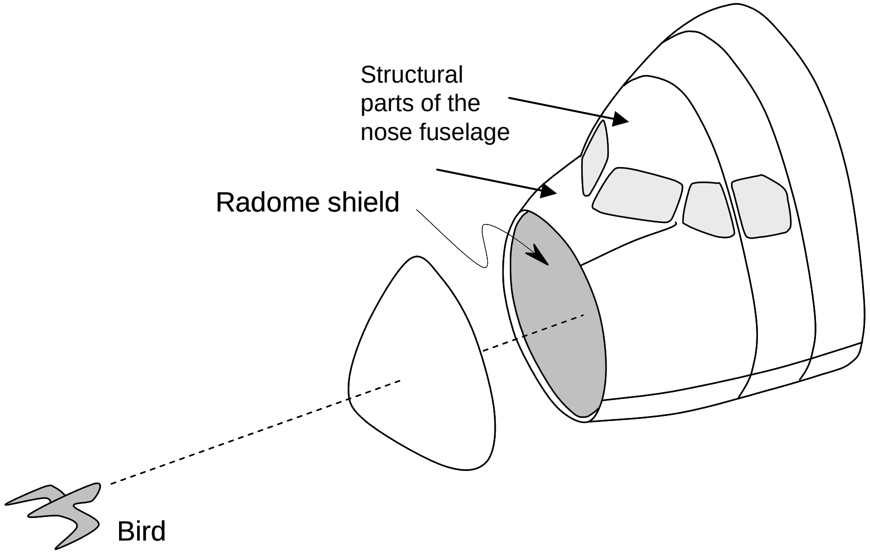
Study of the dynamic behaviour of various cellular materials for aeronautic applications

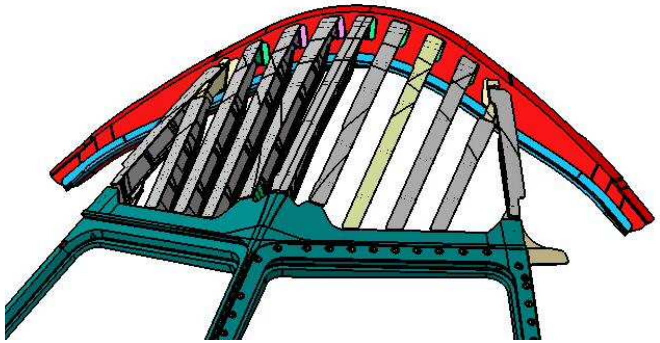
EADS Innovation Works – BSSM seminar Liverpool, April, 2008

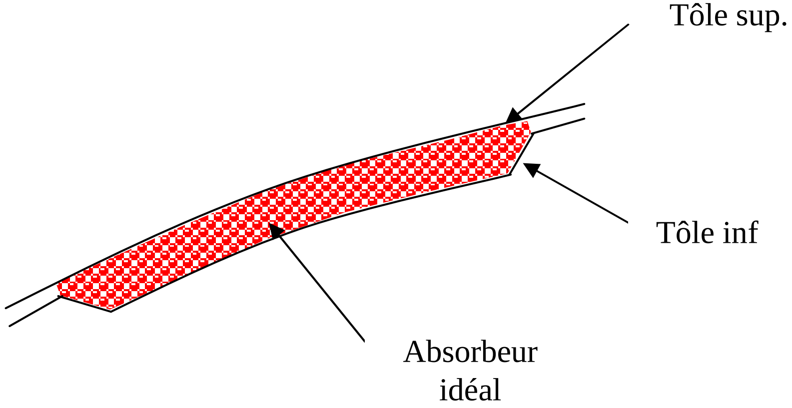
Potential applications on AIRBUS aircraft

