



# 13e rencontre SMAI math-industrie

Physically correct and timely  
simulations: the challenge towards  
Virtual Prototyping

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# Introduction

- Today's industry trend is towards reduction of physical prototyping through simulation driven design in order to reduce drastically the time-to-market of new products. This is called Virtual Prototyping. However, it relies heavily on the capacity to reproduce through simulation the correct physics and in a timely way to respect the industrial development process deadlines.

# ESI Group Offering

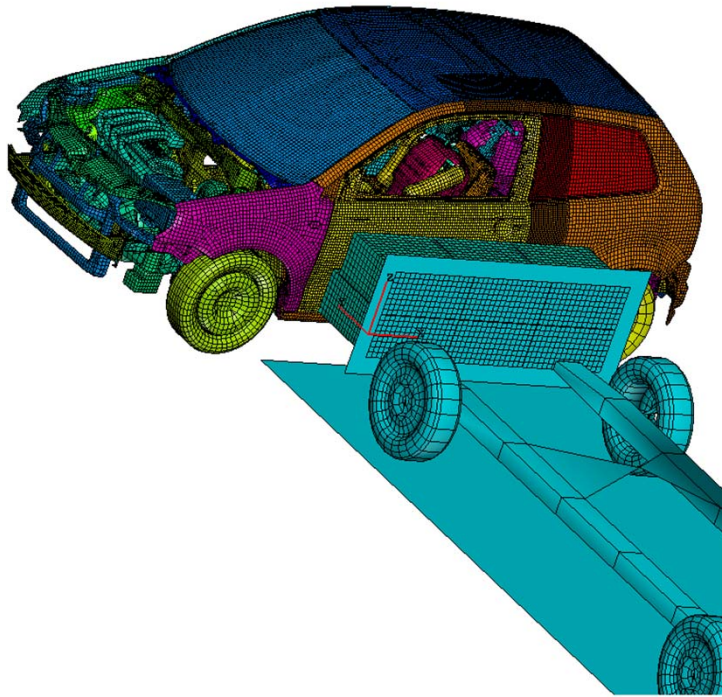


Software & Services  
for  
End-to-End  
Virtual Prototyping

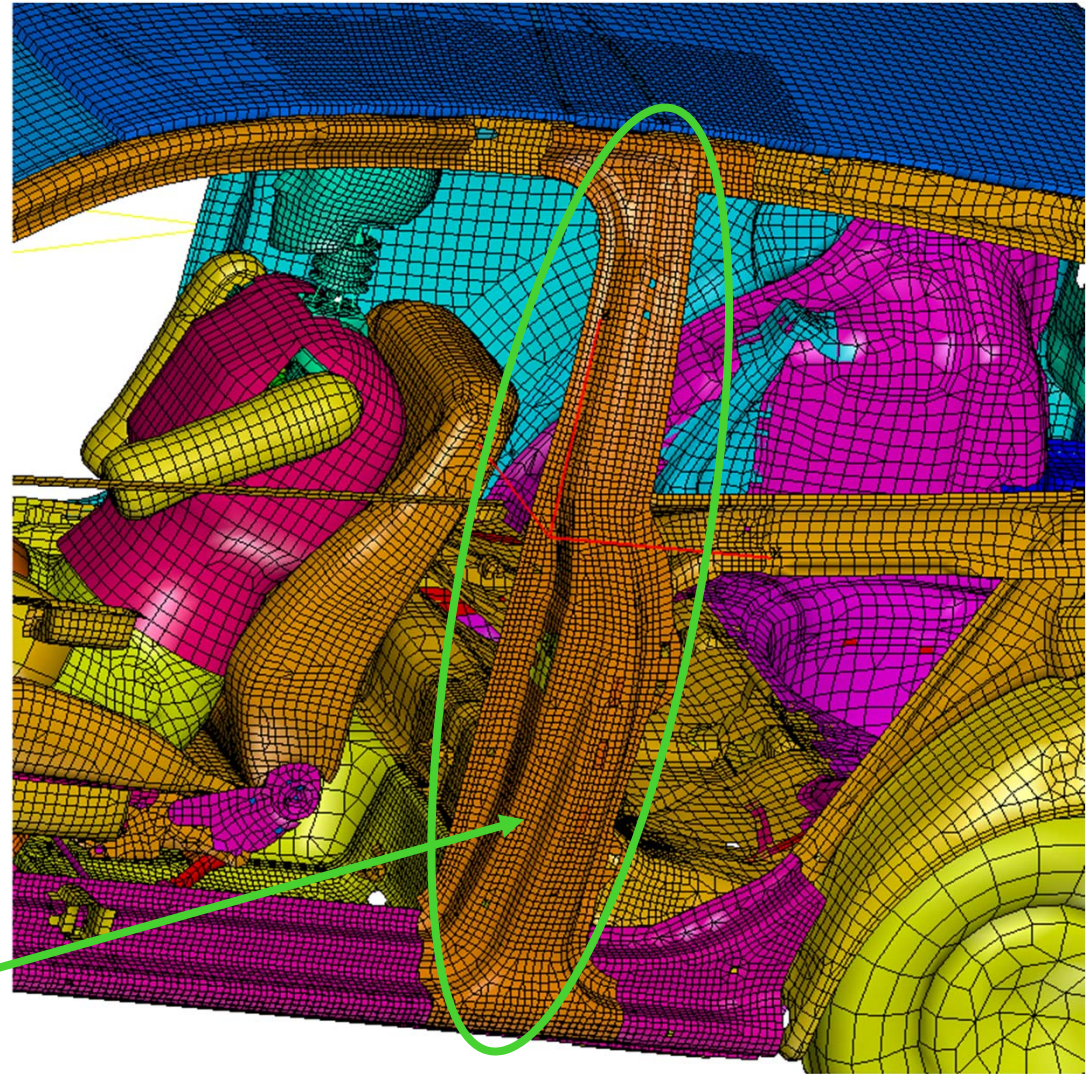
# Enjeux / problématique industrielle

- Crash Failure Analysis as an industrially affordable solution
- Must be performed “over-night”

# A typical problem: automotive side-impact



B-Pillar model



# The Wilkins (EWK) metal rupture model

- Mathematical details -

## A cumulative strain damage model

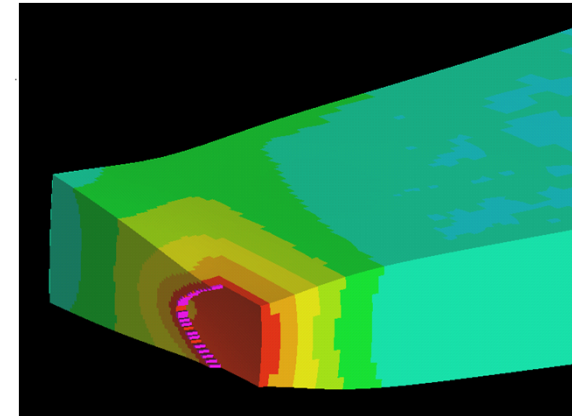
Non proportional loading

$$D_P = \int w_1 w_2 d\bar{\epsilon}^P ,$$

where

Plasticity based

$\bar{\epsilon}^P$  = equivalent plastic strain,



Triaxiality dependence

$w_1$  = hydrostatic-pressure weighting term =  $\left( \frac{1}{1+aP} \right)^\alpha$ .  
(set  $D_P = D^0$  when  $P \leq -1/a$ )

Lode angle dependence

$w_2$  = asymmetric-strain weighting term =  $(2-A)^\beta$  ,

Over a critical volume  $R_c$ : the “Size Effect”

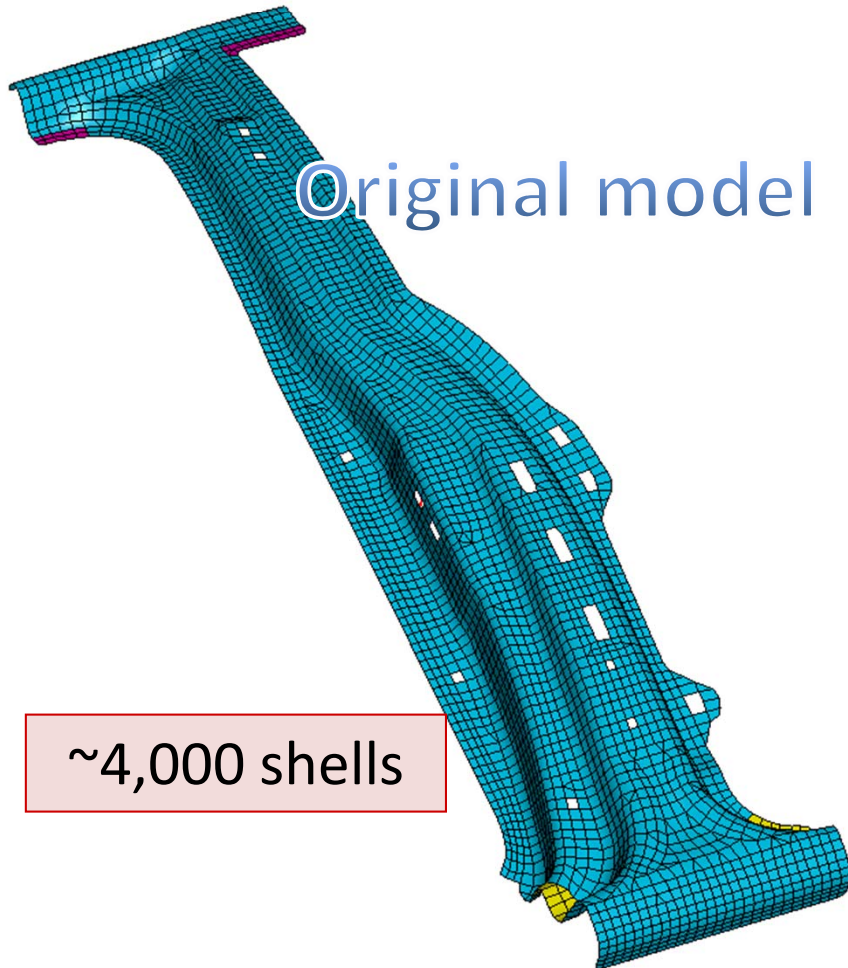
# Importance of "Size effect"

A severe condition imposed on model element size in order to be predictive

## Size effect:

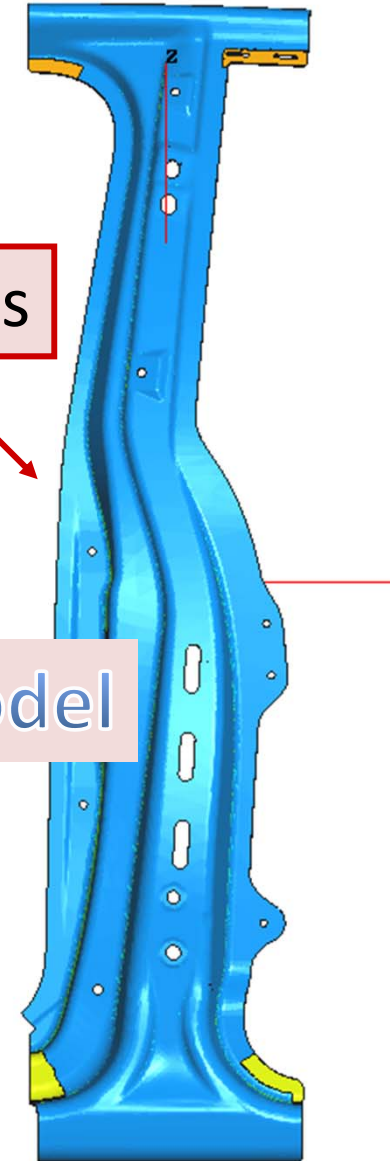
- critical volume to be saturated with damage in order to start a "crack"
- Typical values
  - Aluminum:  $(0.15\text{mm})^{**3}$ 
    - ~6 solid elements per mm
  - High Strength Steel:  $(0.05\text{mm})^{**3}$ 
    - 15-20 solid elements per mm

