# An Innovative Approach To Bonnet Design For Pedestrian Safety

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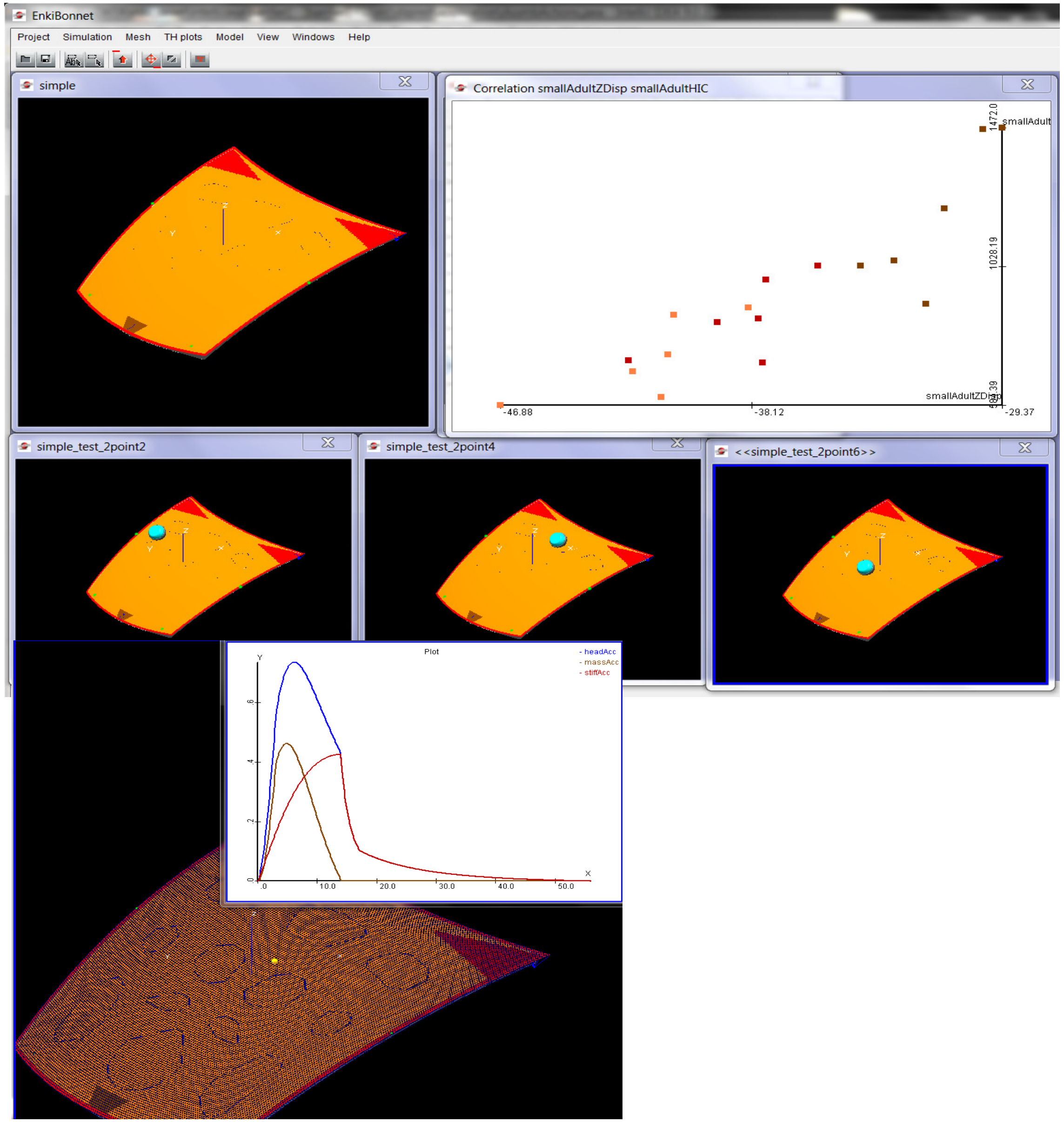
- Background
- Bonnet design as a MDO problem
- Wave propagation in head on bonnet impact
- Head acceleration analysis and prediction
- Software design implementation

# SimTech-SIMULATION ET TECHNOLOGIE

- Founded 1993
- Staff : 2 PhD
  - Princeton University (USA)
  - PhysTech (Russia)
- Focus: Research, Development, Innovation
  - Optimization
  - Specific software development using our ENKIDOU® library
  - Advanced engineering
- Member of SYSTEMATIC PARIS REGION SYSTEMS & ICT CLUSTER

# WHAT IS EnkiBonnet ?

- Environment for bonnet design in multi disciplinary environment
- Based on LSDYNA and NASTRAN solvers
- Easy extension to RADIOSS, PAMCRASH, …
- Belongs to the family of ENKIDOU applications
- Integrates head acceleration prediction features



# EnkiBonnet

## DESIGN =SIMULATION + OPTIMIZATION

GEOMETRY
DEFINITION
PARAMETRIZATION

CAE MODEL
AUTOMATIC
GENERATION

DOE RSA
OPTIMIZATION

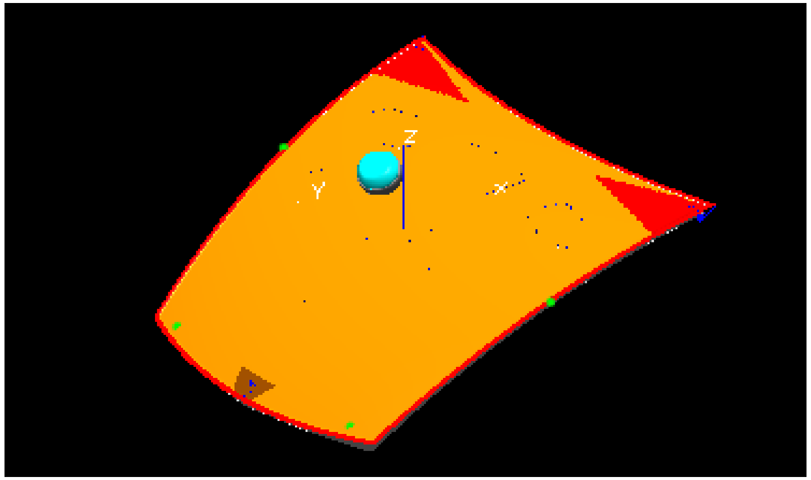
Design cycle takes a few hours
instead of days/weeks

Shorten design cycle
Follow project evolution

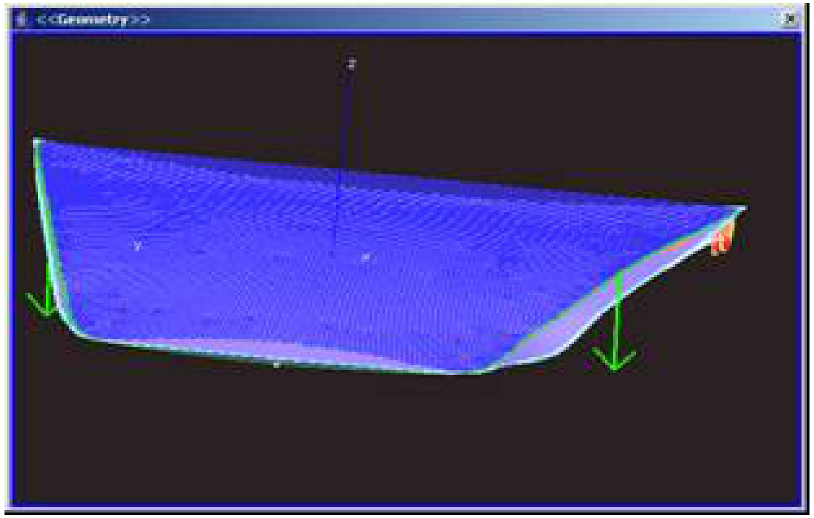
# BONNET DESIGN PROBLEM



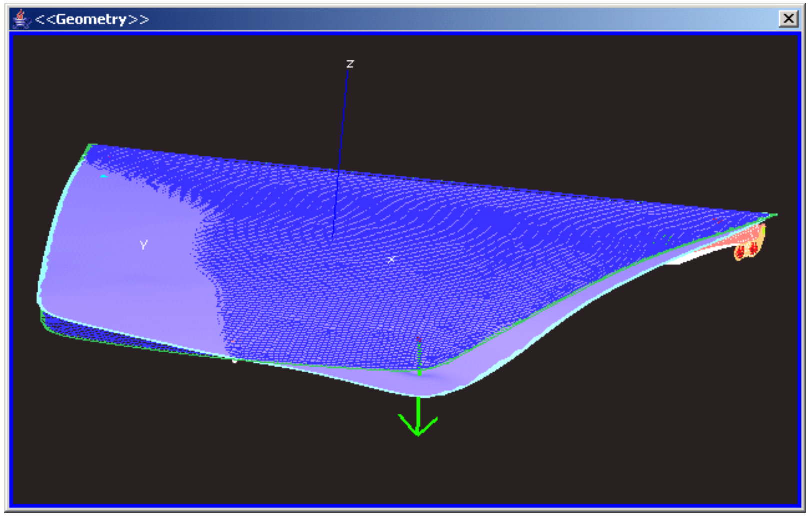
Pedestrian impact loading
Static loading
Denting loading
Snow loading
Aerodynamic loading
Modal vibration frequencies