1 - Protection for bulkhead
Development of a non structural shield



2 – Development of a structural part for load tranfer and bird strike protection





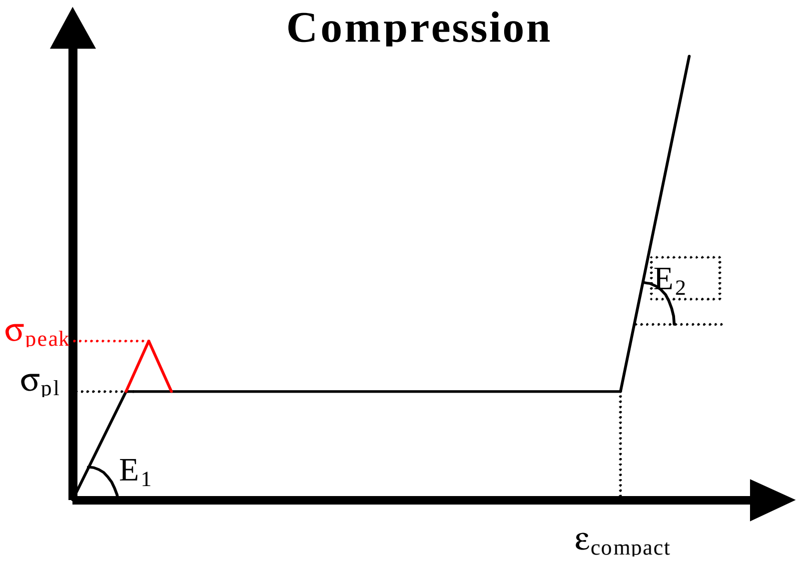
Objectives :
The structure of the aircraft nose shall resist without perforation to an impact of a **2kg** bird projected at **180m/s.**

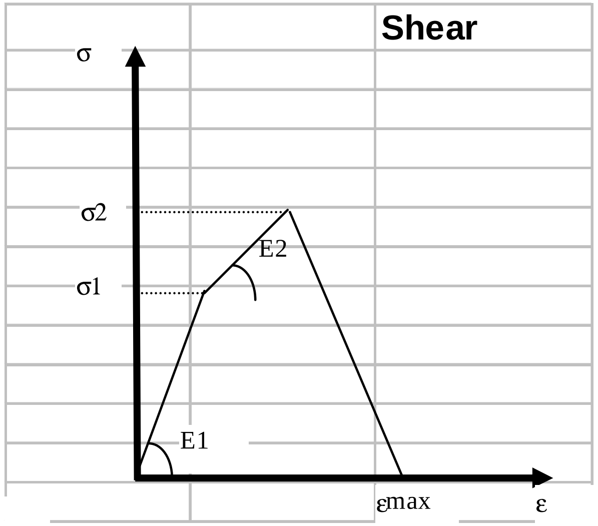
Reference :
Aluminium honeycomb with Kevlar or aluminium skins
The representative size is approx. 1 m^2. with aluminium skins, it weights **13 Kg**.

Stakes
Improving performance/weight
Cost reduction

Design criteria

Static





Material parameters on static compression (E1, speak, spl., E2, ecomp.) and shear (E1, E2,smax, emax) curves

Dynamic

Qualification test on aircraft nose with a 2kg bird projected at 180m/s

Experimental approach, bird strike results
(METEOR and SAFE projects)