# High fidelity modelling of the B-Pillar



~1,000,000 solids

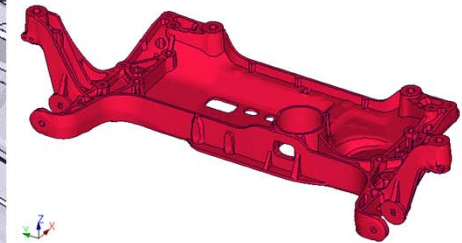
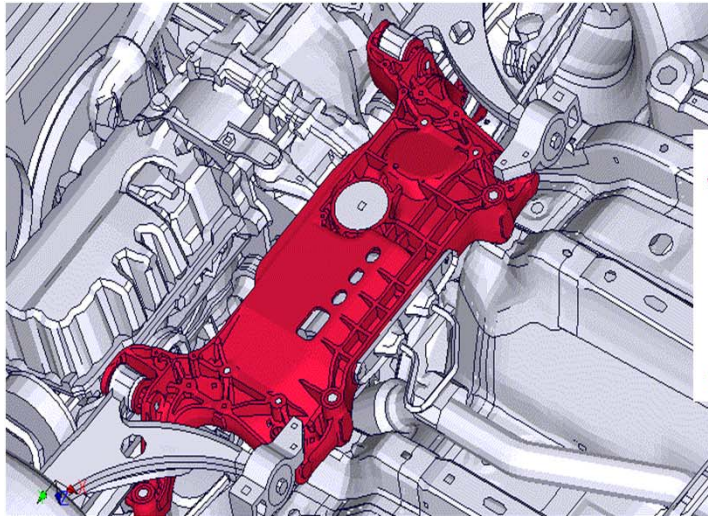
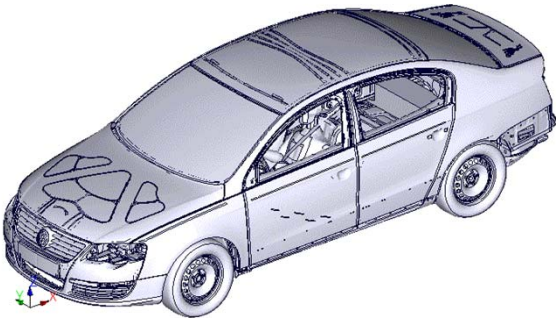
Detailed model





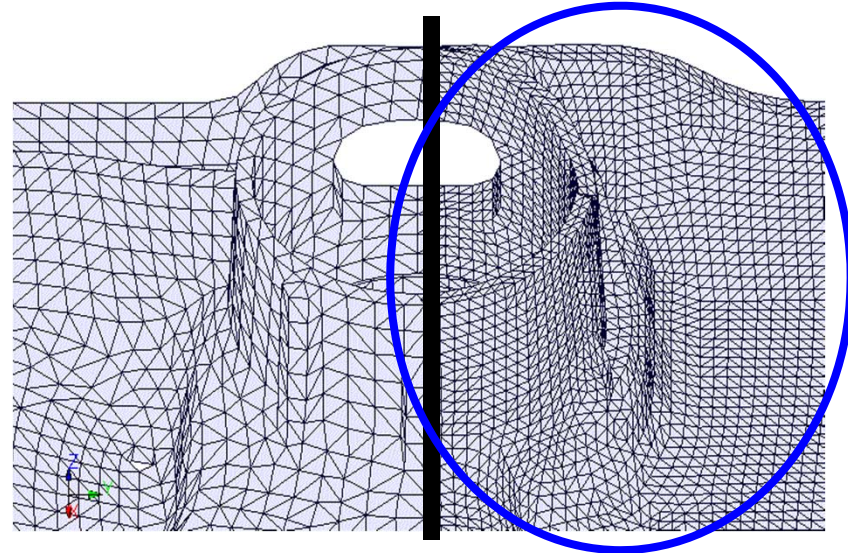
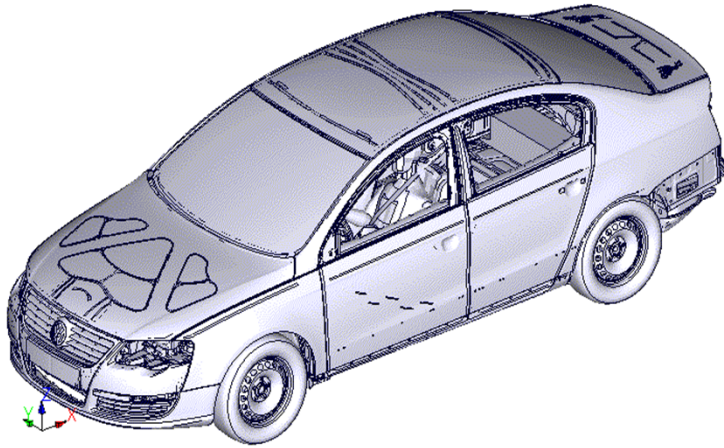
# The industrial challenge

- Crash Failure Analysis as an industrially affordable solution
  - Example



- Must be performed “over-night”

# Towards extreme local refinement



Car Model:  
879,000 Elements  
Time Step: 1  $\mu$ s

Subframe (520k-Model):  
520,000 TET10-Elements  
Time Step: 0.05  $\mu$ s

+

Time step ratio:  $R_{\Delta t} = 20$   
Local model element fraction:  $f_L = 59\%$

Problem: It is not just a matter of "size", but algorithmic, too.  
(Disproportionate distribution of solution effort)

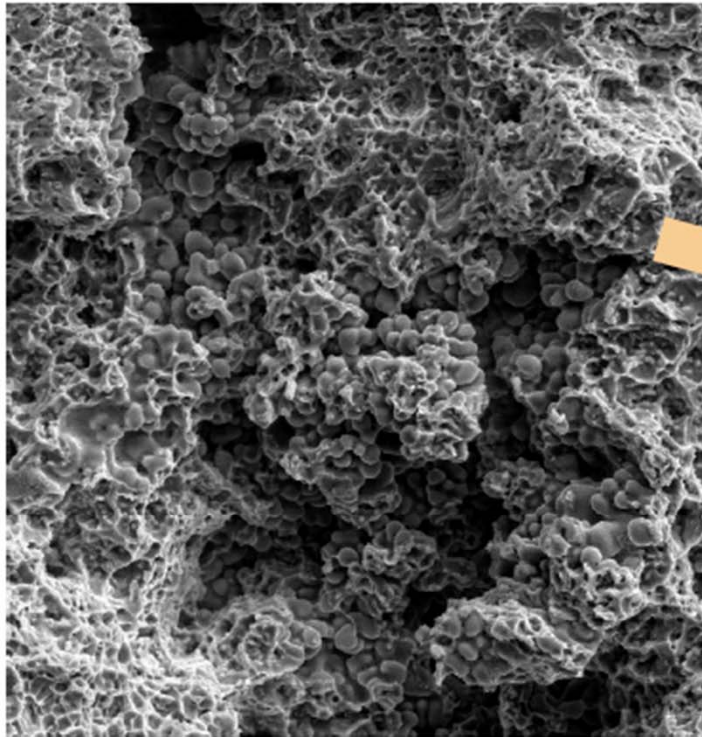
# Casted parts pose a special issue



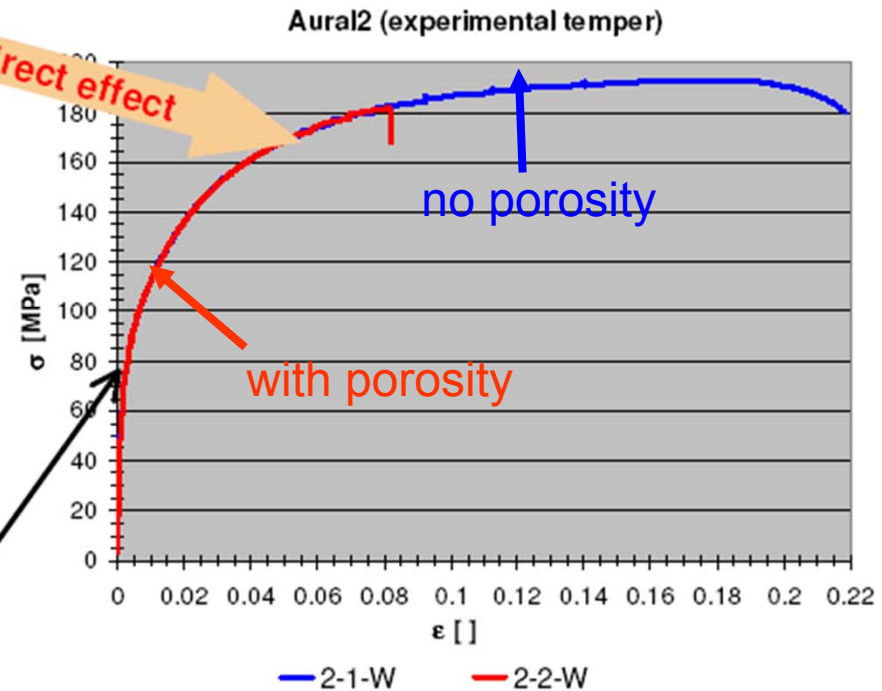
## The effect of porosity in castings...



Gas Porosity, Shrink Porosity, Micro Porosity



### Correlation between porosity's and preliminary failure

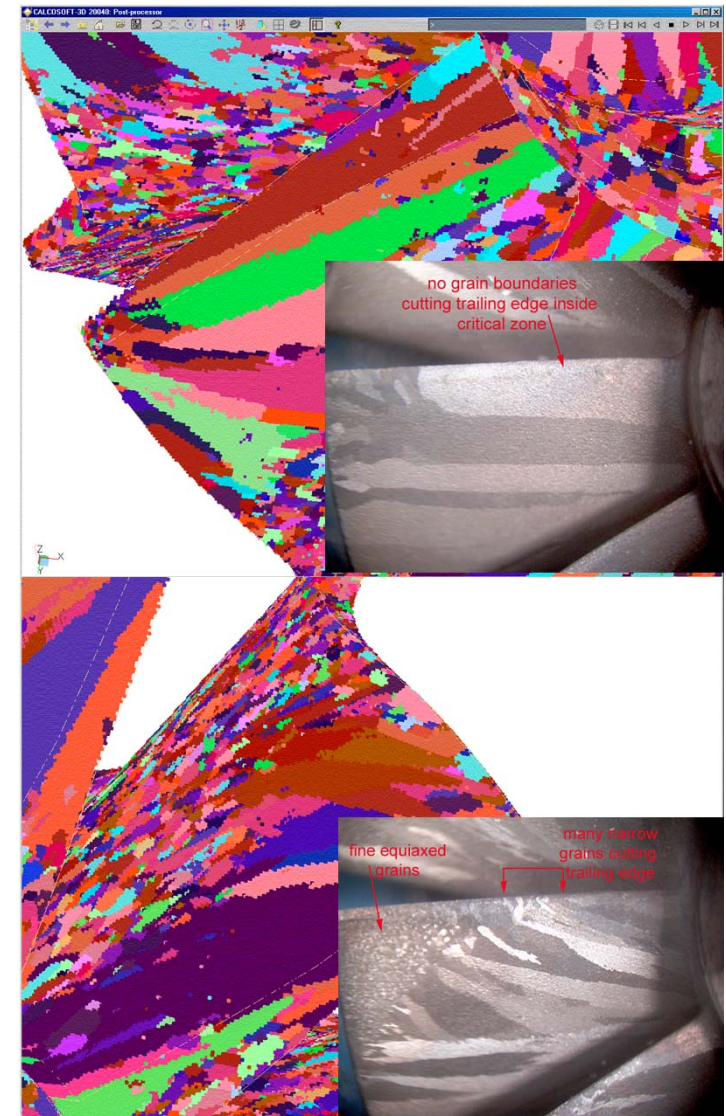
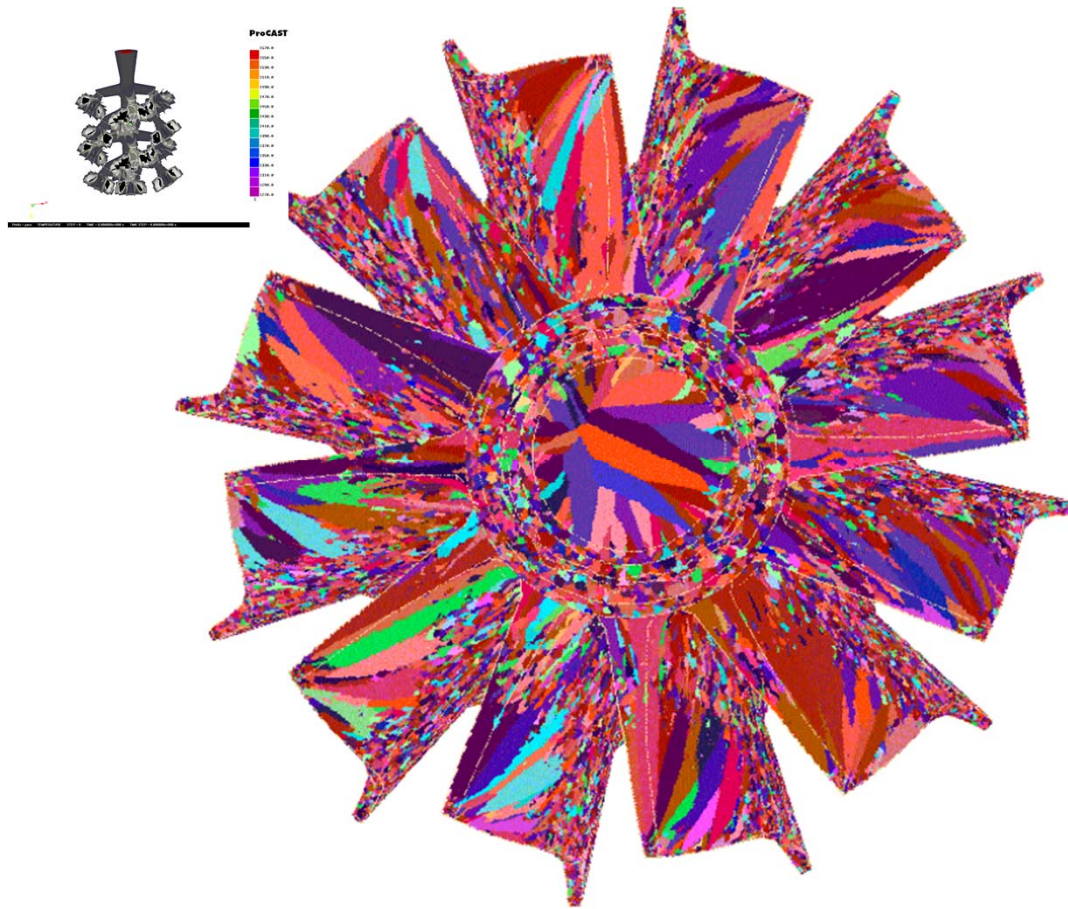