**flexure load**




**torsion load**



# HEAD IMPACT SEVERITY MEASUREMENT

$$HIC = \max_{t_1, t_2 : 0 < t_2 - t_1 < t_m} \left( (t_2 - t_1) \left( \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t) dt \right)^{2.5} \right)$$

$$\Delta t = t_2 - t_1;$$

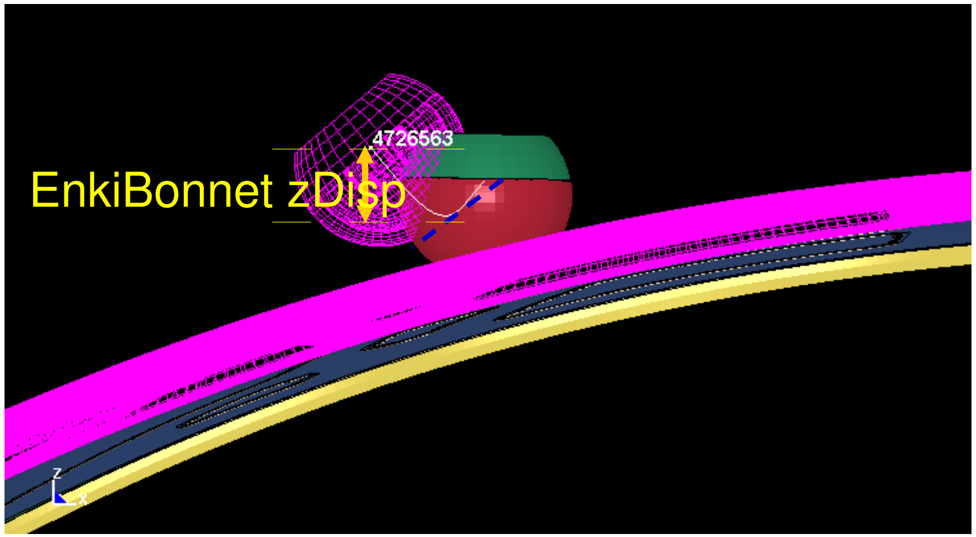
$$t_m = 15 m \sec$$

N.B.: HIC has a dimension:

- acceleration in g
- time in seconds

Head stroke: the distance traveled before motion is reversed

It is important with respect to secondary impact against hard underlying components

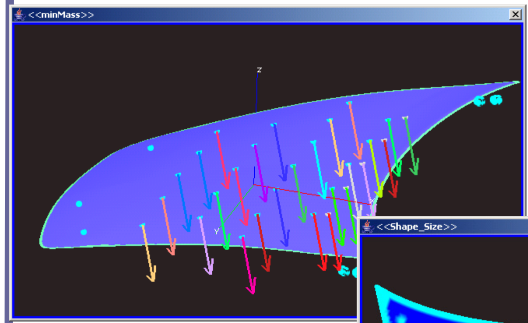


# WHAT IS AN OPTIMAL INNER PANEL ?

- The usual definition of the optimal inner panel is the panel which has the minimal mass while respecting all the constraints (performances)
  - -Pedestrian compatibility
  - -Static stiffness

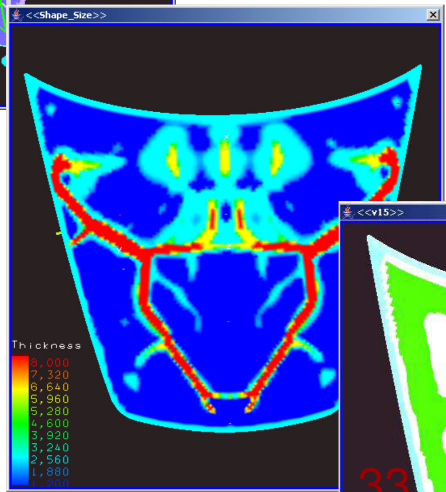
The problem in hood design is that, when we optimize separately the hood for each of these requirement, we get VERY different inner panels

# Sport car bonnet design evolution

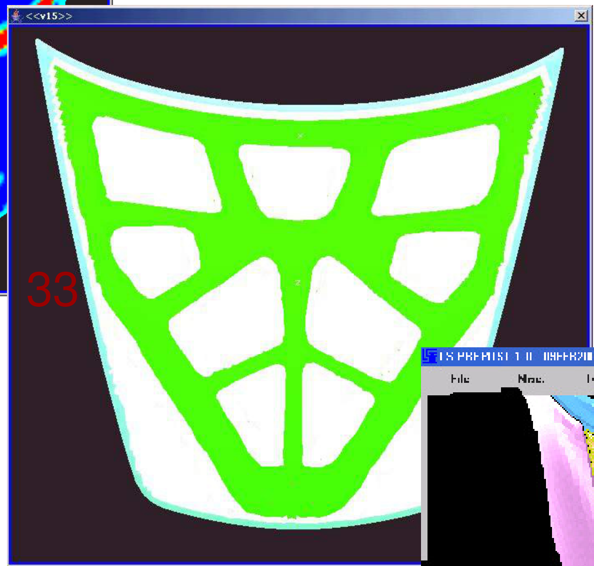


equivalent static
load system

... or, how NOT TO
design a bonnet ...