Bird impact tests at 140m/s

Reference
Aluminium
honeycomb/aluminium
skins
2 sandwiches

No perforation
4,7 Kg
58 mm thickness

Hollow spheres assembly
2 sandwiches
SAFE European project
AIRBUS funding

No perforation
4,3 Kg
24 mm thickness

10% weight saving
overall dimension divided by more than 2

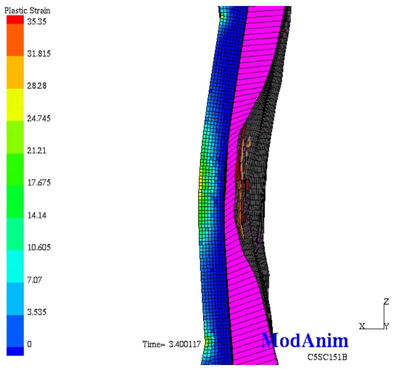
Higher performances

Need optimisation step by modeling

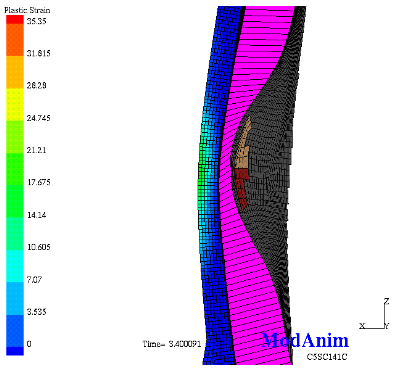
Modeling (1/2) : Optimisation of a sandwich in a real situation (2kg bird arriving normally 180m/s)

	Sandwich Height (mm)	Compression of the sandwich (%)	Maximal deflection (mm)	Plastic deformation of the stringer (%)	Weight of the sandwich
Hollow spheres Titanium skin 0,8/0,4 mm	55	85	59	5,2	13,5 kg/m^2 (8,2+5,3)
Hollow spheres Alu skins 1,8/0,4 mm	70	82	64	4,3	16,7 kg/m^2 (10,5+6,2)
Alu. Honeycomb Titanium skin 0,8/0,4mm	70	92	60	7,2	7,9 kg/m^2 (2,6+5,3)

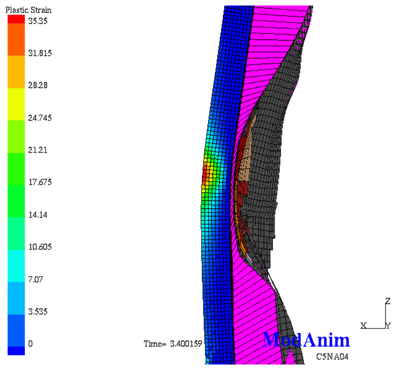
Hollow spheres + Titanium



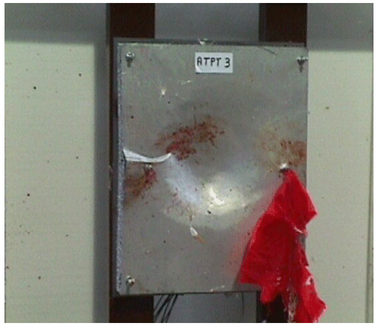
Hollow spheres + Alu

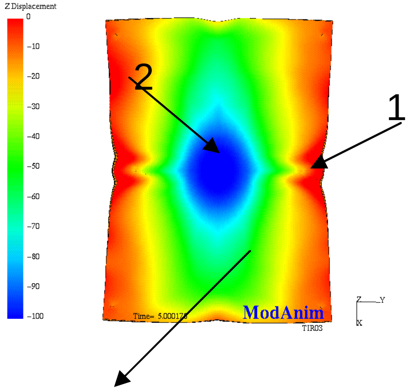


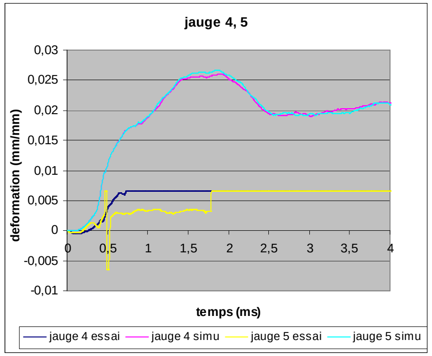
Alu. honeycomb + Titanium

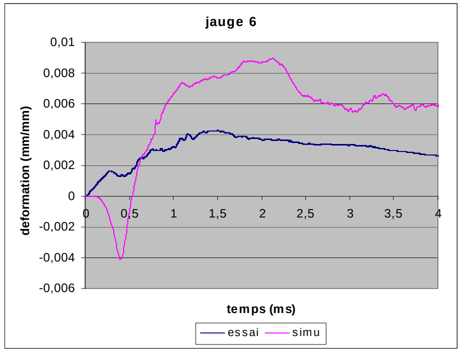


Modeling (2/2) : Bird strike simulation on sandwiches made out of aluminium foam









1 - Important plastification around the fixations
2 - Geometry of the deformed zone