Identical stress level up to failure

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# Very detailed models are needed for the prediction of the grain structure

## Uniform Solidification in Ni Turbocharger

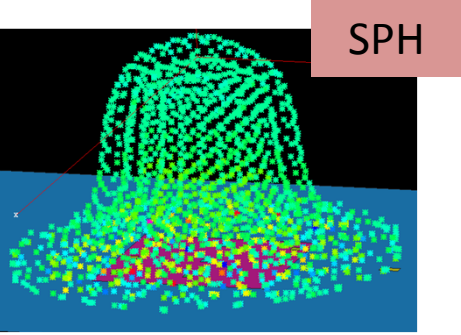
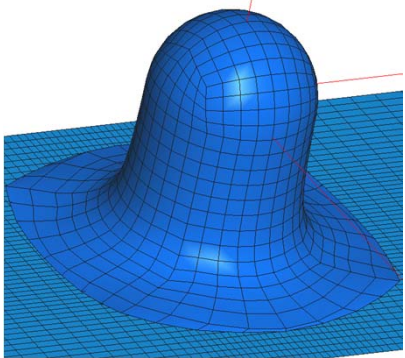


**CAFE (Cellular Automata FE)** was developed in collaboration with:  
**Howmet, Snecma (France), ABB, EPFL (Switzerland), AETC, Rolls Royce (UK), PCC (USA)**

22/03/2011

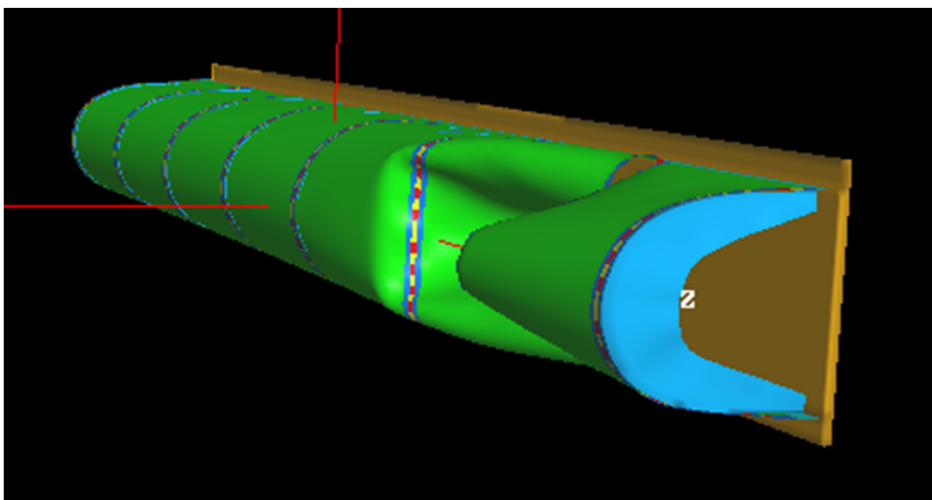
SMAI - HPC

# In Aeronautics the problem of Birdstrike is particularly acute



$$D_p = \int w_1 w_2 d\bar{\epsilon}^p$$

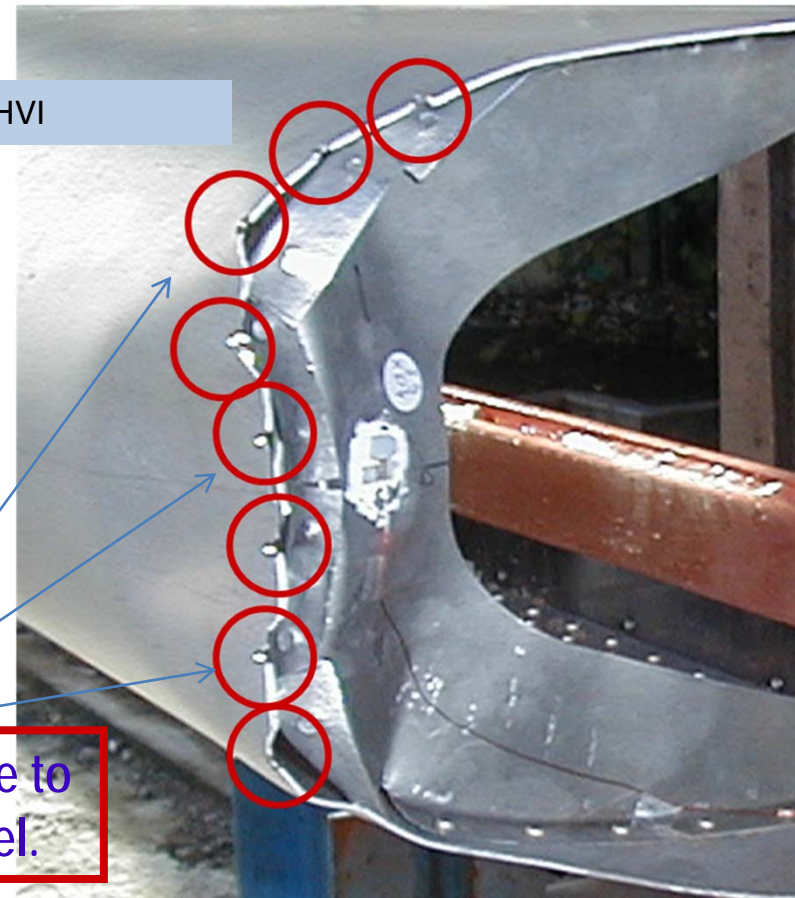
Fracture when  $D_p > D_0$



Courtesy of EC project CRAHVI

# Incorporation of details is critical for performance prediction

- You cannot predict what you do not model for !



The rivets and their effect in rupture have to be sufficiently represented by the model.

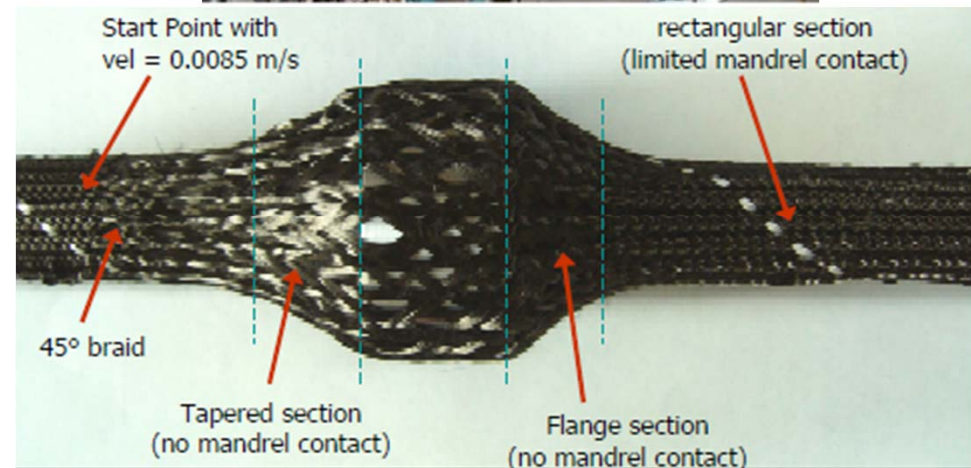
# Les points de blocage

- Mesh size
  - huge meshes needed
- Computational algorithm
  - Dissimilar meshes in size and type (FE / meshless)
- Initial state of structure
  - Manufacture (filamentary composites)
  - Connectors (spotwelds, rivets etc.)

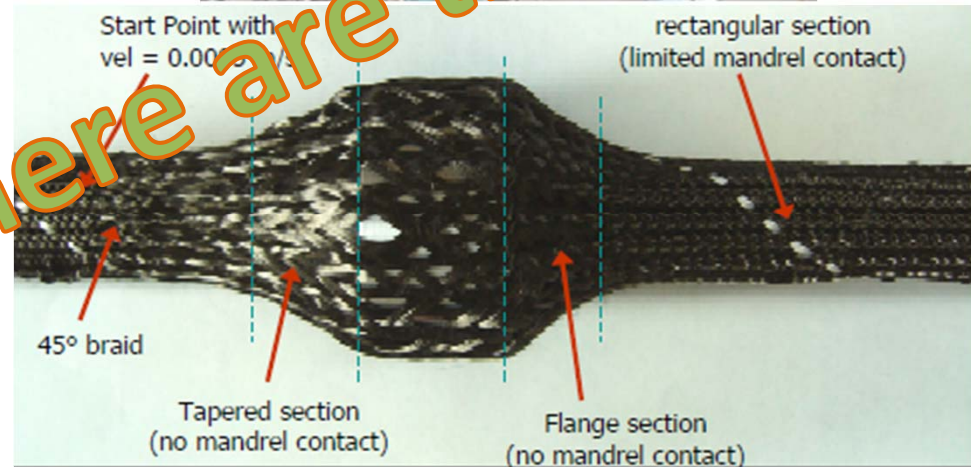
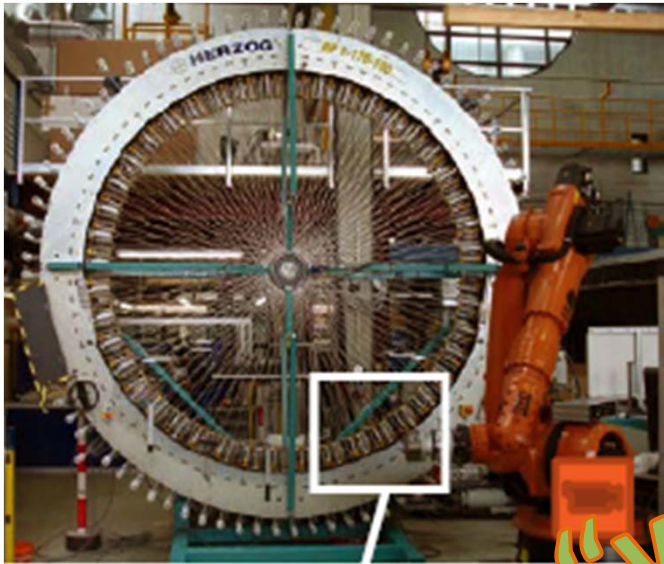
- **Manufacture of Filamentary Composites**