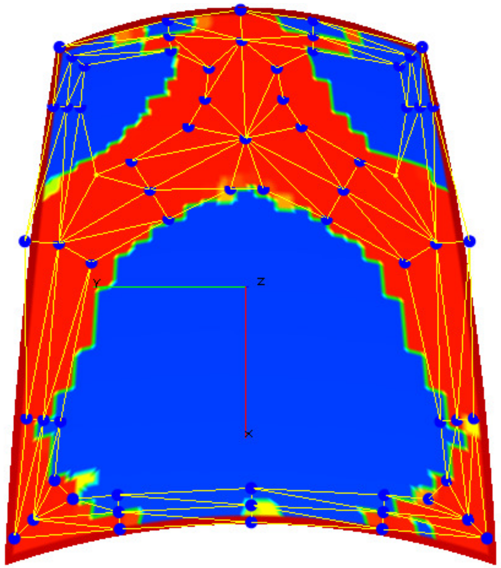



topology
optimization
layout

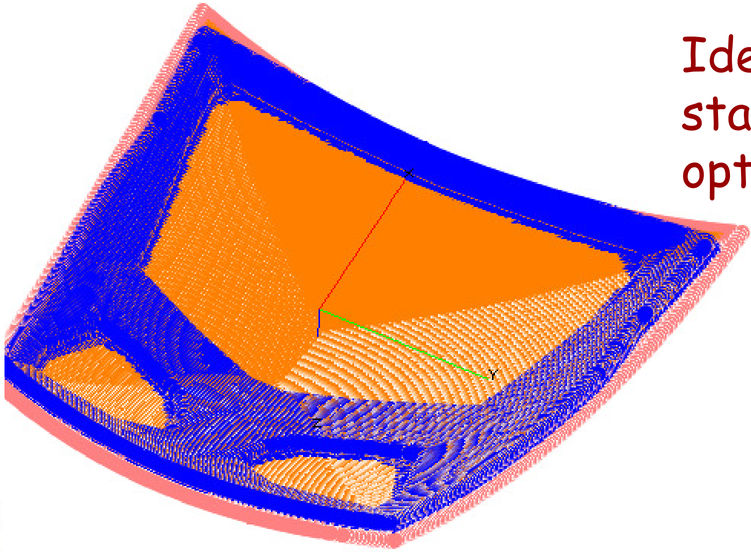



CAE based
inner panel

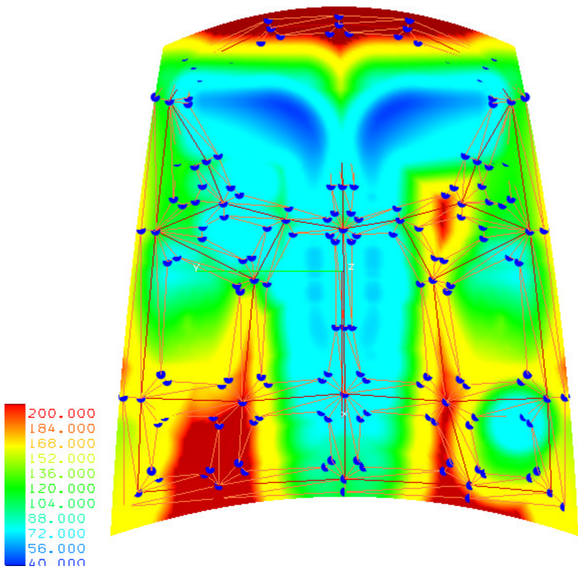
final inner panel
design



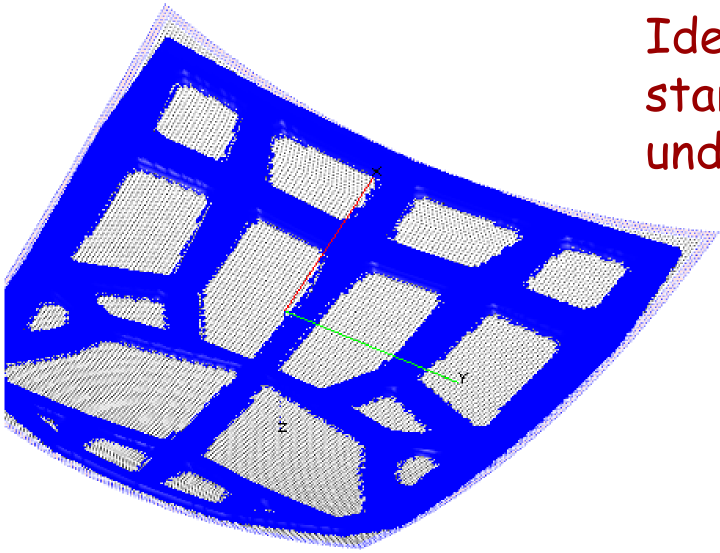
Long, stiff ribs



Ideal static bonnet starts from topology optimization




Short, shallow ribs

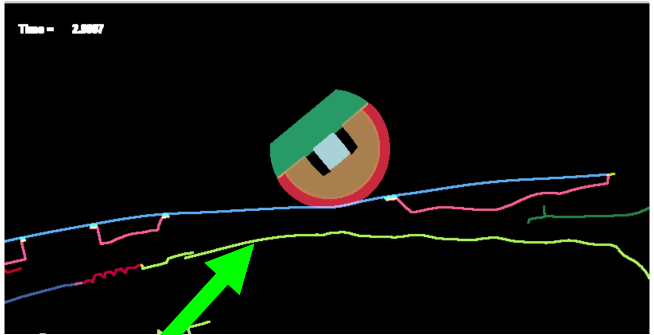


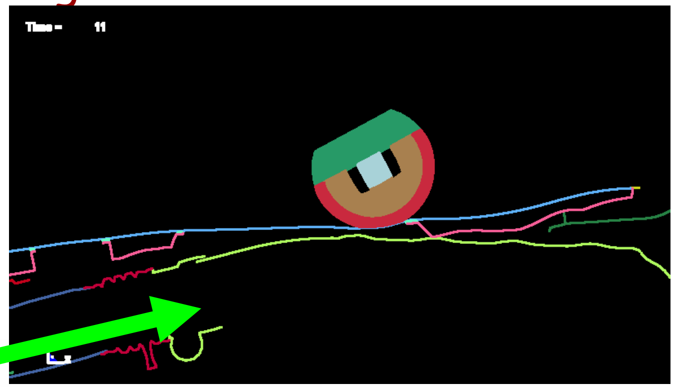
Ideal compliance bonnet starts from map of underlying objects

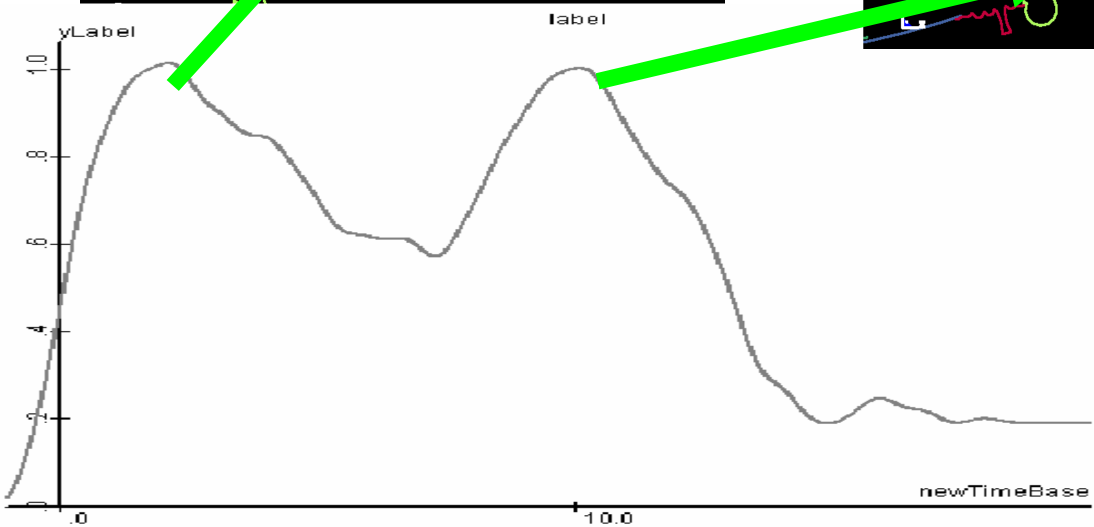
# Understanding the physics

- The shock can be divided in two phases:
  - Inertial phase or free flight: no interaction with the rest of the vehicle. Conservation of moment holds.
  - Secondary impact phase: with supports or with underneath components. Conservation of momentum no longer holds.

The first peak(s) (in free flight) depend(s) ***mostly*** on the geometry and material properties of the bonnet