3 – Higher plastic deformation of the AFT skin
Obtained by modeling

Bad correlations : the simulation does not show the interest of using foams/hollow spheres for energy absorption

Improvement routes

- Study of dynamic properties – comparison to honeycomb
- Optimisation of the model – comparison with an other numerical model

Study of the dynamic properties – Comparison to honeycomb (1/3)

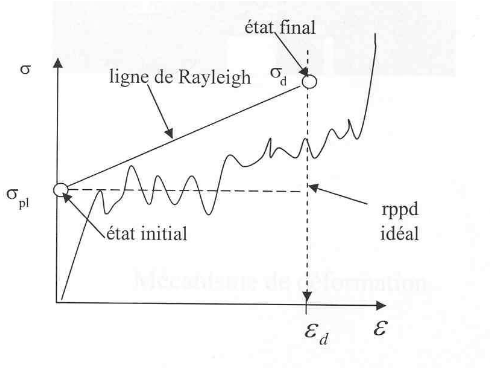
Literature : review of the parameters influencing the properties of metallic foams during a high velocity impact

1 – Effect of the base material (Aluminium) : low
2 – Effect of the air present in the cells : (<0,1 MPa)
3 – Effect of the lateral inertia (mentionned in honeycomb and wood) : medium

4 - Effect of the shock wave : important –At high impact velocity there is a discontinuity, called the shock front that propagates into the specimen and produces a stress enhancement

Increase of the plateau stress with the shock wave (Reid and Peng)

$$\sigma_d = \sigma_{pl} + \rho_0 * v^2 / \varepsilon_d$$

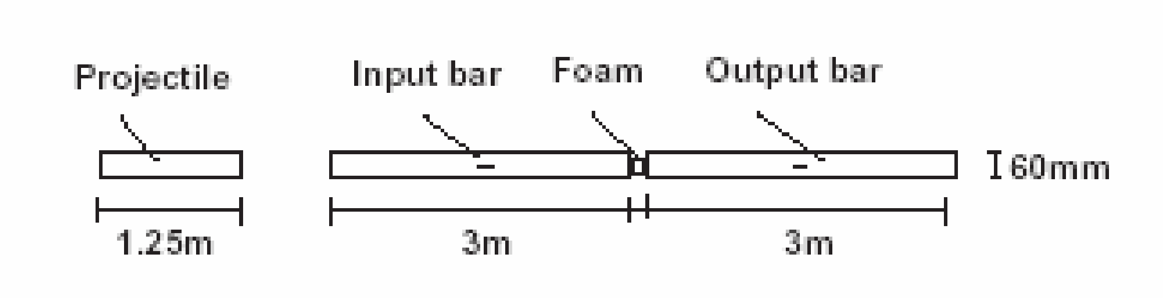


Courbe contrainte –déformation idéale

Study of the dynamic properties - Comparison to honeycomb (2/3)

Investigation of the shock wave effect using a modified Hopkinson device to reach at least 60 m/s (collaboration with LMT-Cachan)

- Split Hopkinson pressure bar set-up for v<25 m/s:



The particularities of SHPB at Cachan :

•Large diameter bars (62mm) to ensure a representative volume of the specimen
•Nylon for the bar material to ensure impedance match when testing soft materials
•For shock front study, low mass striker (400g) and two configurations used (see after)