# New Manufacturing methods for advanced composites

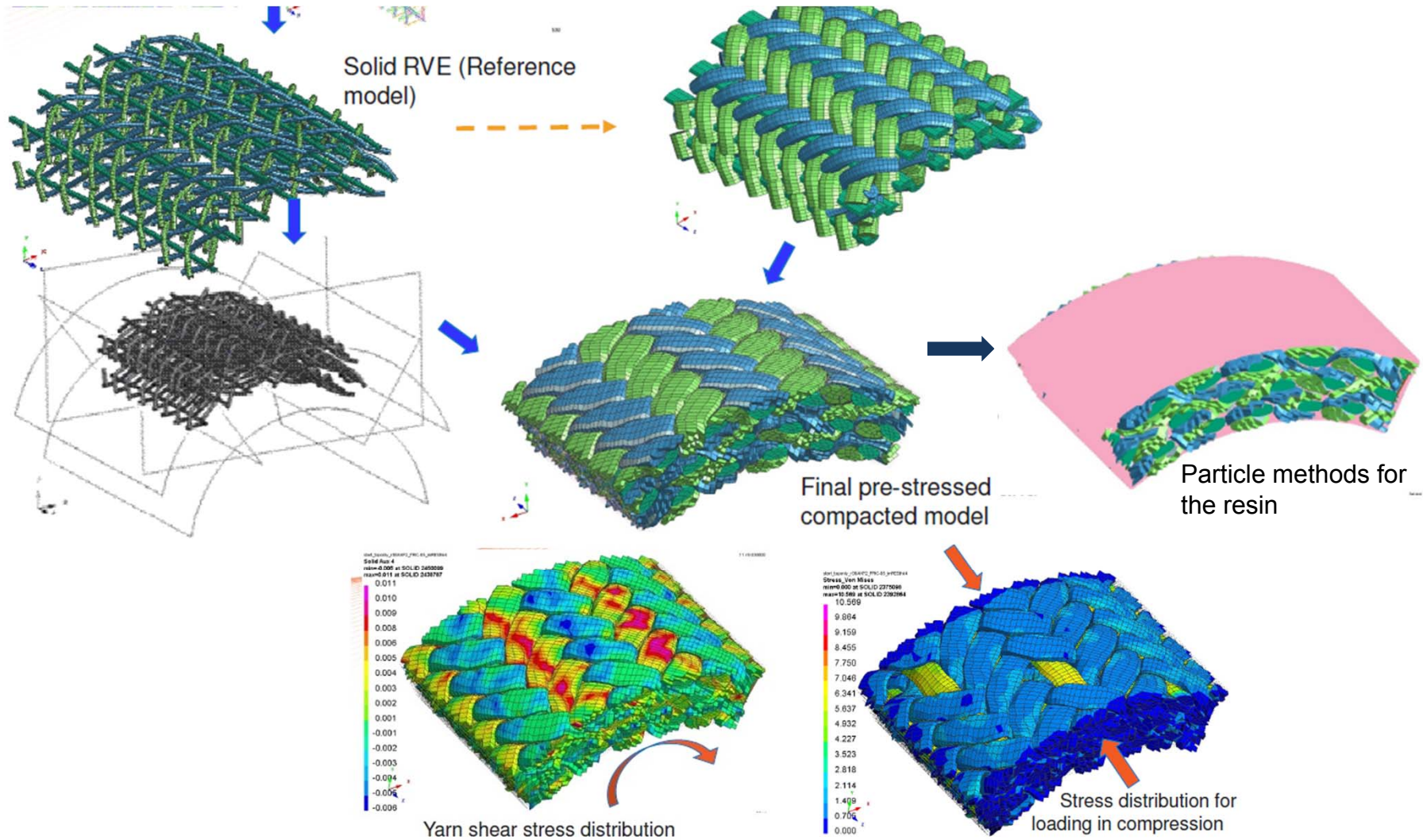


# New Manufacturing methods for advanced composites

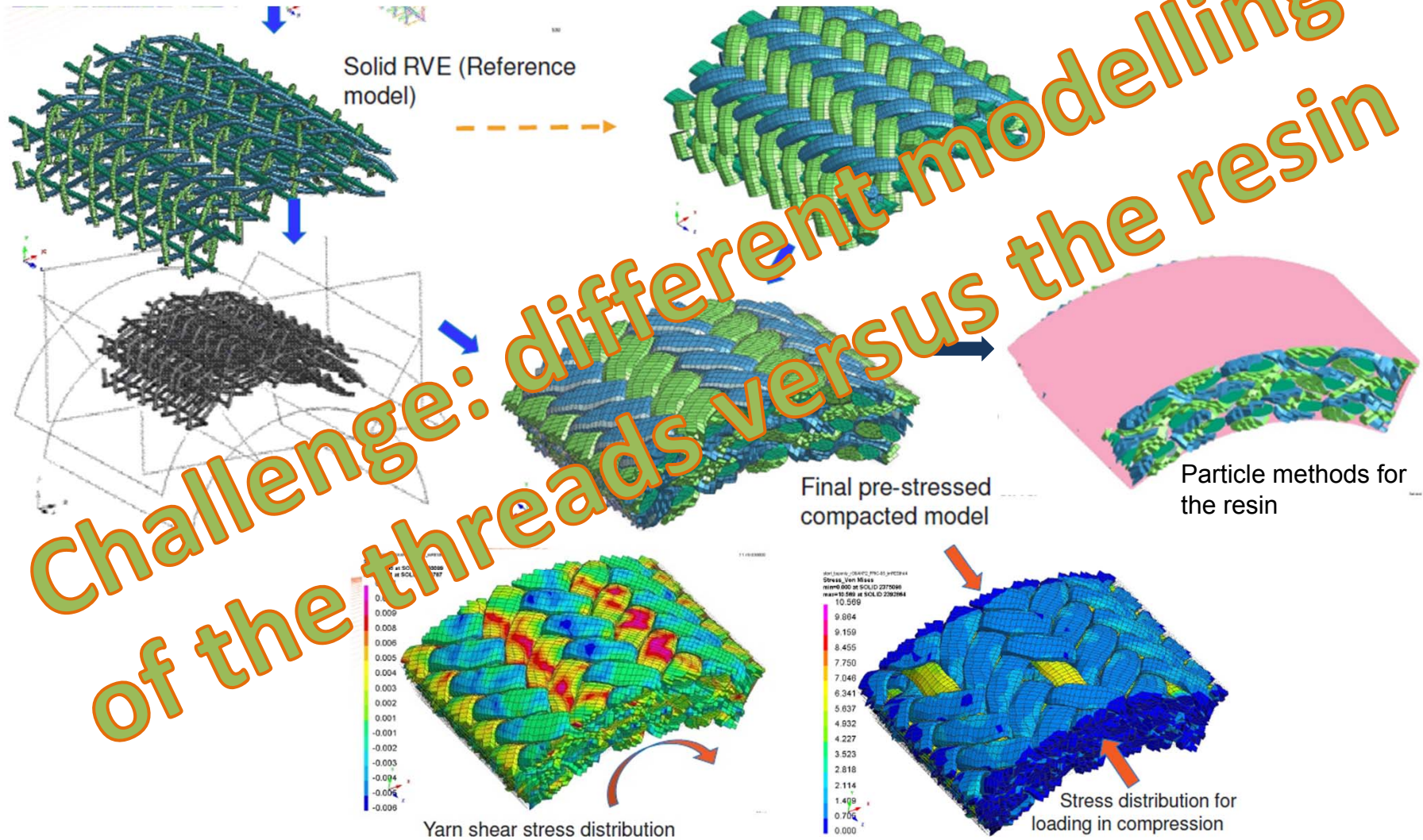


Challenge: "where are the fibers?"

# Virtual Properties prediction (through virtual coupon testing)



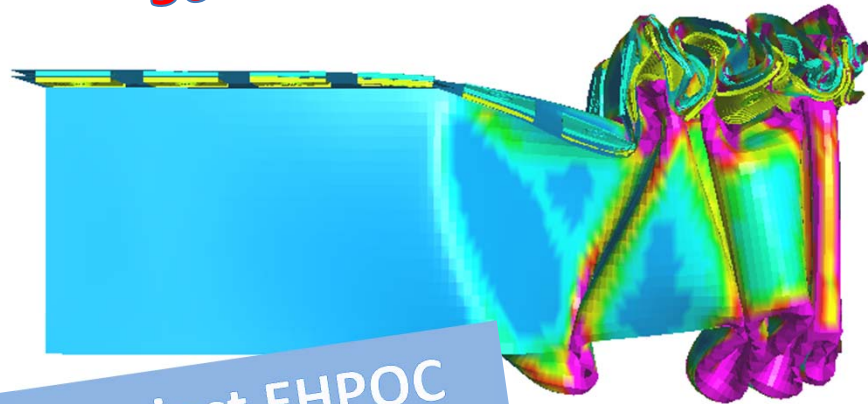
# Virtual Properties prediction (through virtual coupon testing)



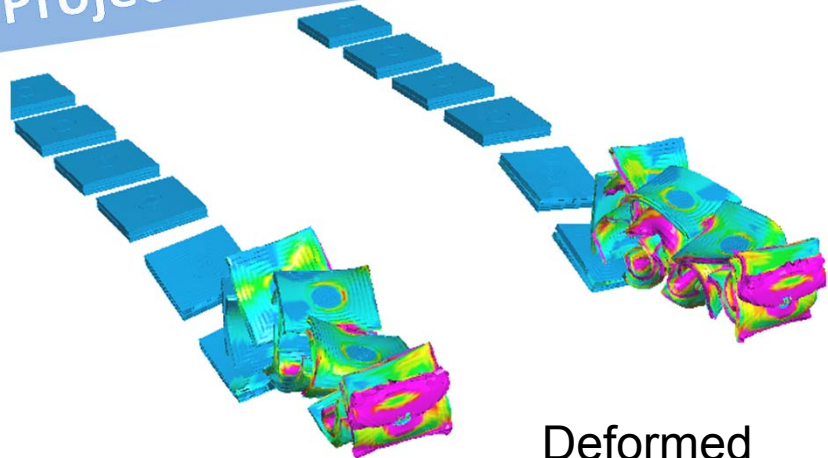
- Modelling connectors (Spotwelds, Rivets etc.)

# Effect of connectors in automotive crash Spotwelded beam modelling

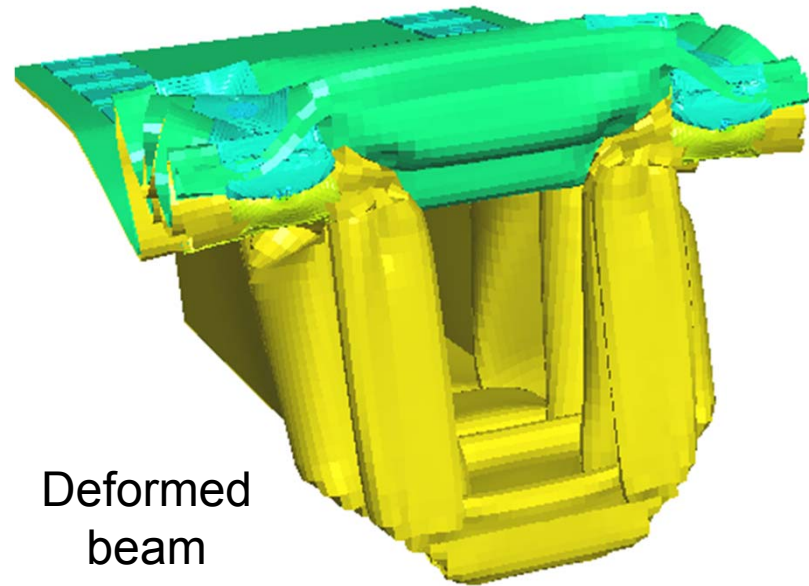
30mm spotweld spacing



Project EHPOC



Deformed spotwelds



Deformed beam

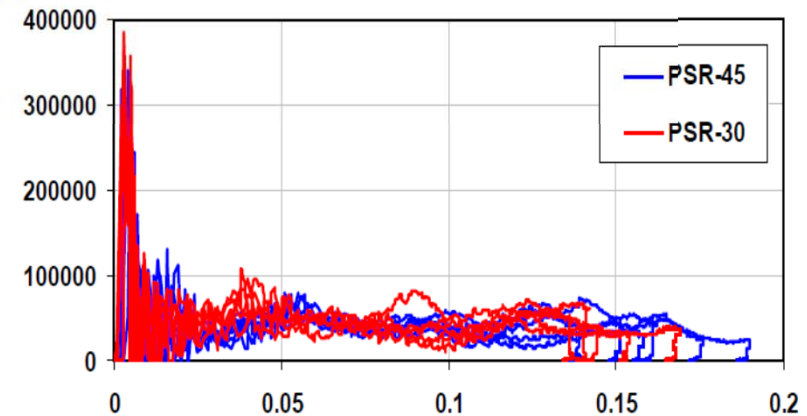
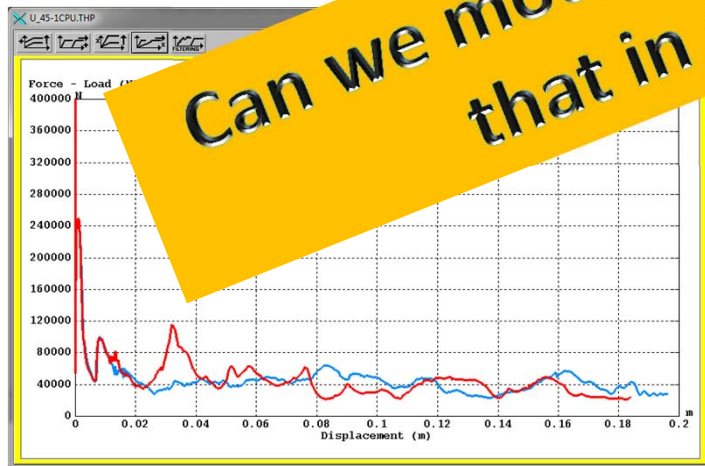
# Effect of connectors in automotive crash Spotwelded beam modelling