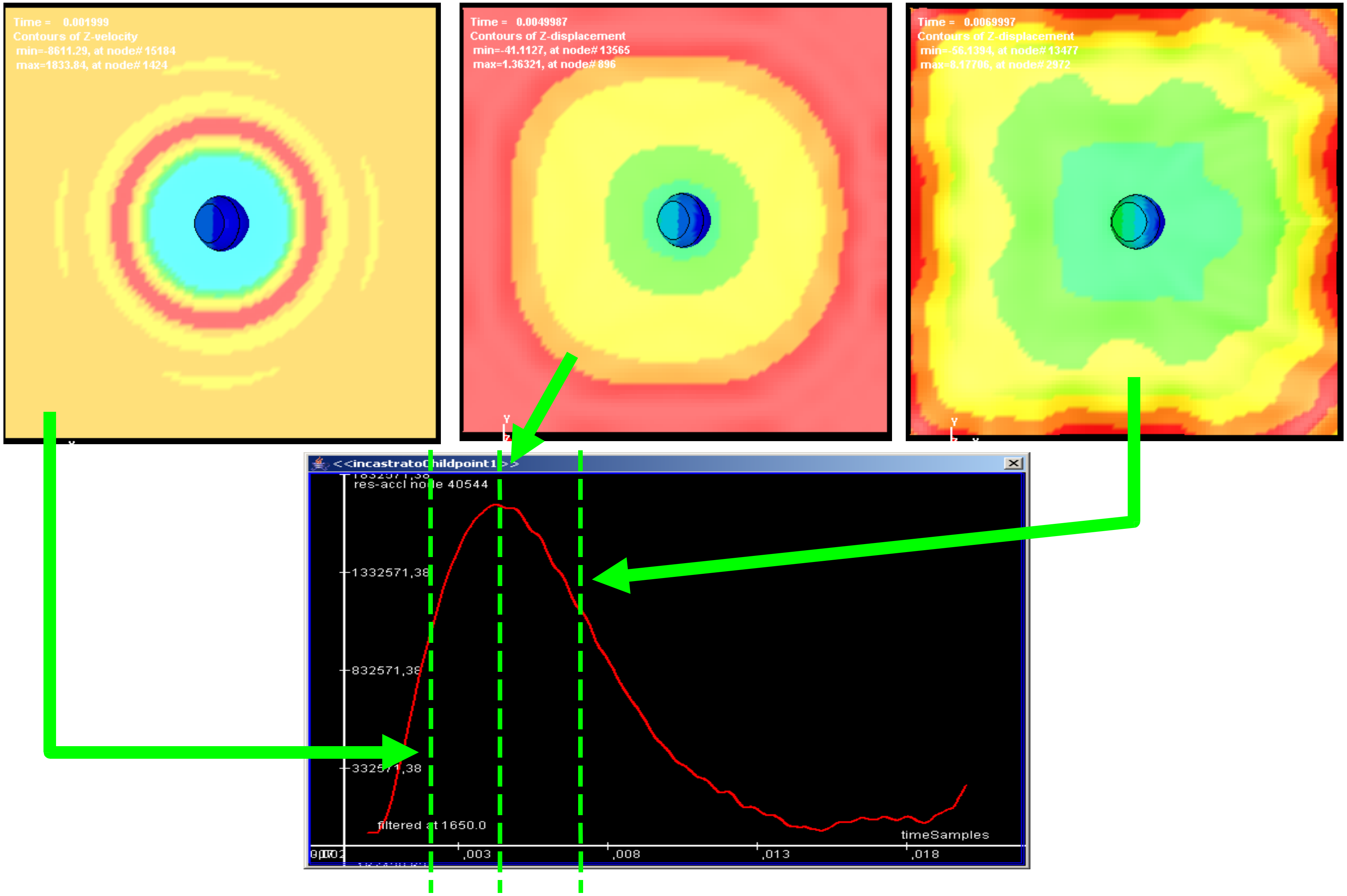




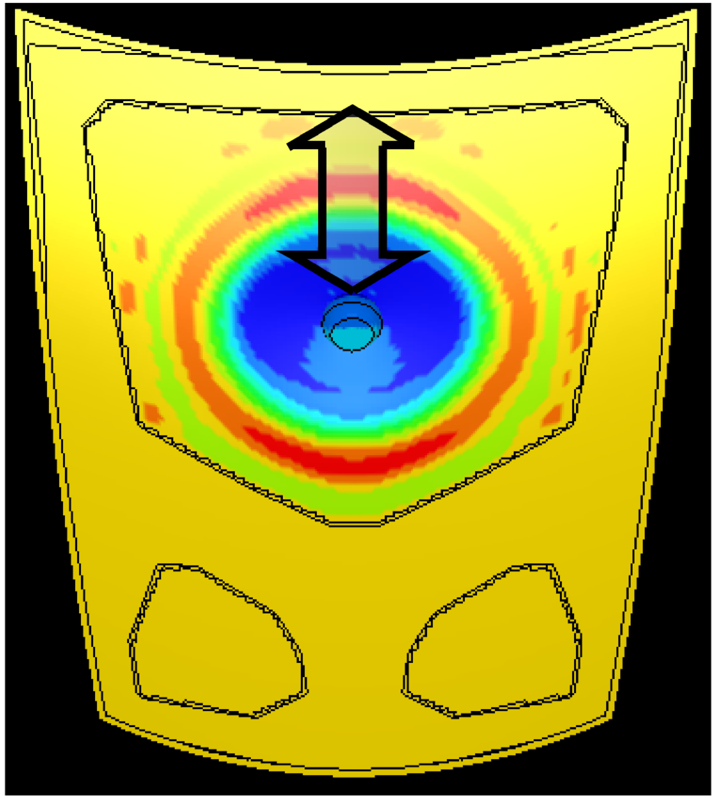


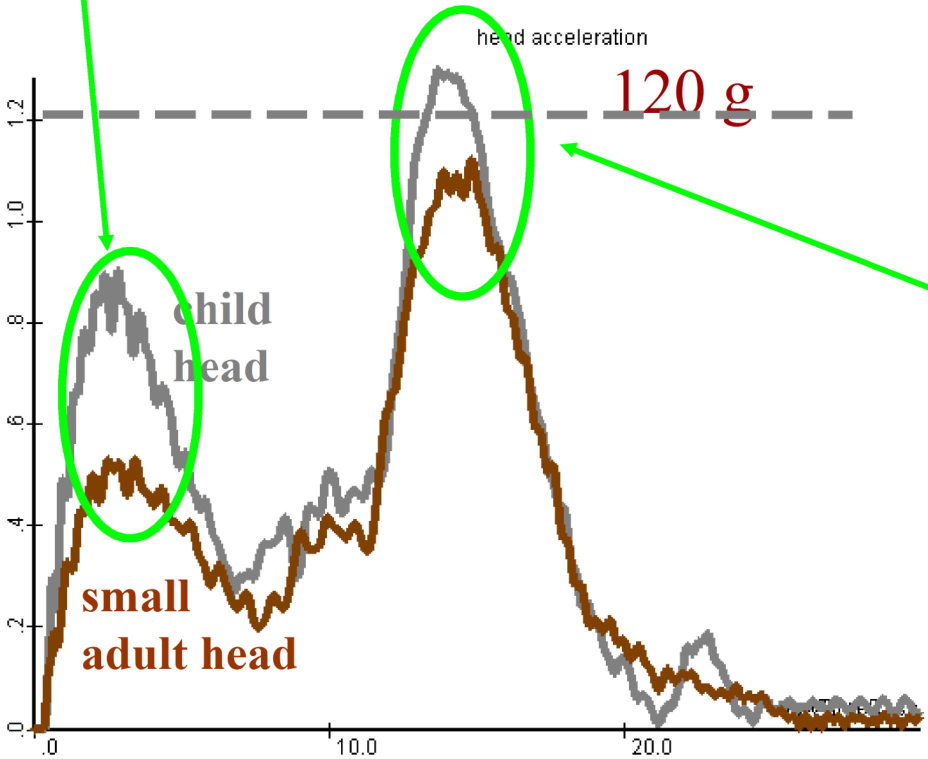

The second peak(s) depend(s) ***mostly*** on the interference with underneath objects and of the energy level at the moment of interaction

# wave propagation controls most of acceleration in the absence of secondary impacts



Wave propagation effects are most apparent with long, stiff ribs, as we find in optimal static inner panels.






Effect of wave reflection is similar to a secondary impact.

# WAVE PROPAGATION AND IMPACT PBS.

## FRONT CRASH

- Event duration: 30 – 50 msecs
- Wave travel time: 1 – 3 msecs
- Pressure waves

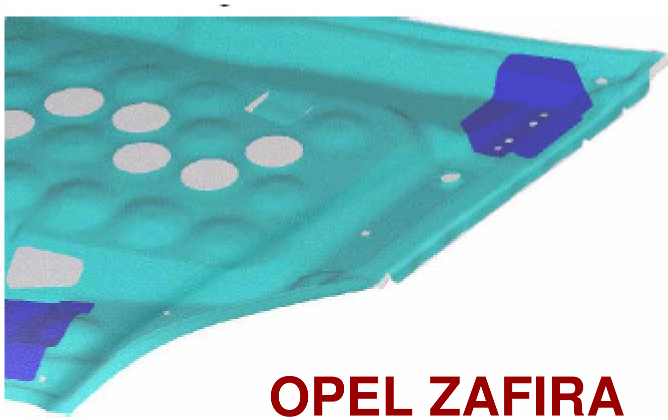
## PEDESTRIAN HEAD IMPACT

- Event duration: 5 - 15 msecs
- Wave travel time: 5 – 15 msecs
- Flexure waves
- Shear and flexure waves in windshields

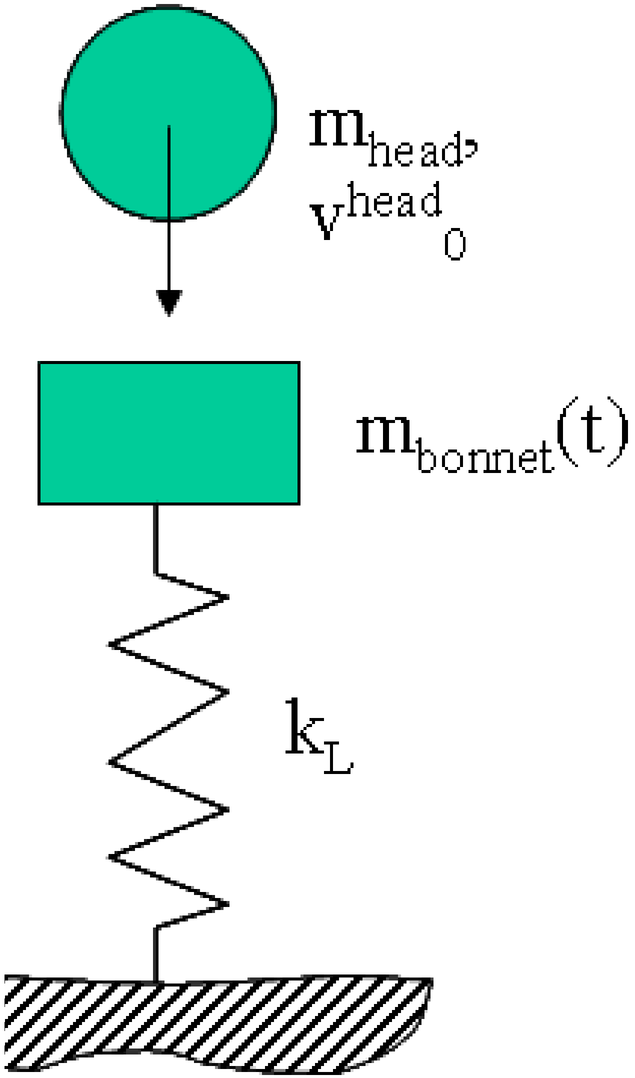
Some inner panel design (photos available on Internet) show the attention to wave propagation requirements.