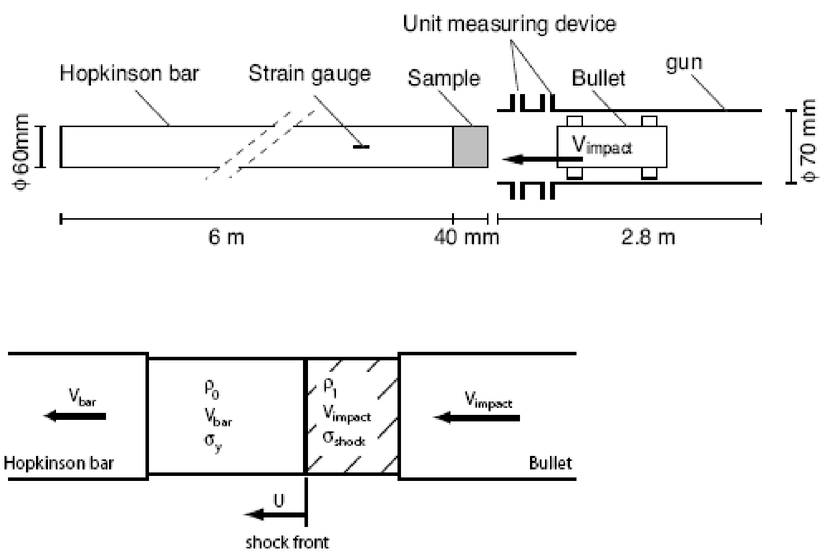
Study of the shock front (3/3)

➔ the foam specimen is fixed either ❶ on the output bar or ❷ on the projectile

❶ the possible shock wave is created at the interface projectile/specimen

❷ the possible shock wave is created at the interface specimen/output bar (thus easier to detect)

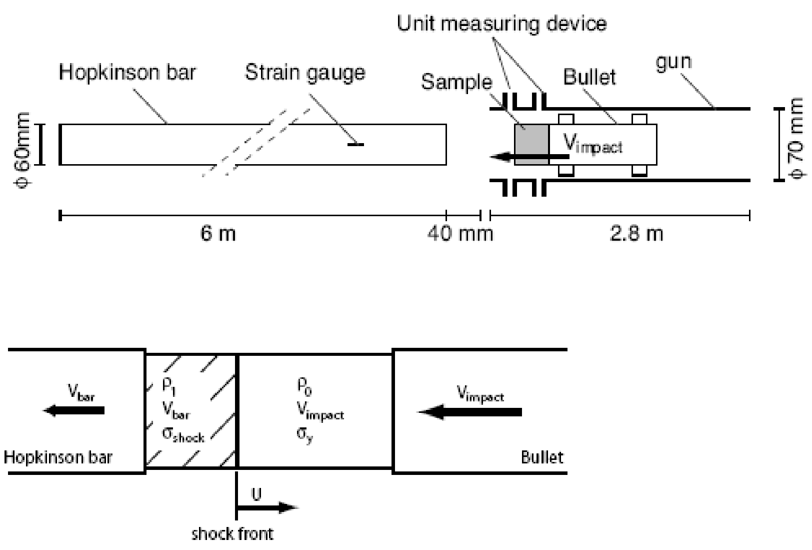
- **Configuration 1: Direct impact**



Shock front initiates on the projectile side

The bar measures stress and velocity *ahead of* the shock front

- **Configuration 2: Taylor impact**



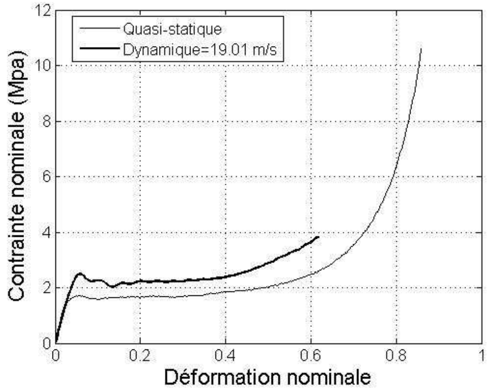
Shock front initiates on the bar side

The bar measures stress and velocity *behind* the shock front

Courtesy from LMT Cachan

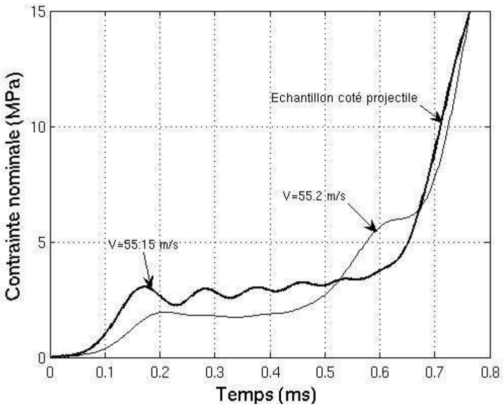
Materials for impacts absorption – Study of the shock wave effect