45mm spotweld spacing

Project EHPOC

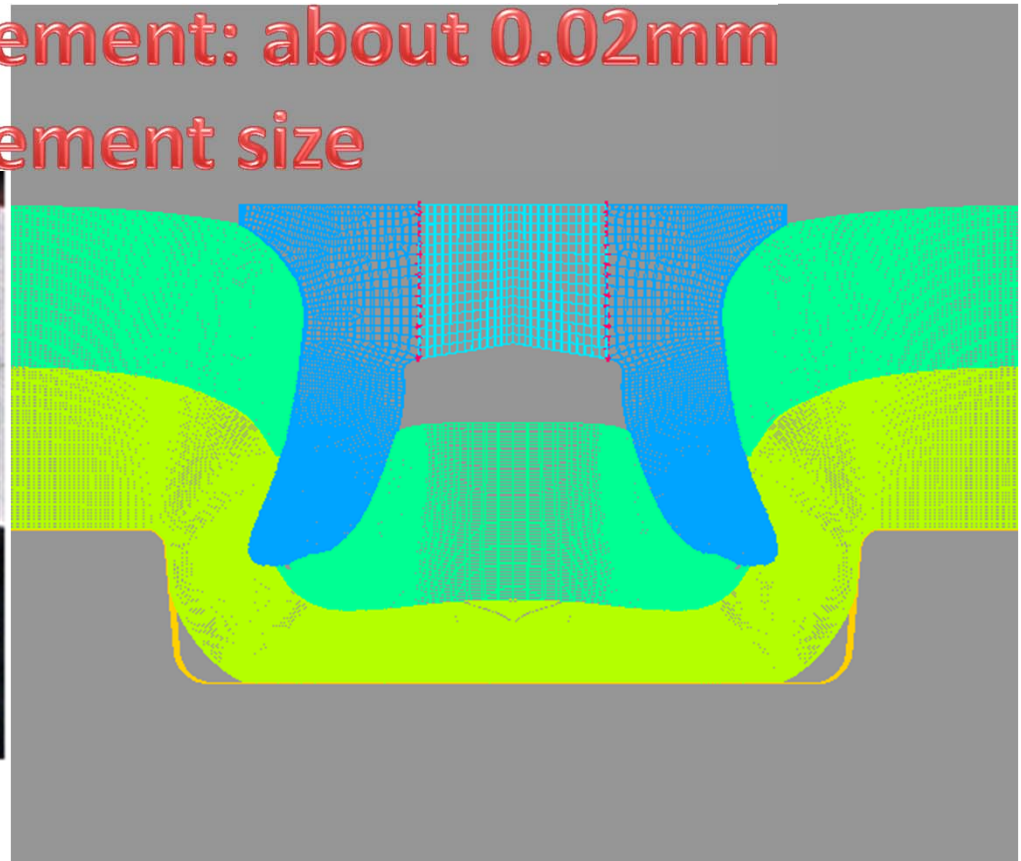
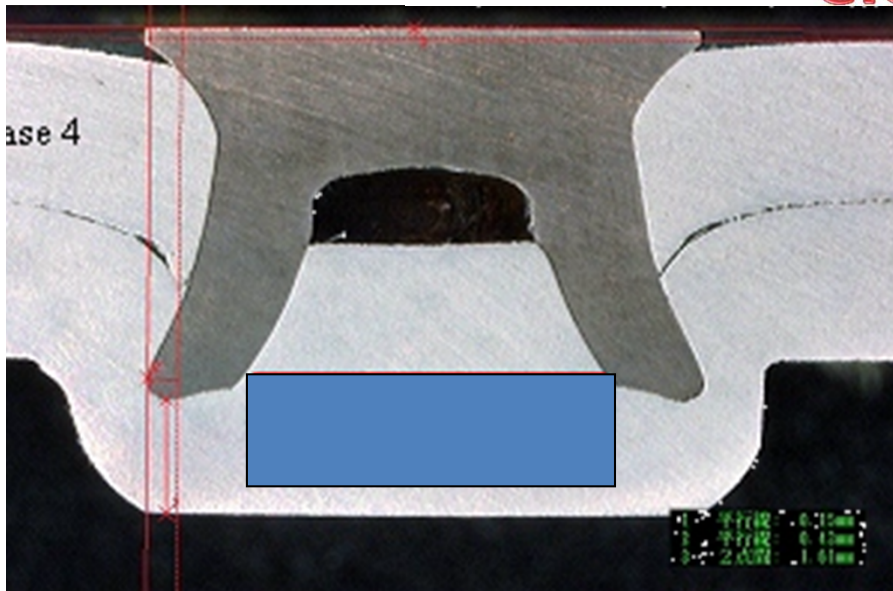


Can we model a few 1000 spotwelds like that in a global car model



# The challenge of Self Piercing Rivets: knowing their shape and state

**Extreme refinement: about 0.02mm element size**

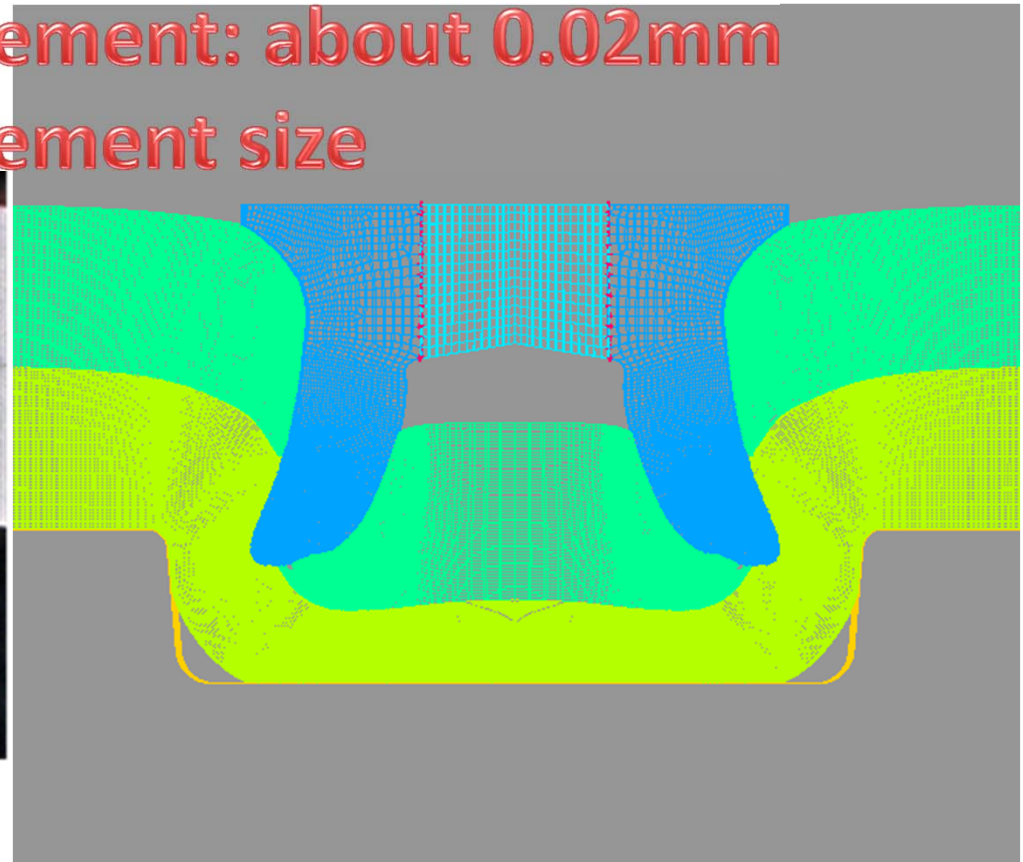
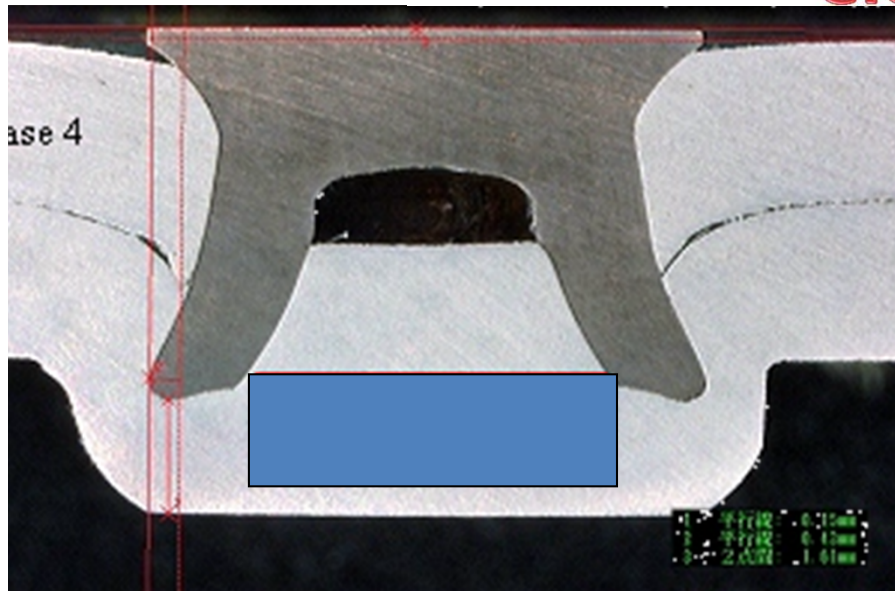


**Full 3D model for a 3D piercing process**



# The challenge of Self Piercing Rivets: knowing their shape and state

**Extreme refinement: about 0.02mm  
element size**



**Shape is OK but not residual stresses!**

# Les points de blocage

- Mesh size
  - huge meshes needed
- Computational algorithm
  - Dissimilar meshes in size and type (FE / meshless)

- Modelling substructures and systems

# Application to Battery Modelling

- **Problematics: material issues**
  - **Microscale structure (20  $\mu\text{m}$ )**
    - Discontinuous
    - Nano-particles, nano-fibers
  - **Modeling**
    - Continuous mechanics
  - **Issues**
    - Continuous mechanics properties
    - Interpretation
    - Calibration