However, « traditional » design is often preferred for manufacturing and cost reasons.



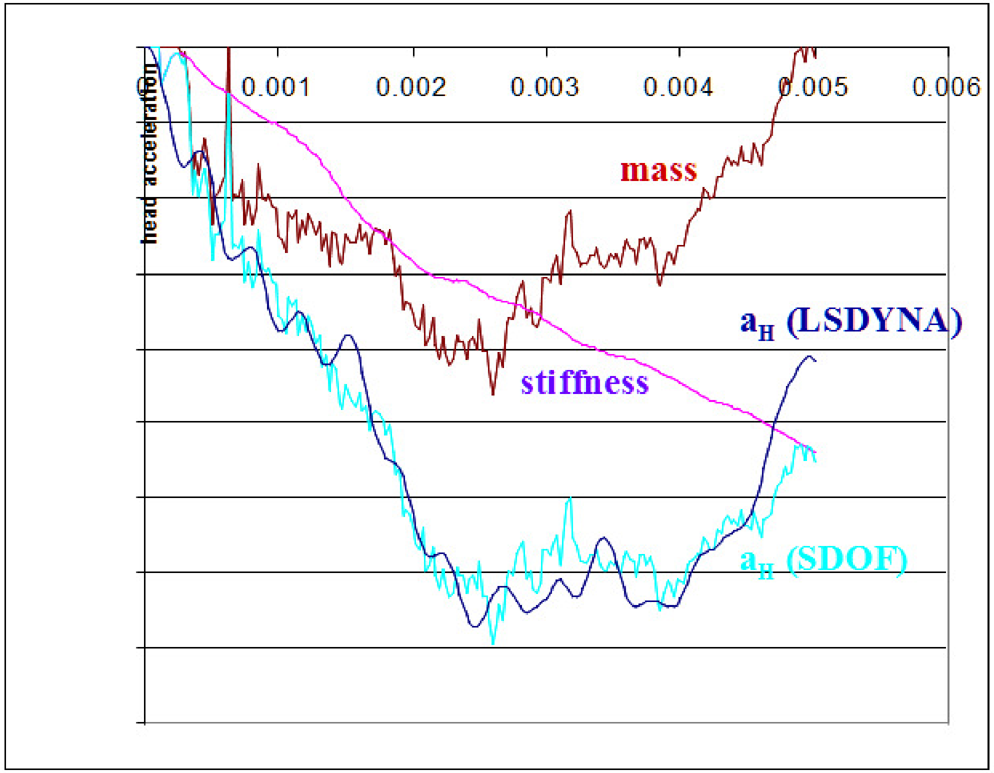


# HEAD IMPACT MODEL FOR FREE FLIGHT PHASE

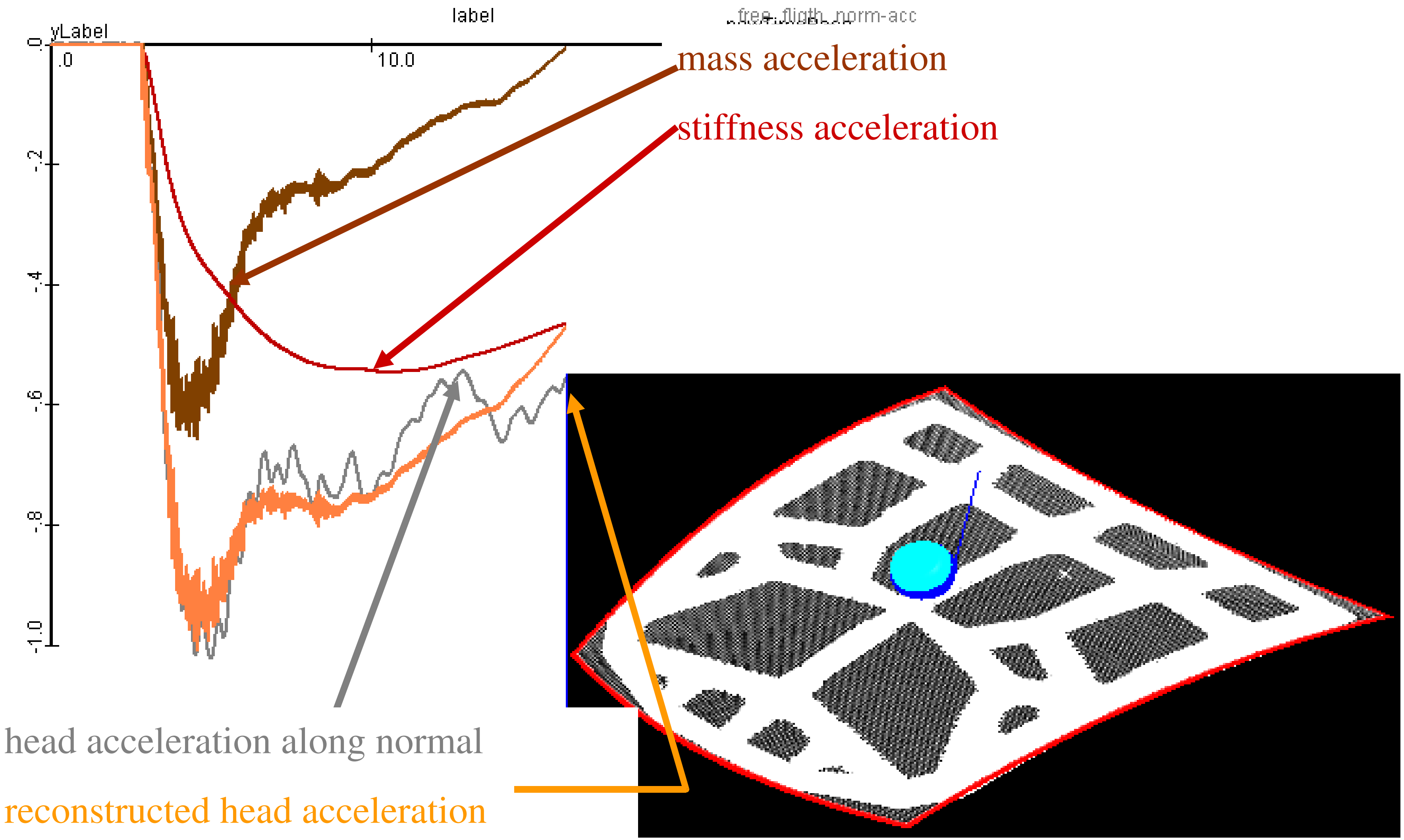



The acceleration is split in two components:

- mass acceleration $a_H^Q$
- stiffness acceleration $a_H^W$



In an effective bonnet, the mass acceleration reaches its maximum and dies out very quickly, while the stiffness acceleration picks up right after it.
Maximum values of the two components are comparable.