Alporas aluminium foam, density ≈ 0.25 g/cm^3

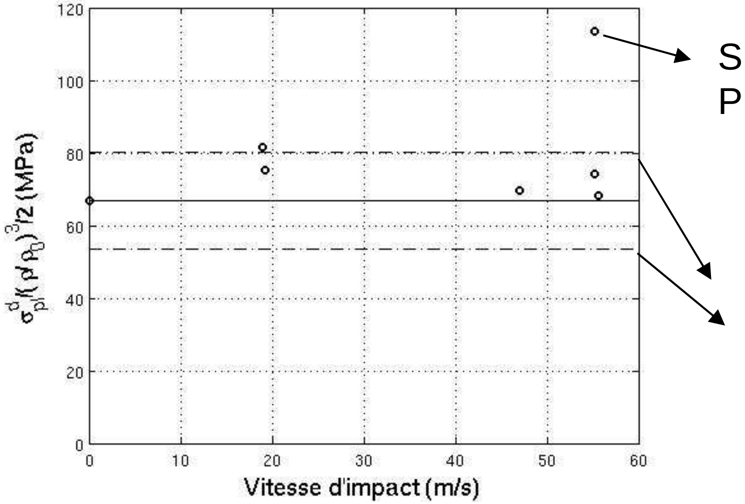


➔20% increase of the plateau stress at 20 m/s

➔Microinertia effect (buckling)



➔Shock wave effect : plateau stress increases by 54% - (plateau stress with spec. on projectile> plateau stress with spec. on output bar)



Spec.
Projectile side

σ_{plQS} and scattering

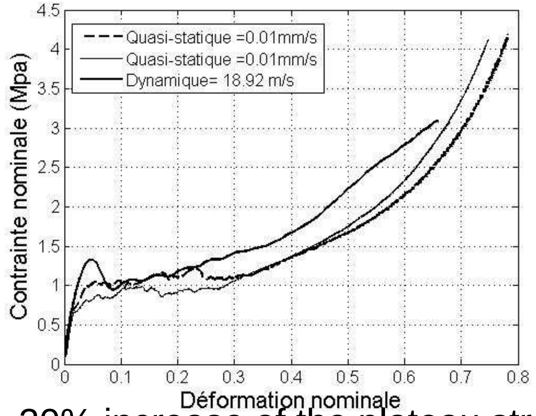
➔**Shock wave effect for v>50m/s**

➔**Increase of plateau stress : 54%**

➔ Effect of the velocity impact on the plateau stress –Alporas foam **(+54%)**

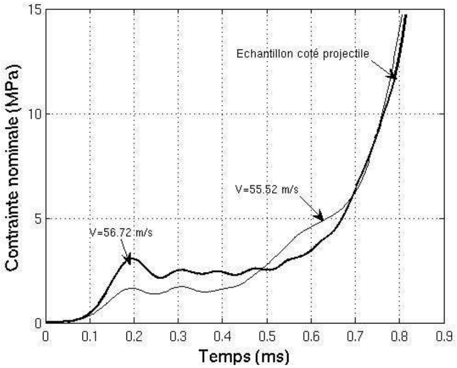
Materials for impacts absorption – Study of the shock wave effect