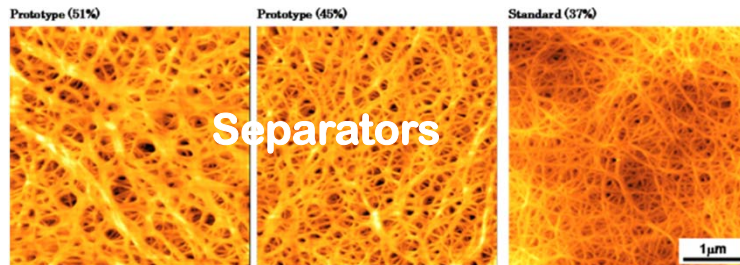
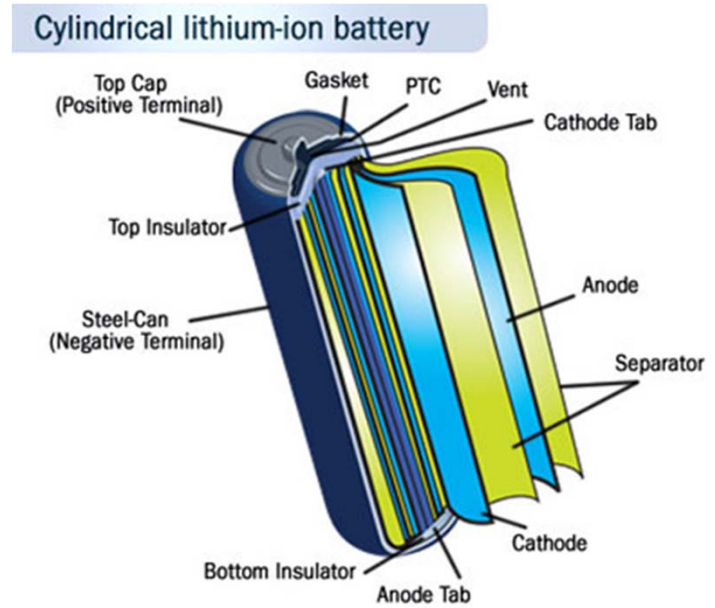
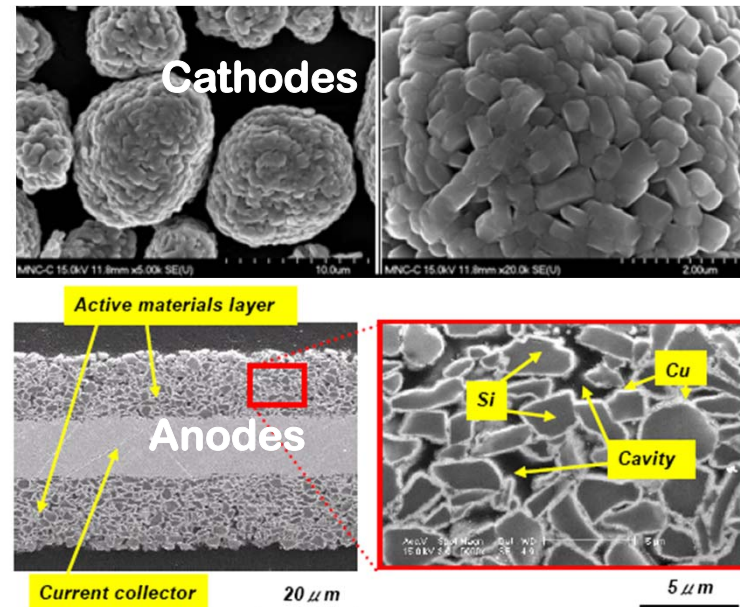
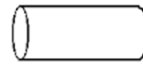


Figure 1. Comparison of the surface images taken with an APM. The numbers in the parentheses are the porosity.

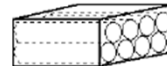


# Application to Battery Modelling

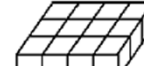
- Structural layout:



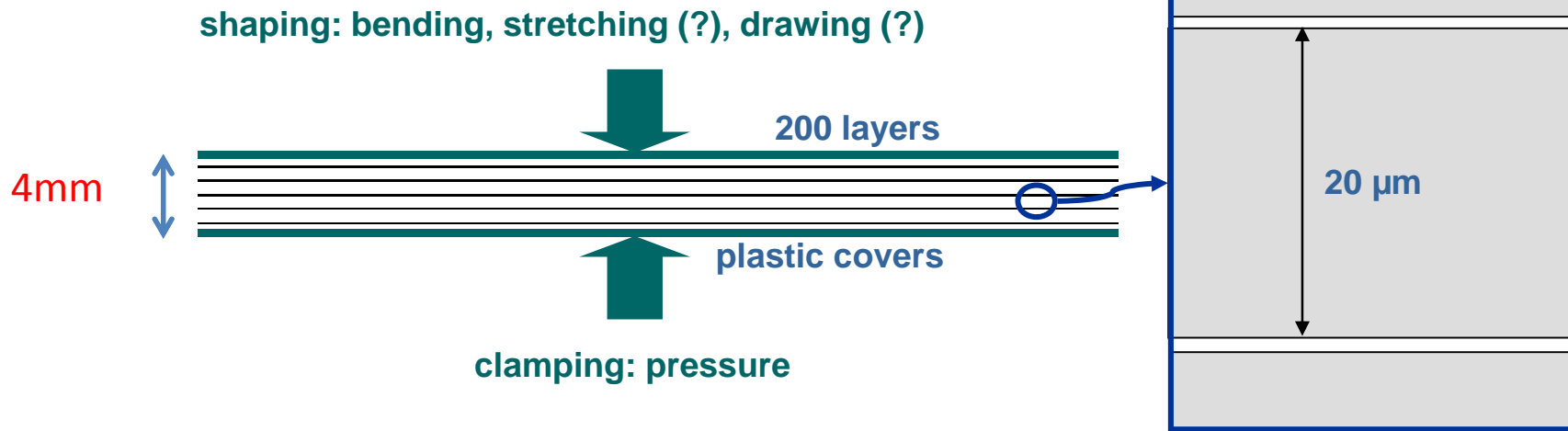
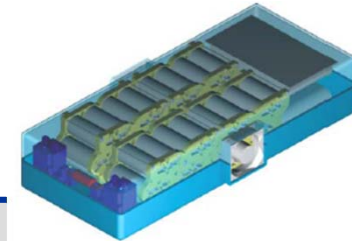
Cell



Module



Pack



- Requirements:

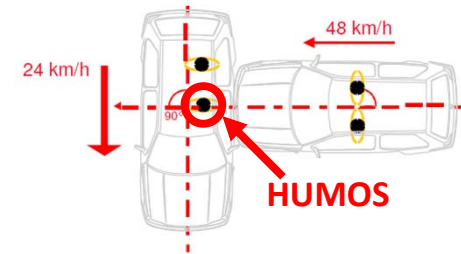
- Stresses and strains in each layer

- Result : 200 elements/mm

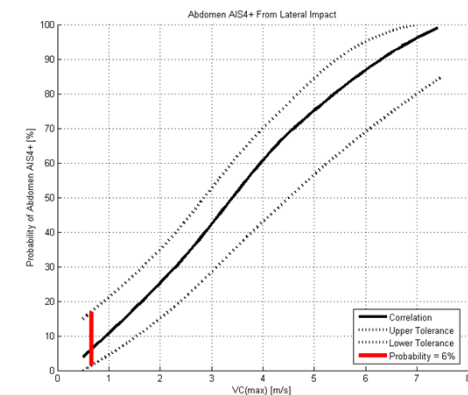
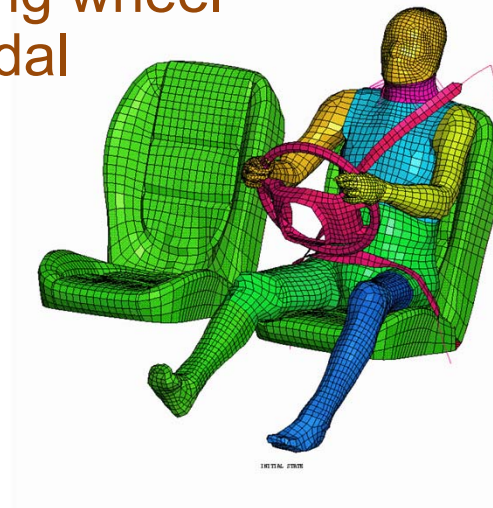
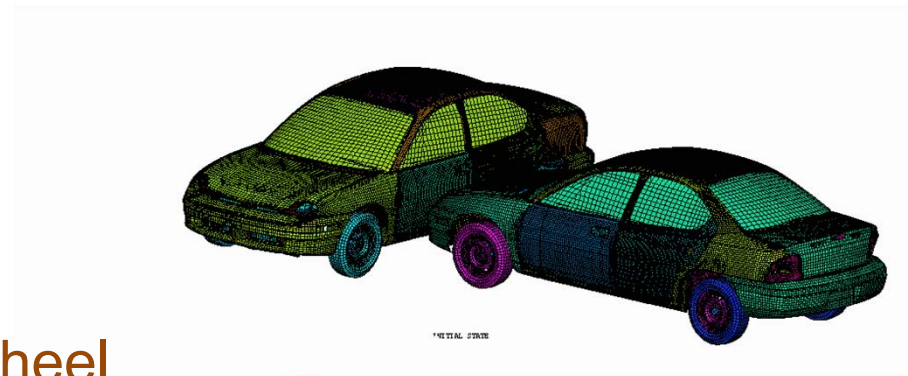
- A 20cm x 20cm ensemble gives **32 Million elements**

# Ultimate goal: be predictive at the system level

EC project HUMOS demonstrator of real car crashes

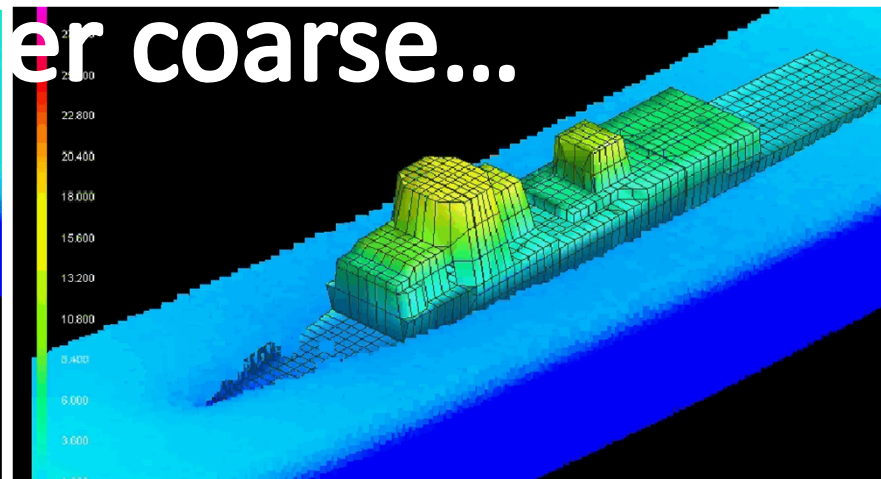
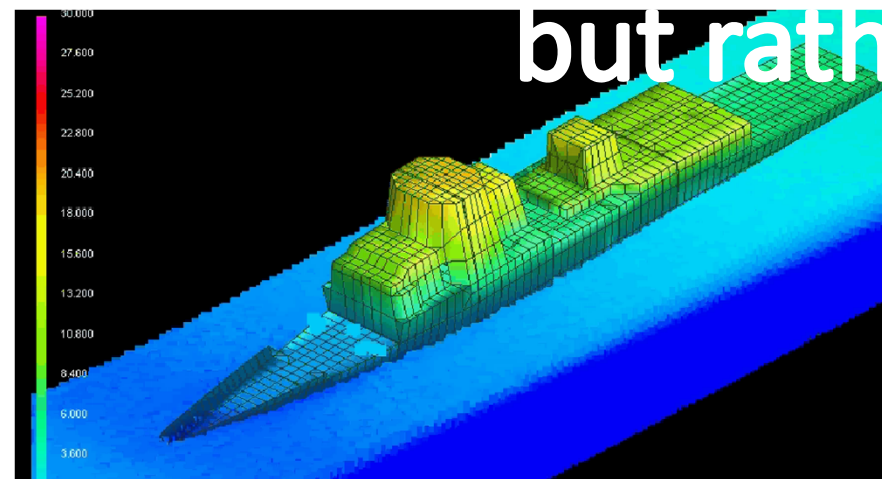
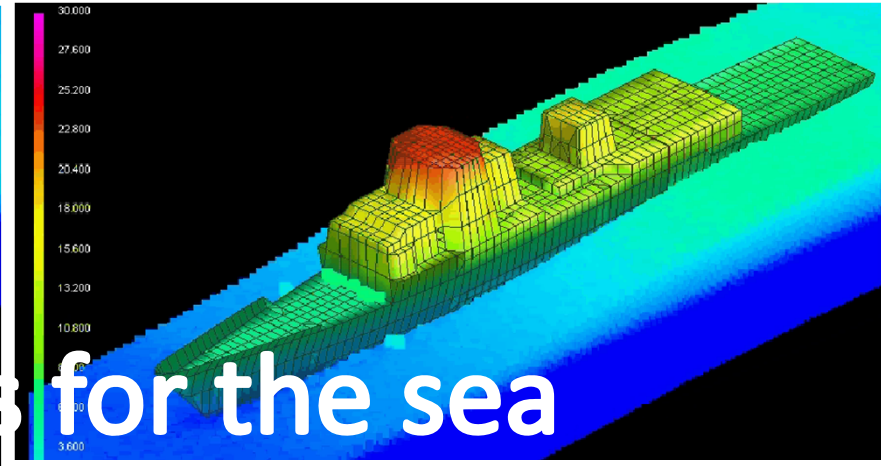
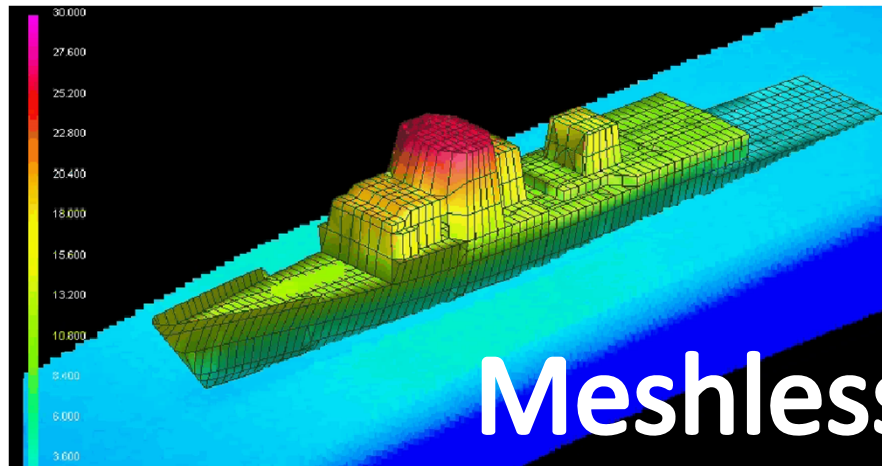