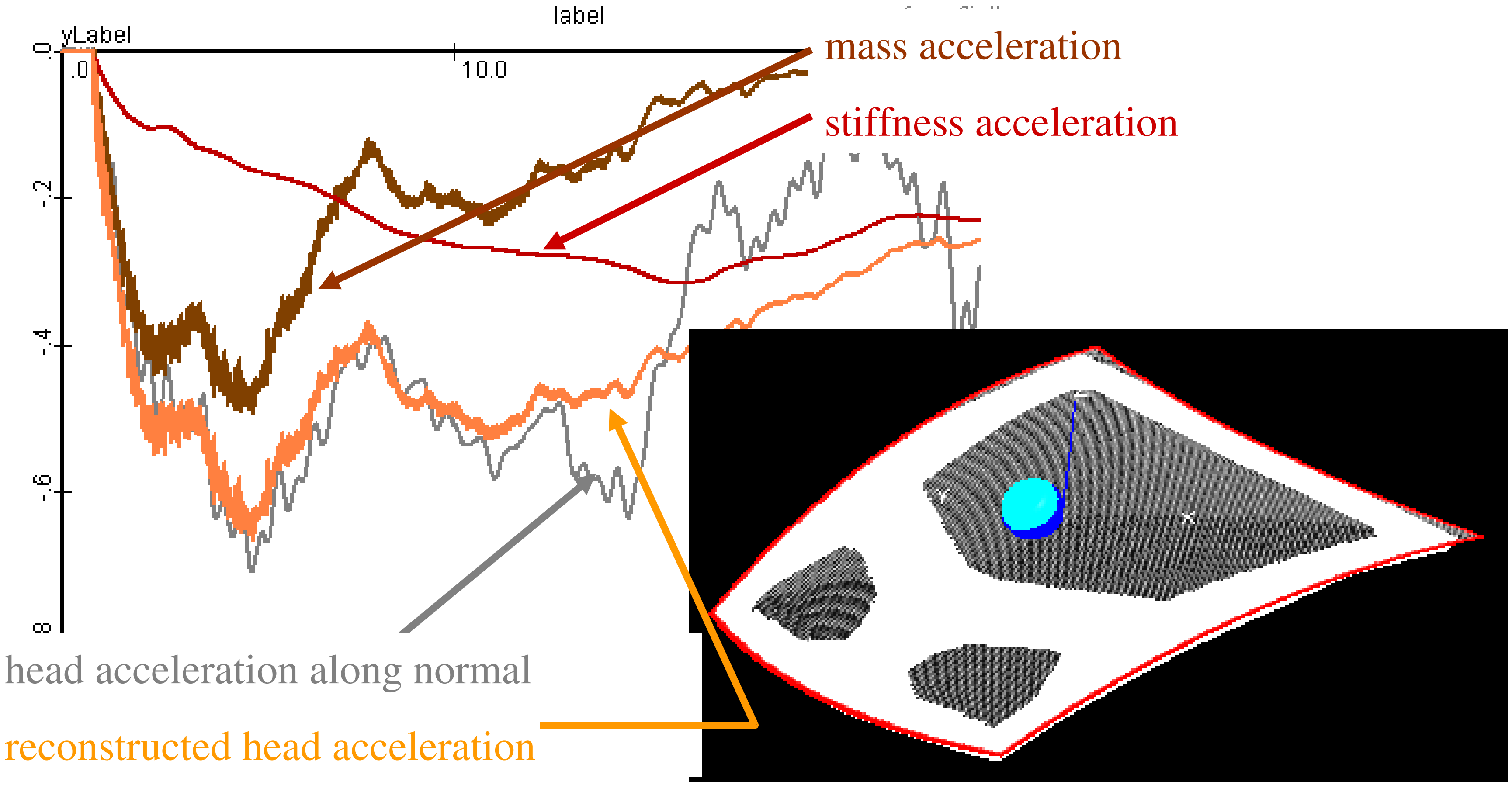


In a soft bonnet, the stiffness acceleration does not pick up after the mass acceleration dies out.

Very often, this leads to high values of stroke and risk of secondary impact.

In a stiff bonnet, the peak of the mass and of the stiffness acceleration occur at the same time.

Very often, this leads to short events and high acceleration values.



# HIC AND STROKE EVALUATION

Simplified model for head impact, estimating acceleration, HIC and head stroke for free flight.

Identifies the mass and stiffness characteristics of the bonnet and reconstructs the acceleration.

Input data:

- Wave shape and speed

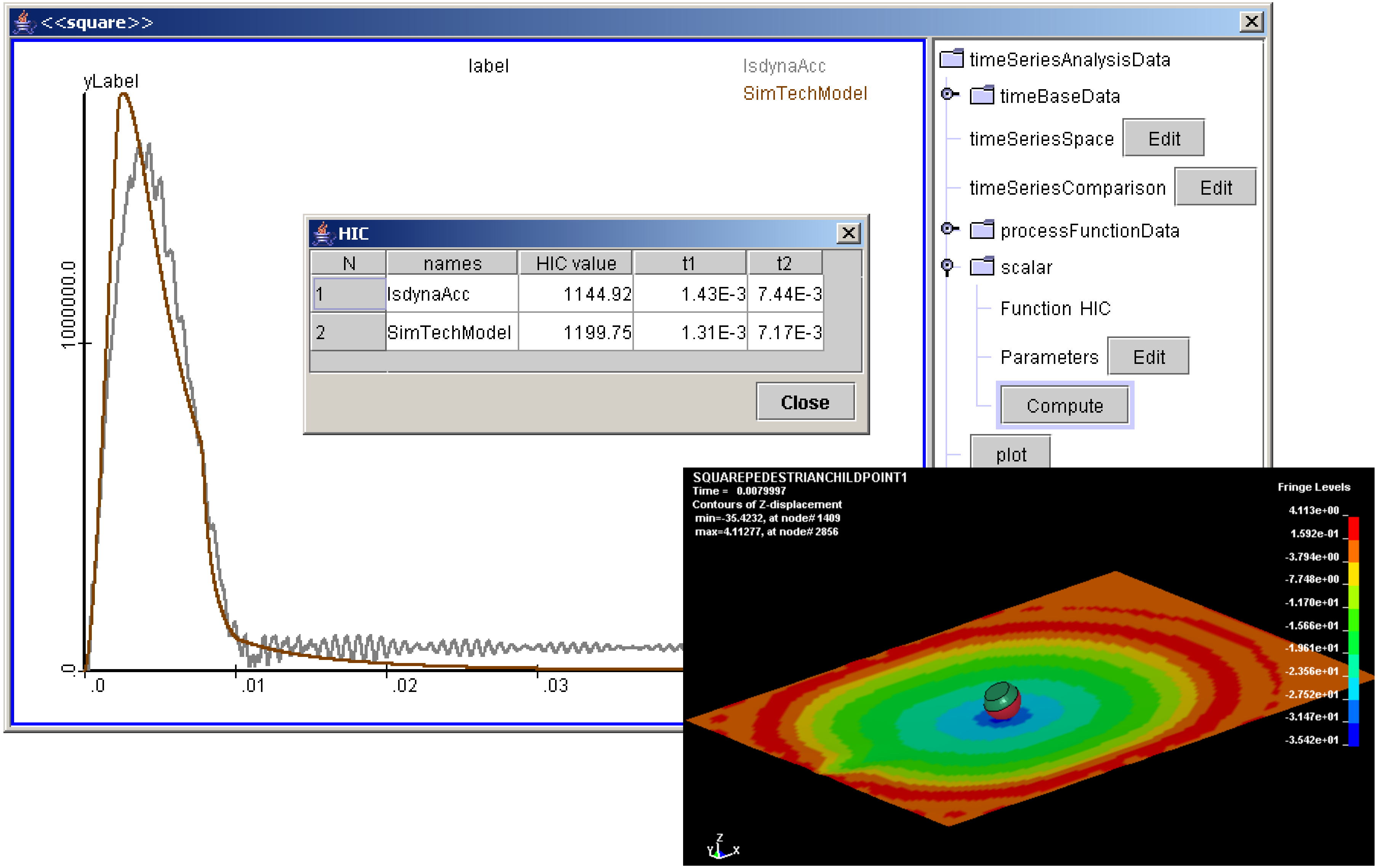
Takes into account:

- Head size, velocity and mass
- Bonnet geometry (outer and inner panel)
- Bonnet thickness and material properties

Does not take into account:

- Secondary impacts
- Hinges, locks, etc ...

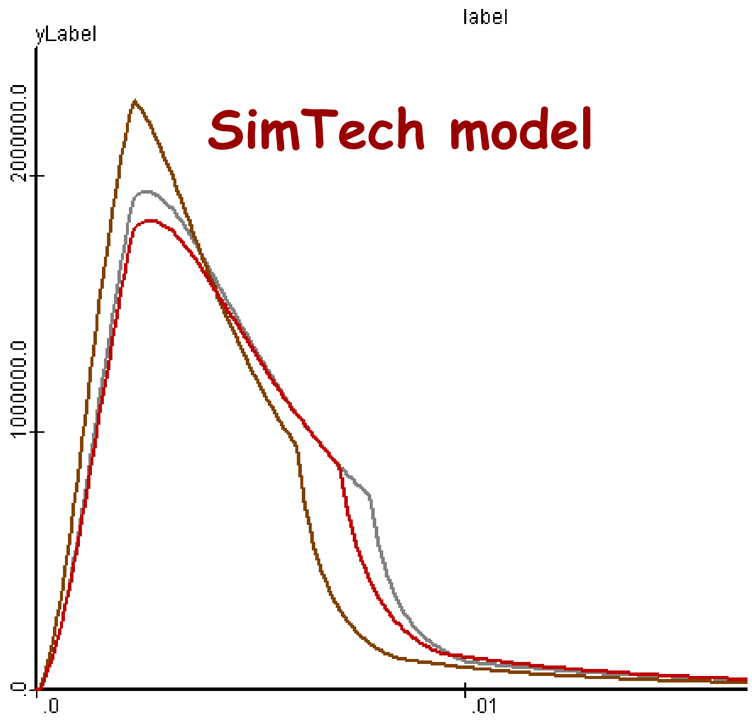
# The simplified model is consistent with LSDYNA results