ATACA hollow spheres (HS) assemblies, density ≈ 0.20 g/cm^3

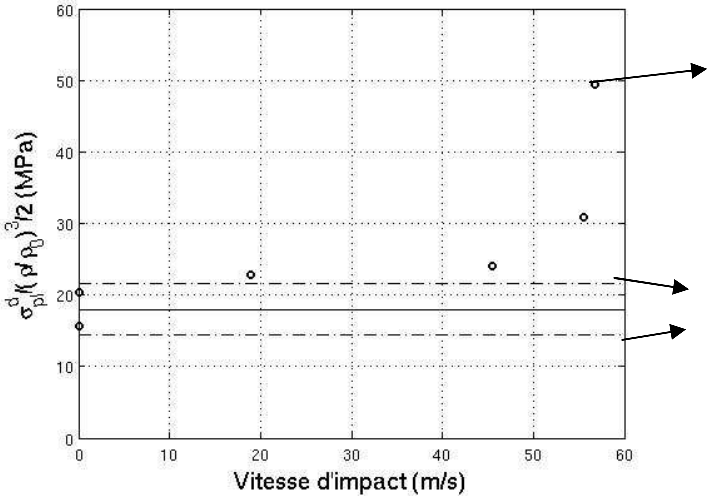


➔~20% increase of the plateau stress between quasi-static and 20 m/s

➔Microinertia effect



Shock wave effect : Plateau stress increase (sp. Projectile side > sp. On output bar)



Echantillon coté projectile

σ_{plQS} et enveloppe de dispersion

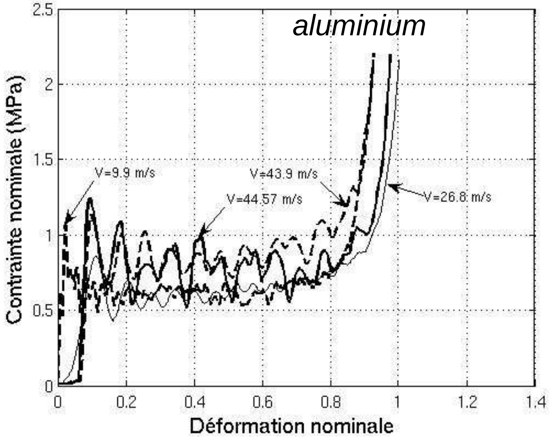
➔Shock wave effect for v>50m/s

➔Increase of plateau stress : 150%

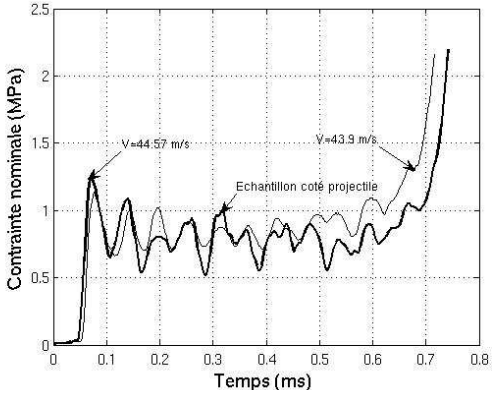
➔ Influence of the impact velocity on the plateau stress for ATECA HS

Materials for impacts absorption – Study of the shock wave effect

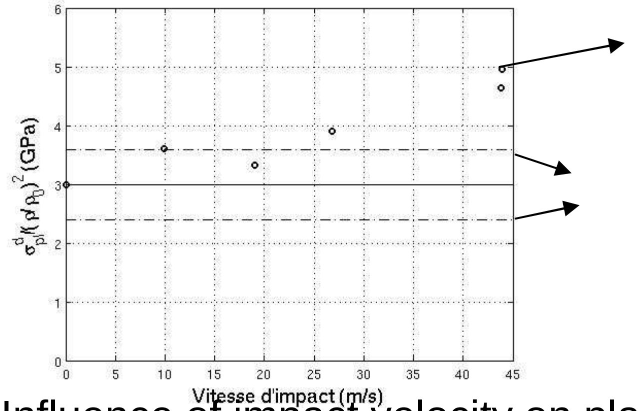
Aluminium honeycomb - density ≈ 0.037 g/cm^3



➔ ~30% increase of the plateau stress between quasi-static and 43 m/s



➔ No shock wave (sp. Projectile side = sp. On output bar)



Echantillon coté projectile

σ_{plQS} et enveloppe de dispersion

The increase of plateau stress in honeycomb is not due to shock wave effect but only to microinertia effect (buckling of the cell walls) even for v>50m/s