- Bullet car speed = 48 km/h
- Target car speed = 24 km/h
- HUMOS 50% male model:
  - Driver of target car
  - Hands attached on steering wheel
  - Right foot on breaking pedal
  - Left foot on the floor
- Restraint devices: belts
- Injury assessment



# Marine applications are the next frontier

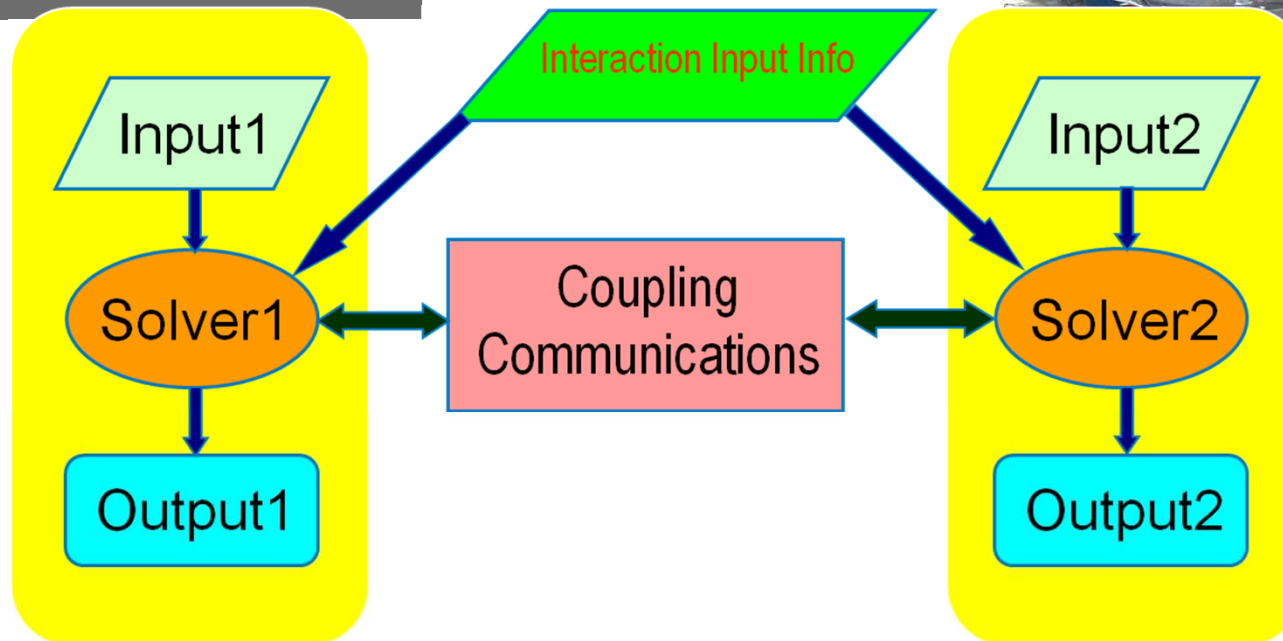
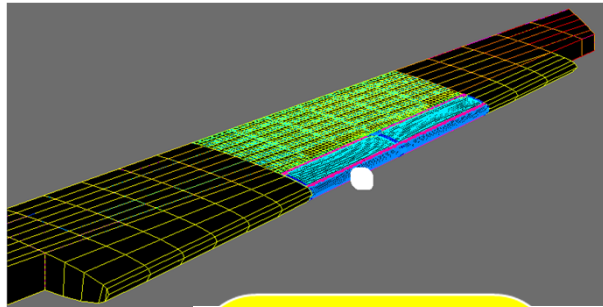
Motion in Waves: Regular head waves of 8 meter height and a wave length of 294 meter



- What are the answers ?
- What needs to be assessed / improved ?



# Multiscale ???



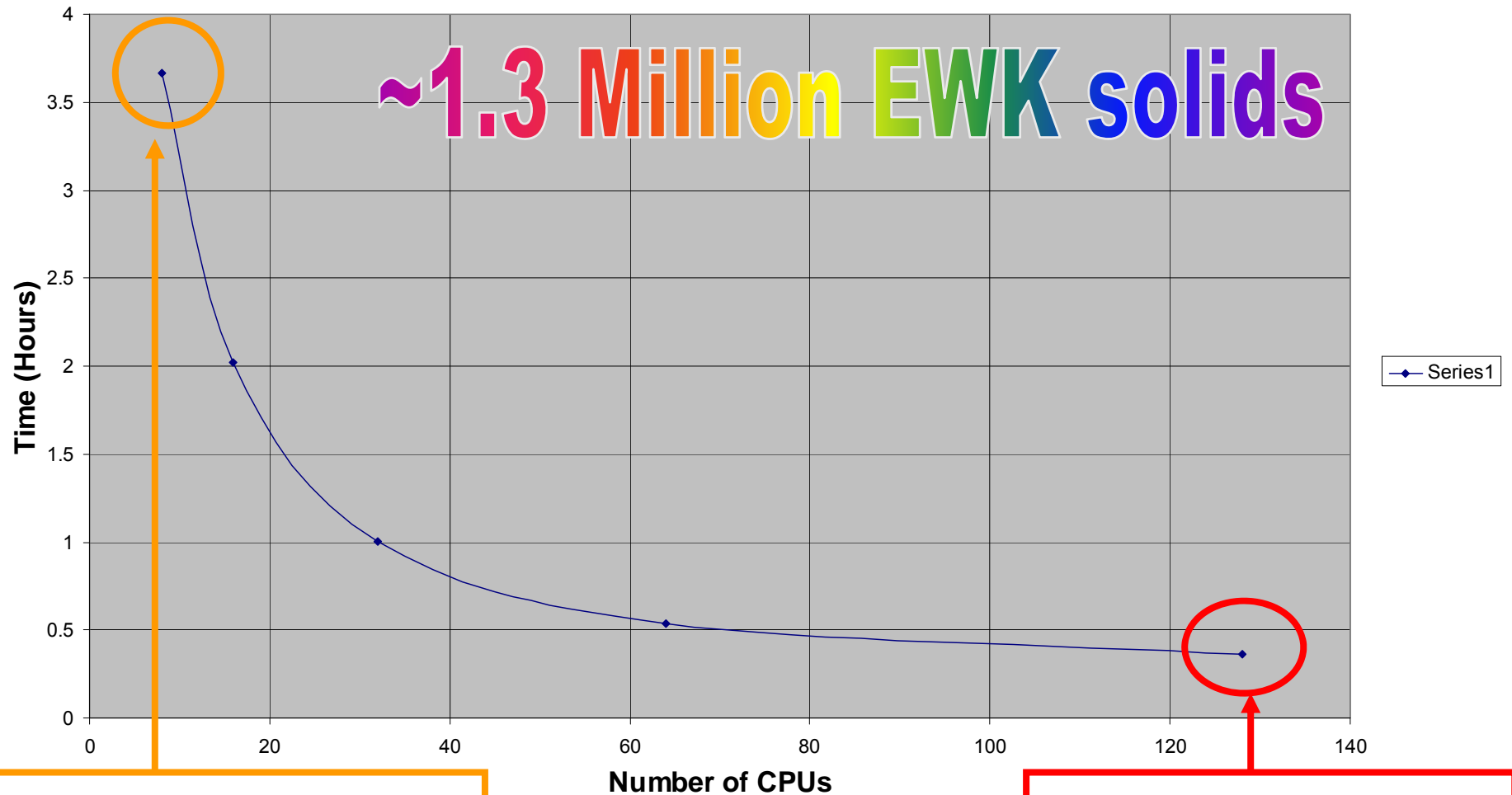
Model 1

32 processes

Model 2

128 processes

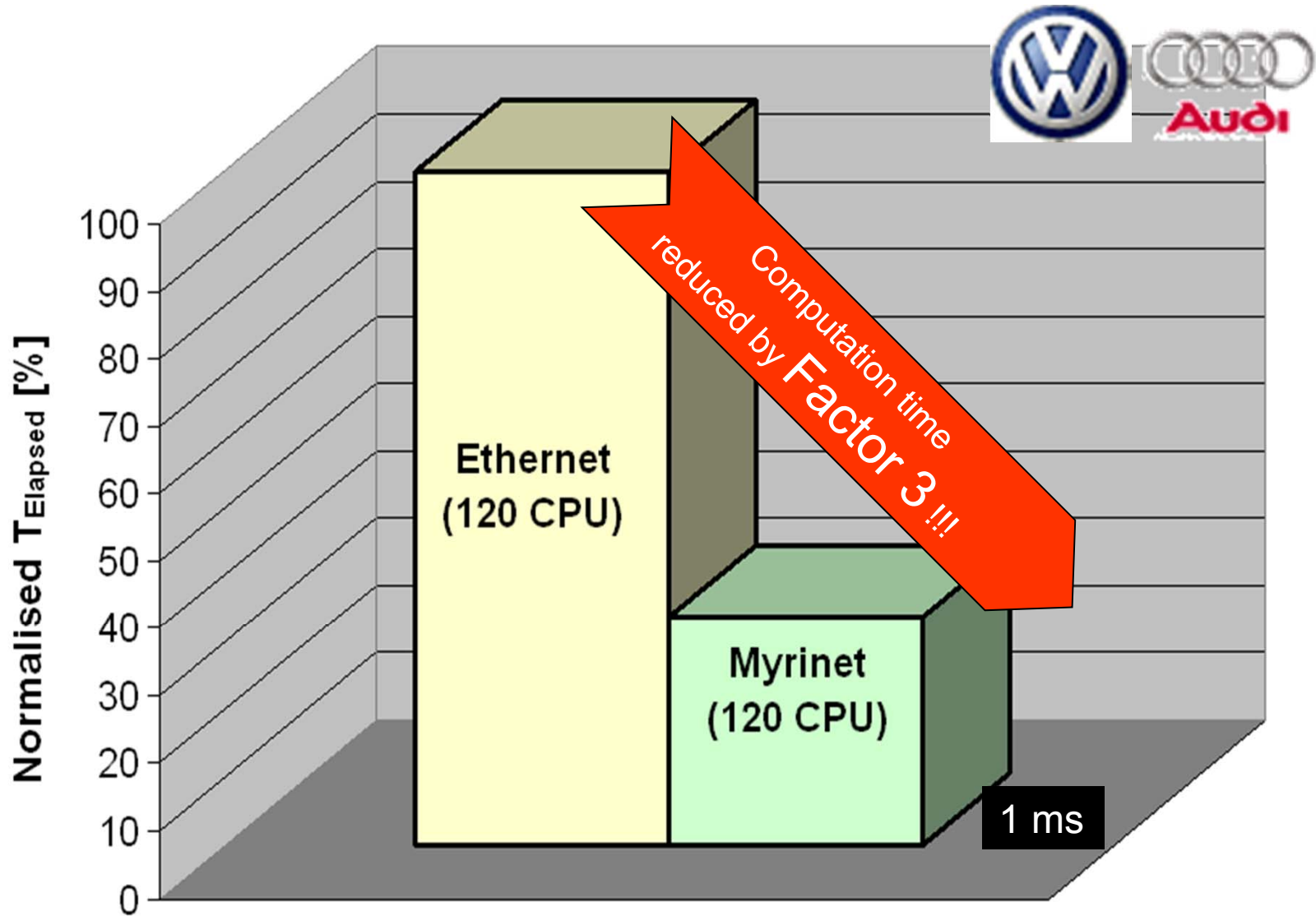
# Parallelisation ??? (DMP etc.)