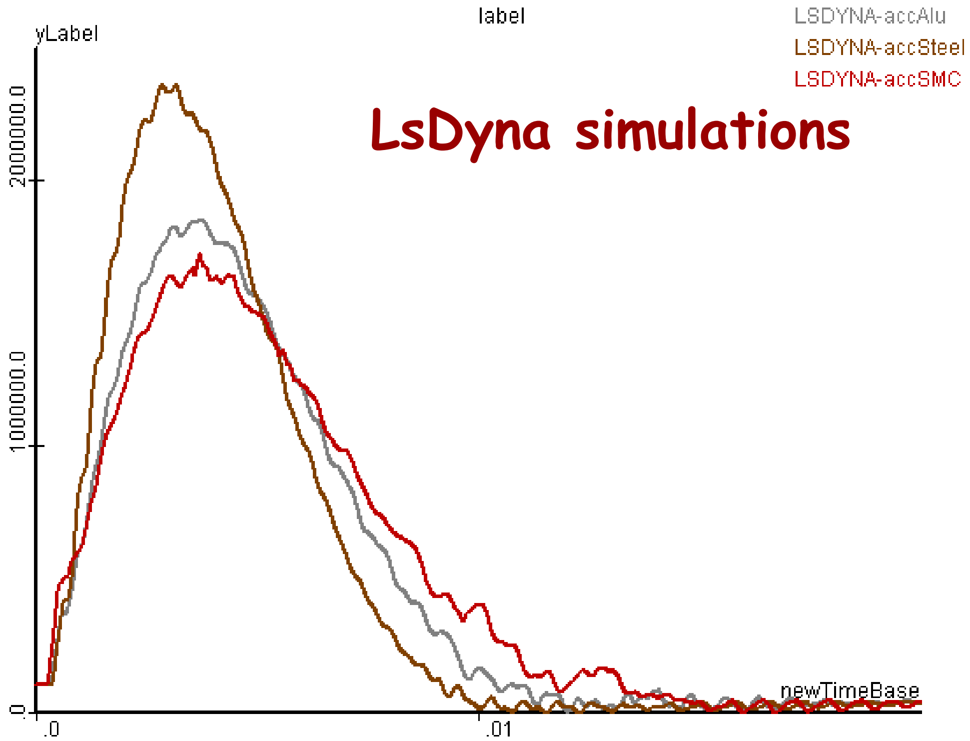


# The model predict different material behavior

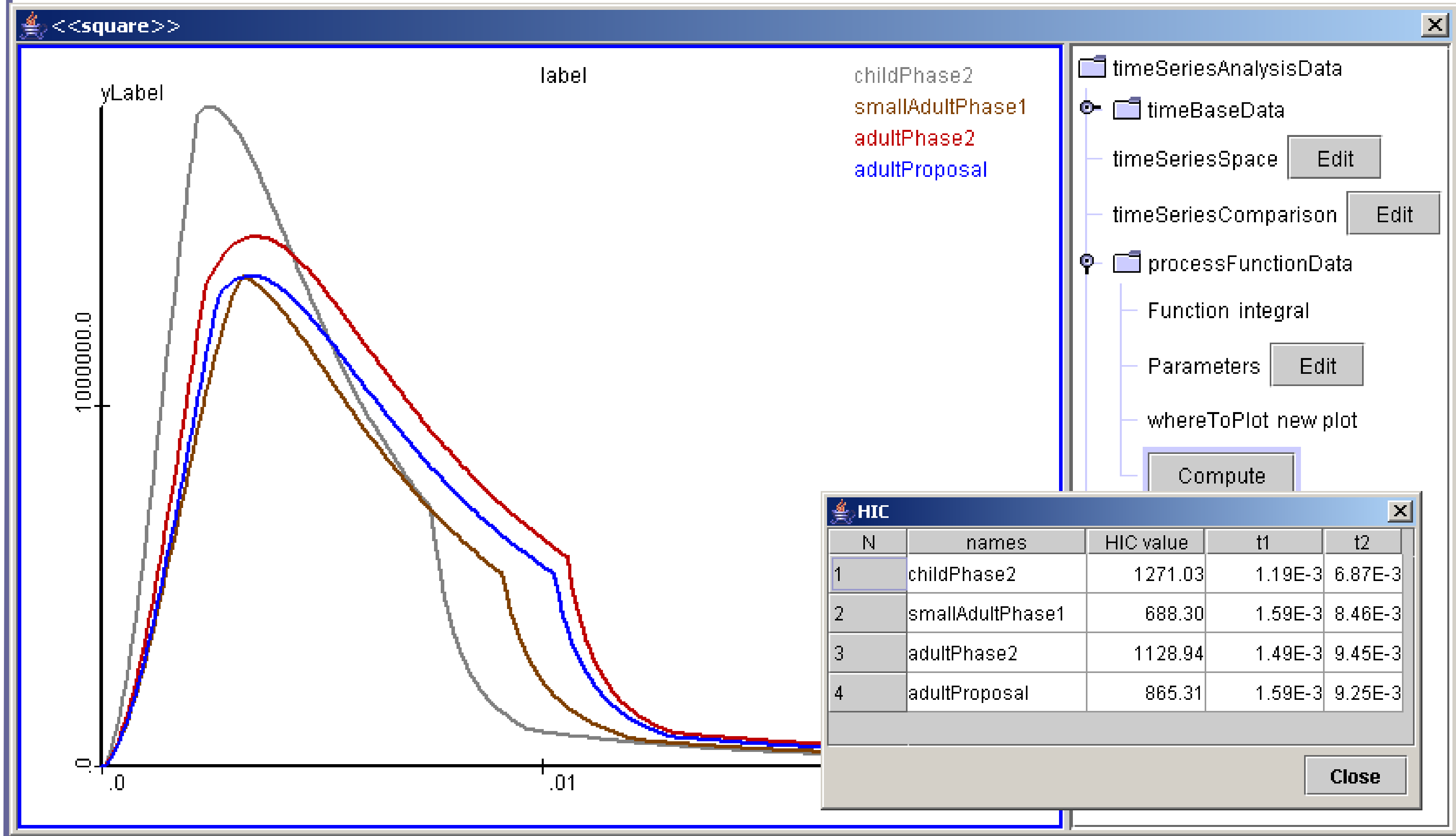
| | Young mod. | thickness | density | Eq. FlexStiff |
|---|---|---|---|---|
| Alu 1.25 mm | 69000 | 1.25 | 2.90E-09 | 107812.5 |
| Steel | 210000 | 0.71651438 | 7.80E-09 | 107812.5 |
| SMC | 14000 | 2.77504826 | 1.80E-09 | 107812.5 |