➔ Influence of impact velocity on plateau stress for aluminium honeycomb

Study of the dynamic properties - Comparison to honeycomb - Conclusions

Achievements/Current Status:

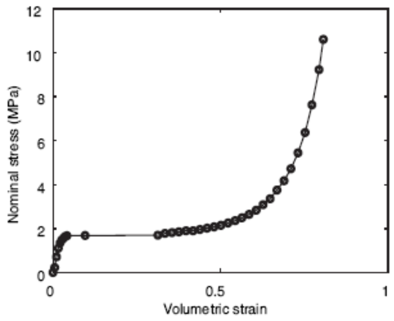
- The study of the dynamic compression of absorbing materials as Alporas and CYMAT aluminium foams, hollow spheres assemblies and aluminium honeycomb sandwiches was realised using the Hopkinson bars of ENS Cachan.
- The results show the influence of a speed until 50-55m/s on the increase of the resistance of the materials. The damage mechanisms are also interpreted from the direct impact tests.
- For Alporas foam and hollow spheres supplied by ATECA, the very high increase of resistance at 55m/s (respectively +54% and +150%), is explained by the apparition of a shock wave inside the material that produce a compression area in front of the shock wave. This phenomena is certainly at the origin of the good behaviour during bird strike
- The increase of 30% of the resistance observed in the aluminium honeycomb sandwiches is attributed to an inertia effect during damage of the cells based on the material geometry that delay the crushing of the honeycomb cells.

Perspective

- perform impact tests with adequate instrumentation to assess properties of the materials at 180m/s to complete the comparison with honeycomb

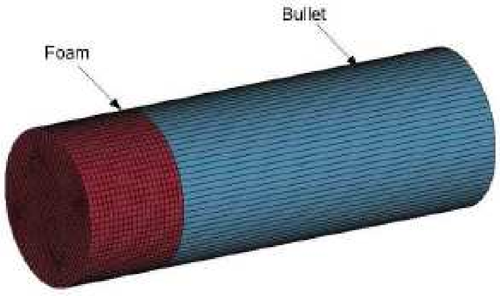
Optimisation of the modeling – shall we include the shock enhancement into the behaviour law ?

LS DYNA Crushable foam law (no strain rate sensitivity)

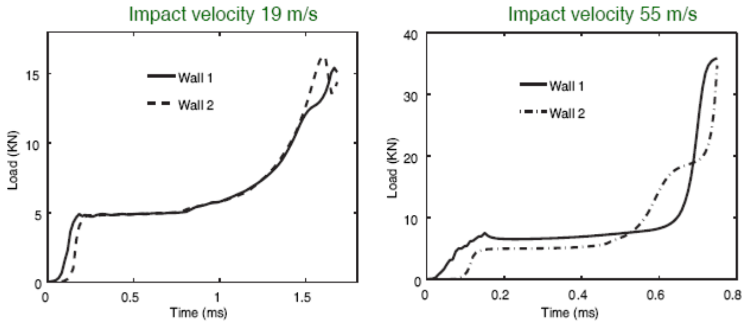


Configuration 2

The system {foam + bullet} is given an initial velocity



- **The shock front effect**



▶ The stress enhancement is correctly depicted

The shock front effect can be predicted without taking care of the dynamic behaviour law (structural effect)

The hardening law can be used to predict stress enhancement and propagation velocity of the shock front (70m/s)

Conclusions

- Description of the applications
- Results of experimental approach (bird strike)
- Problems for simulating the behaviour of the cellulars as foams or hollow spheres
- Experimental work to understand better the dynamic properties (effect of the shock wave propagation) and the valdation of the modeling from HB tests using LS DYNA code with a »simple » crashable foam law
- **Perspectives** :
  - to complete the HB tests at highest velocity for the investigtion of the shock front in honeycomb
  - Moreover to continue to develop new periodic materials with the objective of improving the static criteria (CELPACT project)