8 processors : a bit more than 3.5 hours

128 processors : less than half hour

# Infrastructure ???



# GPUs ???

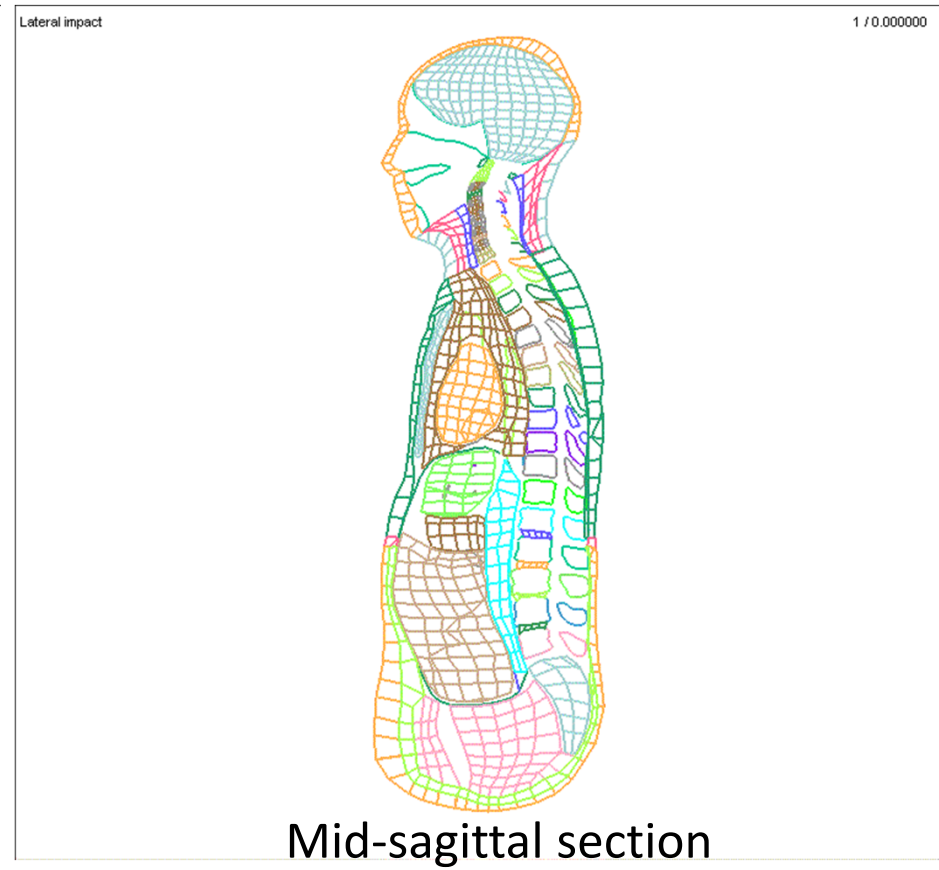
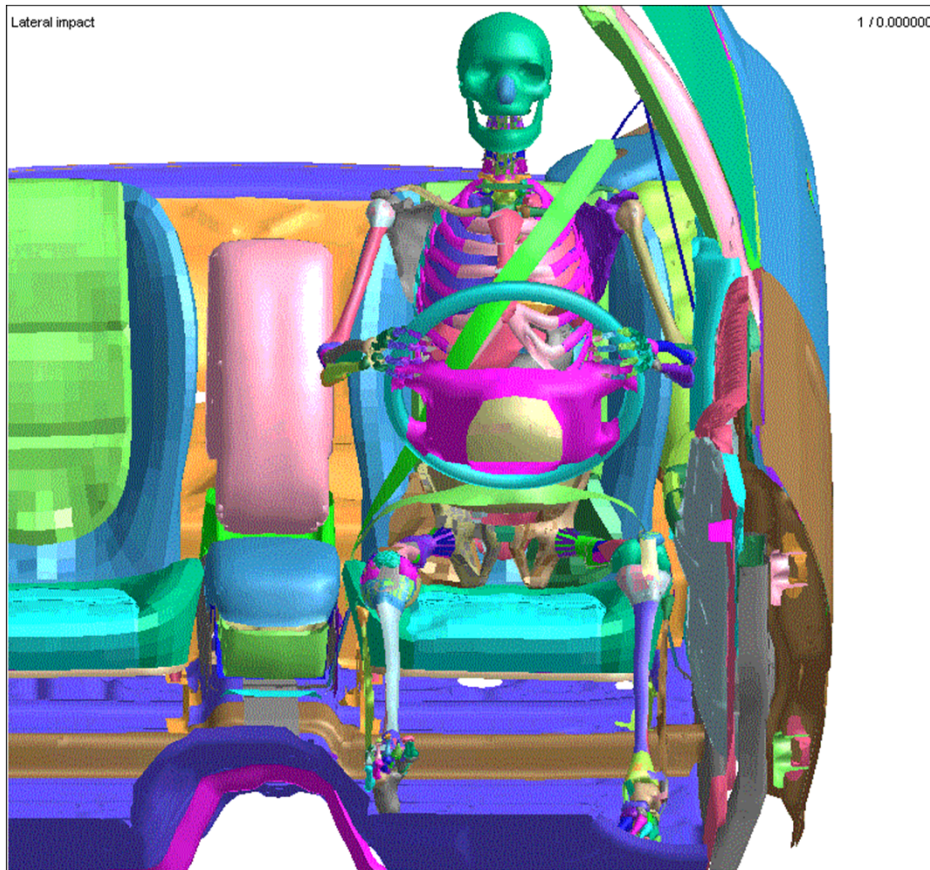
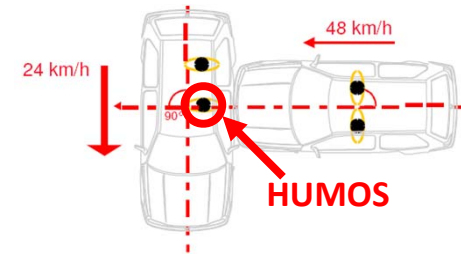
## For FE and meshless !!!

# Methodology ???

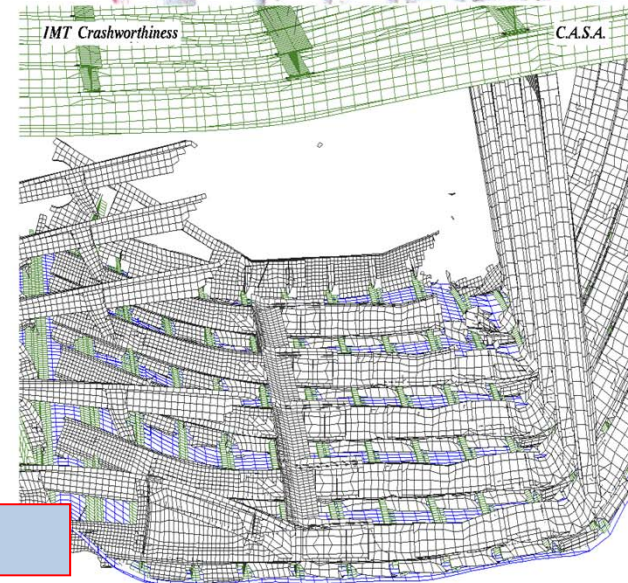
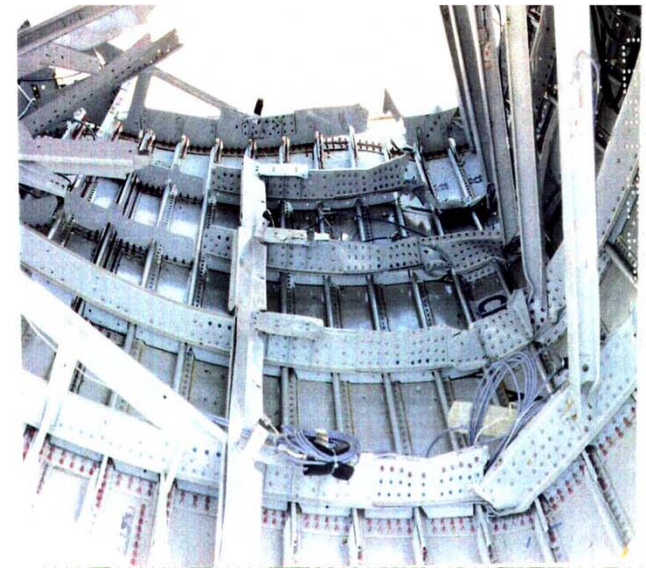
FE versus meshless for fracture  
or  
XFEM  
etc.

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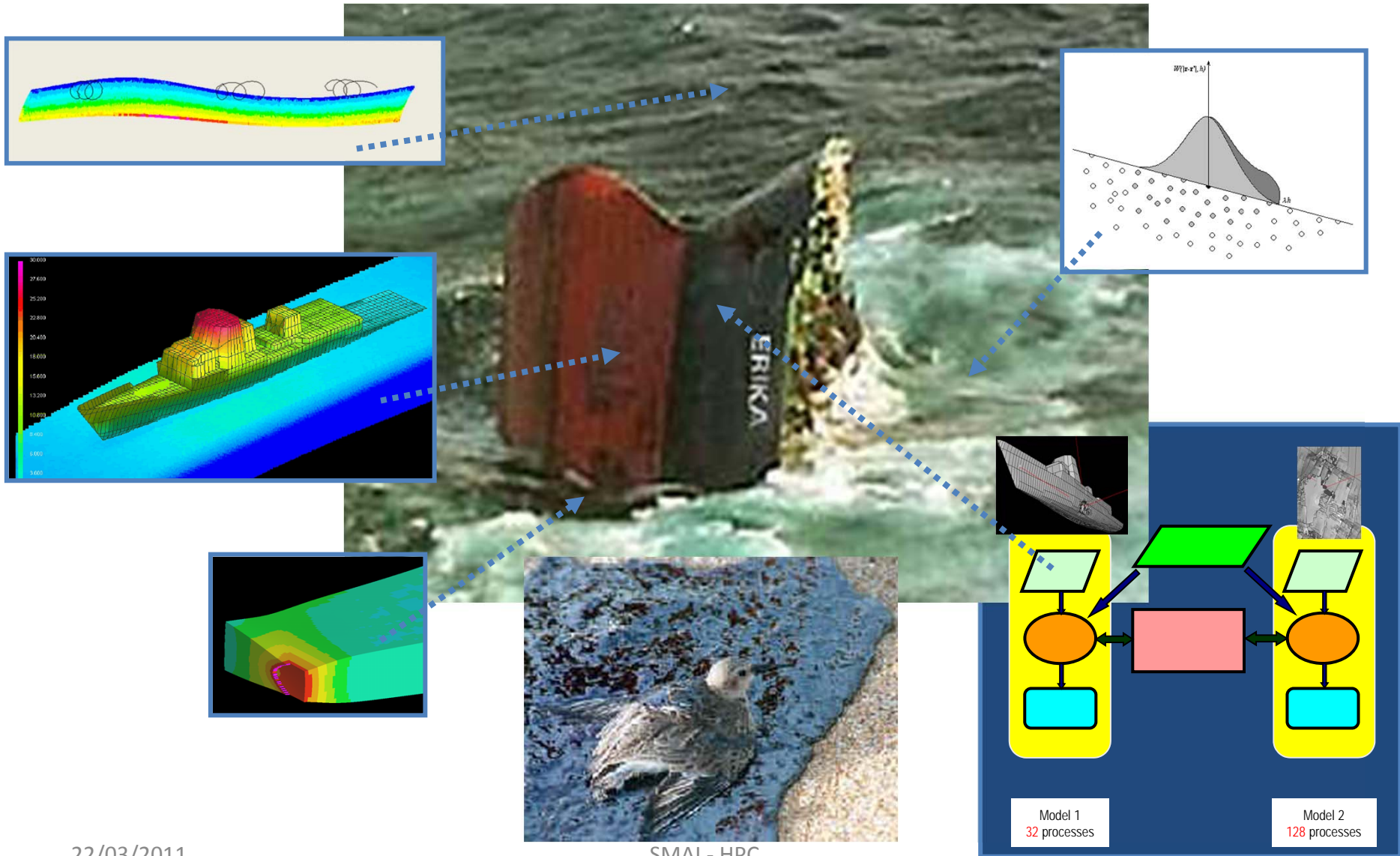


# Towards virtual prototyping at large scale ...



Courtesy of EADS-CASA

# ...and "full system" predictability



22/03/2011

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**Merci !!!**