**Steel and SMC are compared to aluminum for same flexural stiffness**



# The model predict the effect of different impactors and test conditions

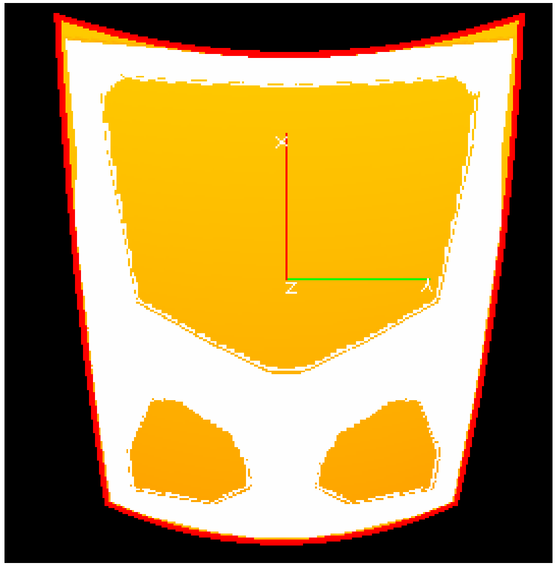


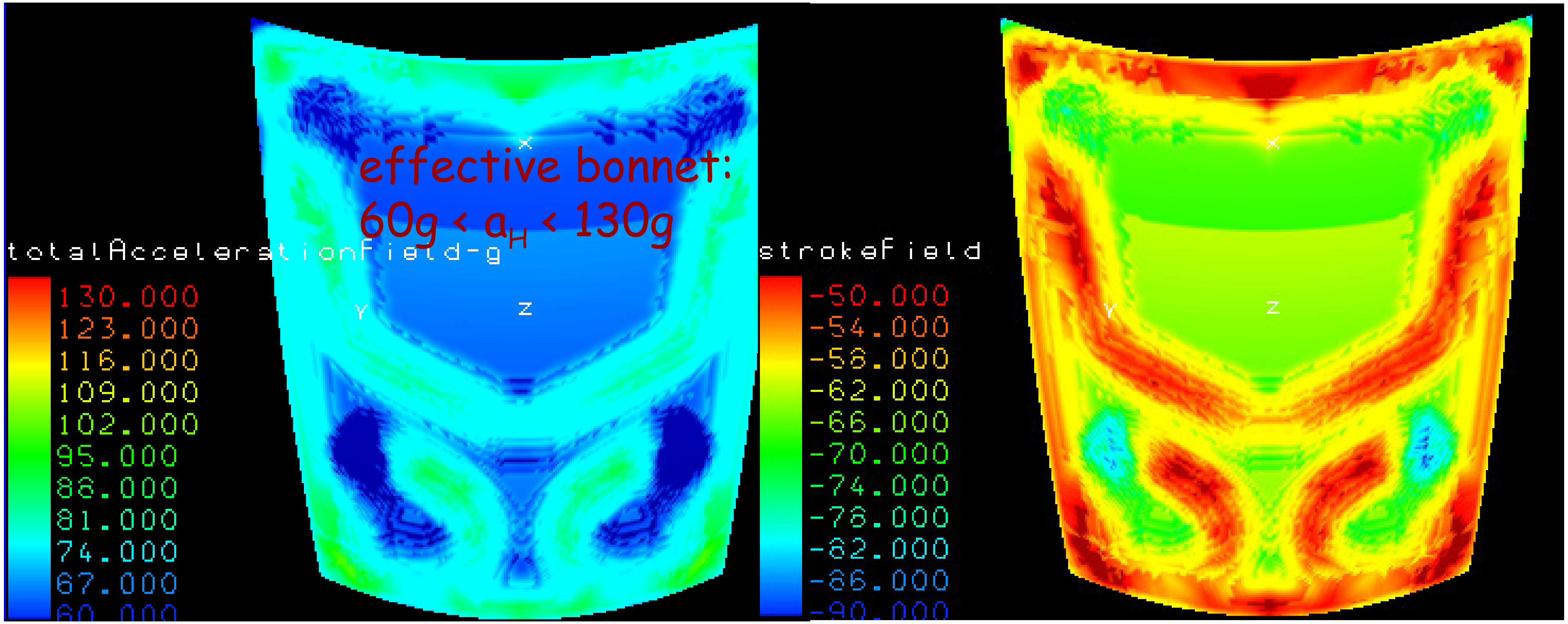
# EnkiBonnet HIC AND STROKE EVALUATION

We study a bonnet based on static stiffness optimal design.

Without running non linear impact simulation, we can see that the bonnet is “weak”:

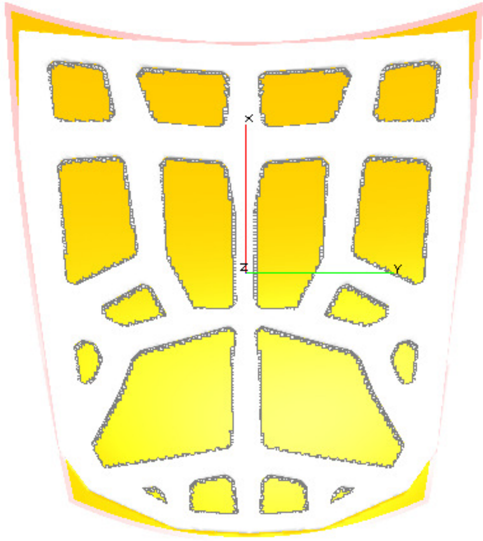
- Low HIC
- High strokes (secondary impacts)





# EnkiBonnet HIC AND STROKE EVALUATION

We study a bonnet based on the minimization of secondary impact (distance from underlying obstacles).



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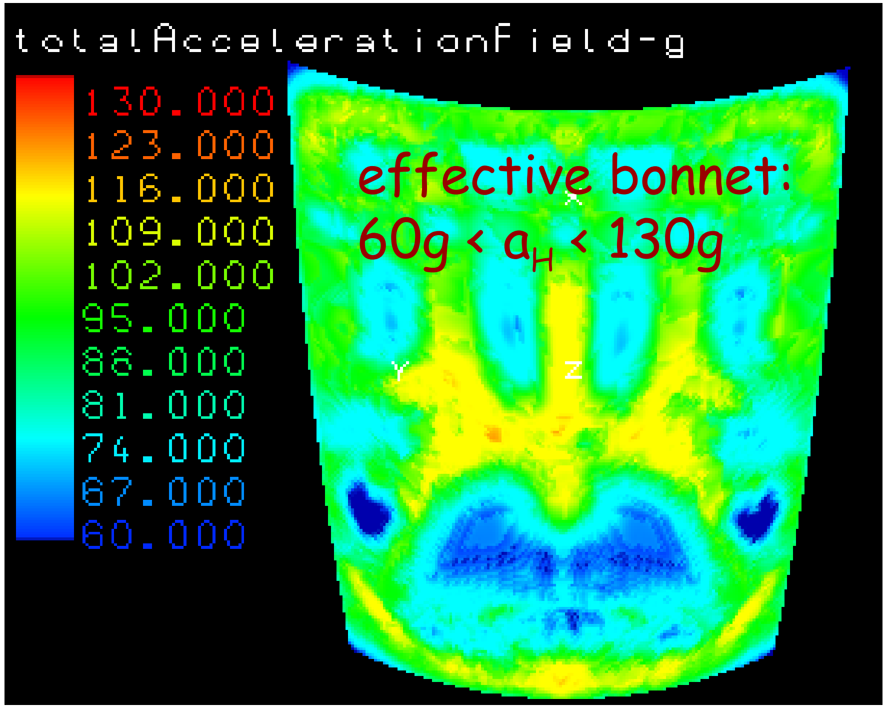
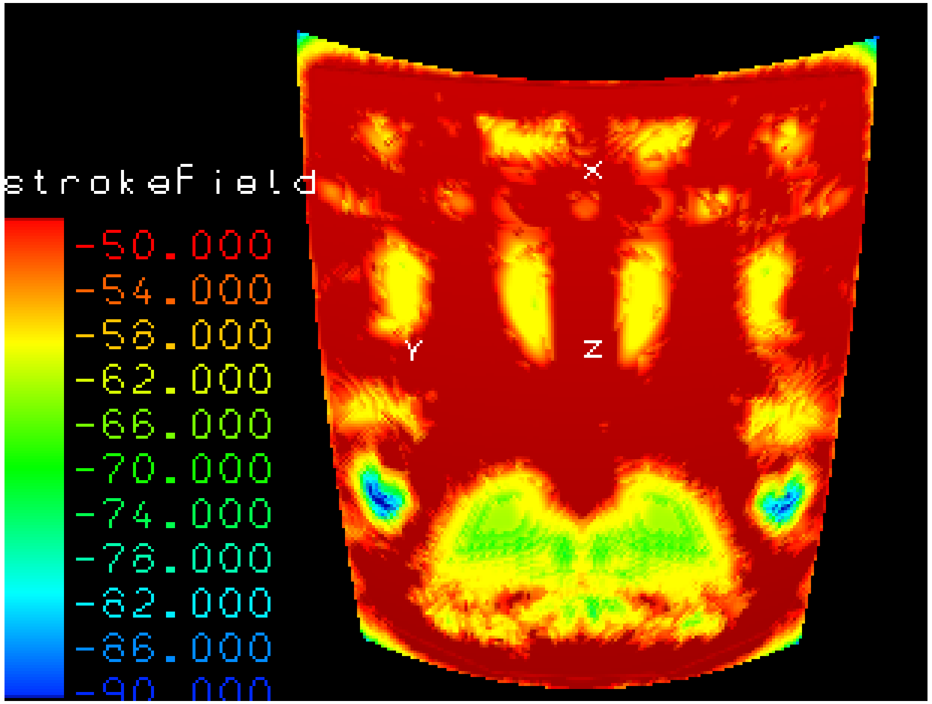
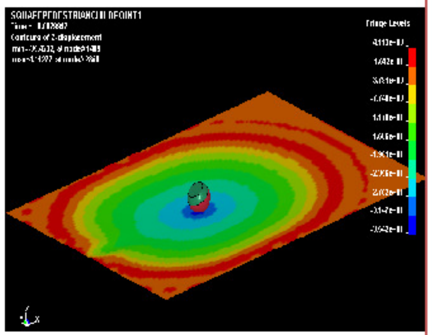
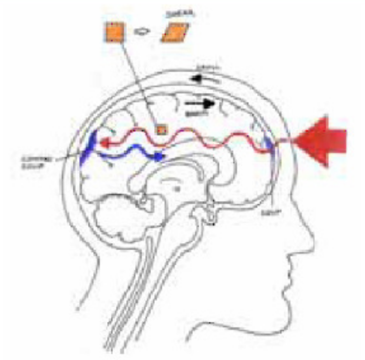
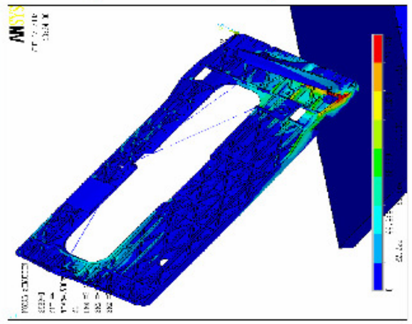


# CONCLUSIONS

- The physics underlying the automotive bonnet design suggests that wave propagation problems should be taken into account.
- This leads to an original methodology for fast and accurate prediction of head acceleration.
- The methodology has been implemented in EnkiBonnet software.
- Any connections ?

| Pedestrian impact | Head concussion | Telephone drop test |
|---|---|---|
|  |  | <br>(Impact Enginnering Solutions) |