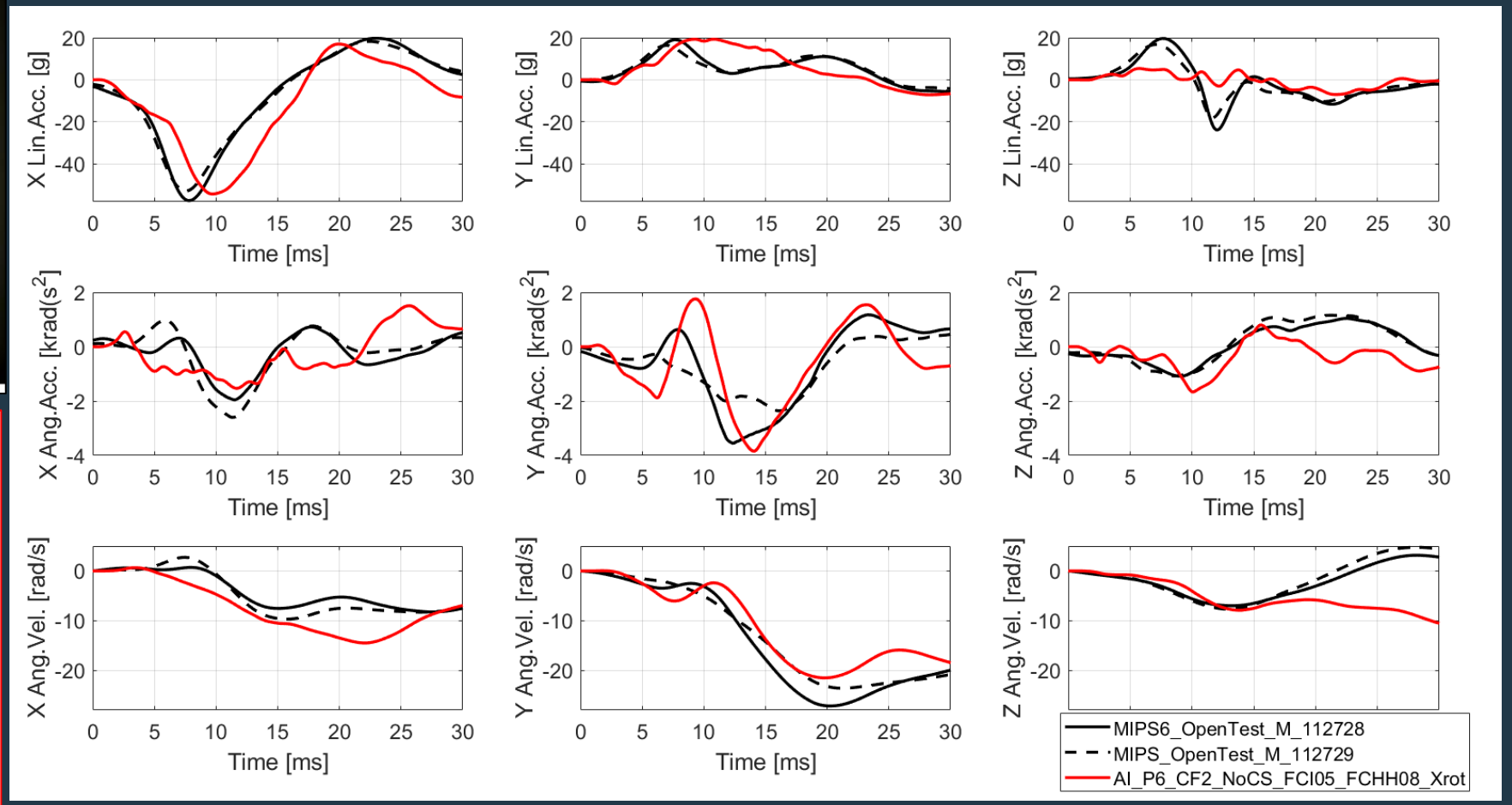


Youngest – largest risk mainly due to the fontanel/suture

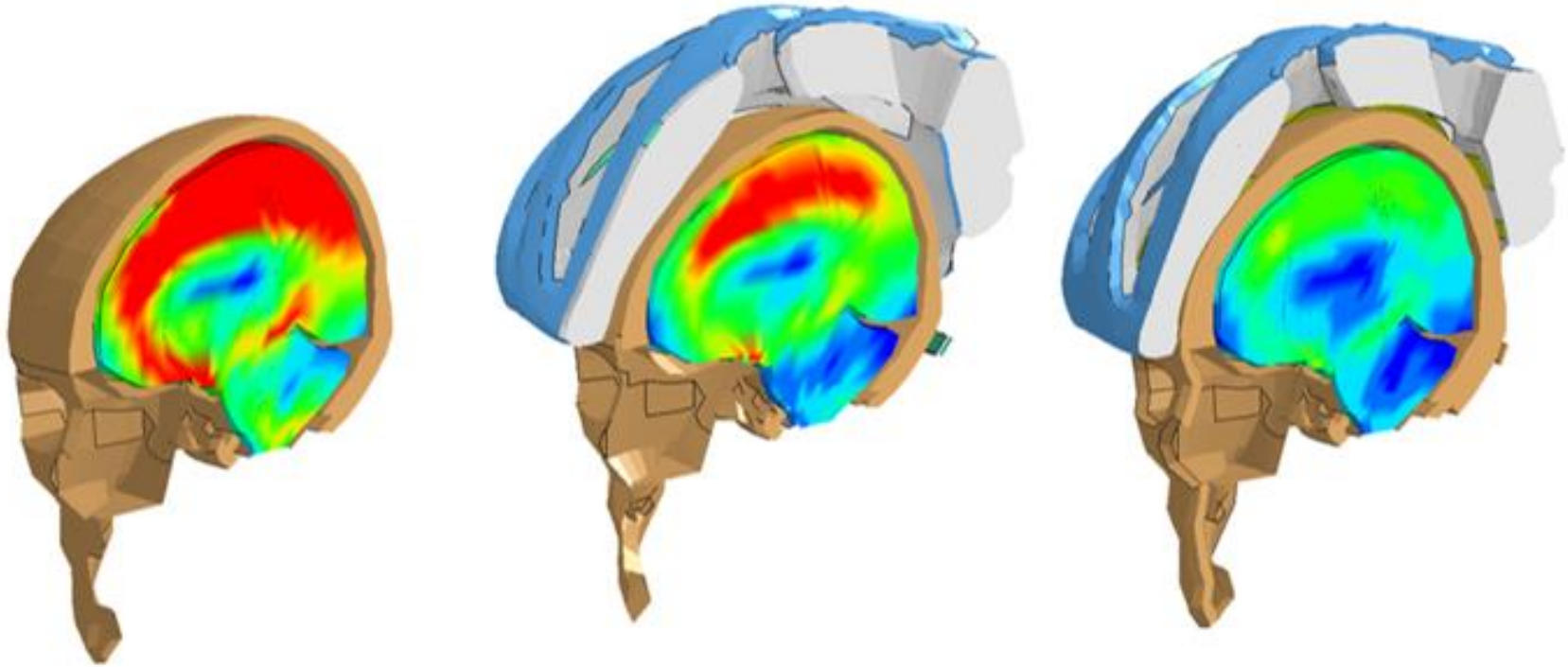
Chin bar impacts







All helmets are safe !



No Helmet

Traditional Helmet

Helmet with Rotation Protection

Mips

Thank you
for your attention

Quality good enough for parametric studies